THE CONTRIBUTION OF CANADIAN EDUCATION TO INDUSTRIAL PRODUCTION: AN EXPLORATION IN HUMAN CAPITAL THEORY

by

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Submitted in partial fulfillment of the requirements

for the degree of Doctor of Philosophy

at

Dalhousie University

Halifax, Nova Scotia

January, 1997

0-612-24780-5

DALHOUSIE UNIVERSITY

FACULTY OF GRADUATE STUDIES

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DATE: MARCH 10, 1997

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TITLE: THE CONTRIBUTION OF CANADIAN EDUCATION TO INDUSTRIAL PRODUCTION: AN EXPLORATION IN HUMAN CAPITAL THEORY

DEPARTMENT OR SCHOOL: EDUCATION

DEGREE: Ph.D. CONVOCATION: SPRING YEAR: 1997

[redacted]

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To my parents with love and gratitude

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Abstract

The objective of this study was to provide a quantitative assessment of the role of education in the Canadian industrial production. For this purpose, some quantitative estimates of the magnitudes of the impact of industrial workers possessing higher educational levels on the employment and productivity of those who possess lower educational levels, and on the use and price of physical capital in Canadian industries, were obtained. Output contributions of these workers were also analyzed. These quantitative assessments were conducted within the framework of human capital theory, according to which education affects productivity and, also industrial output and economic growth. A translog production function was estimated using cross-sectional industrial data grouped by provinces for the years 1980 and 1990. The relevant inputs were capital and labour, the latter being disaggregated by four levels of education. Three sets of estimates were obtained separately for the years 1980 and 1990; one for the entire Canadian economy, one for the service sector, and one for the goods sector. Data from Statistics Canada were used.

Five major findings were obtained: (1) workers disaggregated by levels of educational attainment were substitutes for one another, in general; (2) capital and all labour groups disaggregated by education were complements; (3) workers with university education were the most complementary with capital; (4) as educational attainments increased, wages became less sensitive to changes in the quantity of workers in the same labour group; in general, and (5) if wages reflected marginal productivity, then workers with higher levels of education were found to contribute more to industrial output than their counterparts with lower levels of education;

Acknowledgments

I wish to thank my supervisory committee, Professors Ather Akbari, Joseph Murphy, Tomson Ogwang, and Eric Ricker, for their guidance and generous support. I am grateful to Professor Dennis Maki for his valuable comments and suggestions. I also wish to acknowledge Professor Atul Dar, whose lectures on production and cost helped me gain better understanding of issues relating to production functions.

I appreciate the assistance of Phyllis Ross and Shui Chua in procuring and preparing the 1981 Census data.

I thank Dalhousie University for providing research funding for this study. I also thank my fellow graduate students for providing a congenial atmosphere for academic pursuits.

Finally, special thanks goes to my family and friends for their ever present encouragement and support.

CHAPTER 1: INTRODUCTION

The objective of this study was to provide a quantitative assessment of the role of education in the Canadian industrial production.[1] For this purpose, some quantitative estimates of the magnitudes of the impact of industrial workers possessing higher educational levels on the employment and productivity of those who possess lower educational levels, and on the use and price of physical capital in Canadian industries, were obtained. Output contributions of these workers were also analyzed

A quantitative assessment of the role of education in Canadian industrial production can shed light on a number of pressing public domain issues concerning education in today's political and economic climate. The present study is therefore relevant for at least two reasons. First, it contributes to a better understanding of the role of education in the production of goods and services in Canada. Second, the findings of the study may be used to inform political discussion of educational issues, and thereby advance the level of political awareness and improve the quality of public policy. The following section highlights the various public policy issues concerning education that the present study can help to address.

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[1] Industrial production throughout this study refers to the production of goods and services in the major Canadian industries. A further discussion is provided in Chapter 3.

Importance of the Study

The economic benefits of education, for the individual as well as for society as a whole, have been recognized by economists since the seventeenth century (Kiker 1966). However, it was not until the eighteenth and nineteenth centuries that Canada witnessed the birth of its public school systems (Katz, 1974). The recognition of the importance of education, along with the emergence of the Canadian Confederation, led to the establishment of government-funded schools, and universal education became a reality.[2] The major developments in Canadian education, however, came much later; significant qualitative and quantitative improvements were made between the 1940s and the 1970s. The Organization for Economic Co-operation and Development (OECD) reported:

> ... until the late 1940s, Canada could be counted as one of the less developed (educationally) of the great democracies. Today, it is numbered clearly among the educational leaders (OECD, 1976: 22).

Indeed, Canada's leading role in education has been well reflected in its educational attainments of Canadians. By 1976, the schooling of Canadians between the ages of 25 and 64 averaged 10.6 years (see Table 1). The rise in educational attainments of Canadians was marked during the four decades from the 1960s to 1990s. The percentage of Canadians between the ages of 25 and 64 who had only high school education or less fell from 91 to 69.5, and the percentage of those with a

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[2] The Constitution Act (formerly the British North America Act), 1867, section 93, specifically made education a provincial rather than a federal responsibility.

university degree rose from 4.8 in early 1960s to 7.6 in 1976. This remarkable increase in the educational attainments of Canadians, however, was concurrent with a greater commitment of public funding to education. Munroe (1974) noted that, in Canada, the share of Gross Domestic Product (GDP)[3] devoted to public expenditures increased from 4.6 percent in 1961 to 8.3 percent in 1969, whereas expenditures on education grew from 14 percent of all government's spending in 1960 to 22.2 percent in 1970.[4] Canada has continued to allocate a sizable portion of its public funding to education during the last three decades, and the educational attainment of Canadians has also continued to increase (see Table 1).

Table 1 Educational Attainments of Canadians Aged 25-65

	1961-65	1971	1976	1981	1986	1991
Average years of schooling	8.6	9.6	10.6	11.5	12.2	12.3
With high school or less education (%)	91.0	88.9	69.5	60.4	52.6	47.2
With university degree (%)	4.8	5.8	7.6	9.4	11.6	13.5

Source: data for 1971,1981, 1986, and 1991 are obtained from the respective population censuses microdata. Data for the years 1961-65 are averages for the years 1960 (obtained from Statistics Canada, 1966), 1961 (based on the 1961 Census reported in Pahdekur, 1995), and 1965 (obtained from Statistics Canada, 1966).

[3] GDP measures the total value of the goods and services produced within the geographic boundaries of a nation. In deriving total GDP. Statistics Canada uses the "value added" approach. This approach entails subtracting the value of intermediate inputs used in each industry from the corresponding value of industrial output. GDP differs from GNP (Gross National Product); GNP represents the market value of all final goods and services produced in the country plus net foreign investment income.

[4] The large increases in educational expenditure in Canada in the 1950s and 1960s made possible the systematic build-up of a comprehensive public school system in all ten provinces and the two territories, which according to OECD (1976), was the most important development in the Canadian educational system.

Today, education is one of the three pillars of Canada's social welfare system.[5] Canada's total public expenditures on education as a percentage of the Gross Domestic Product (GDP) ranked as one of the highest among developed countries in 1988 (see Table 2). As a percentage of total public expenditure, Canadian taxpayers spent more on education than their counterparts in any other developed countries (Table 2). In 1990, the education sector employed 7 percent of the total work force (Table 3). In recent years, Canadian taxpayers have continued to spend more than seven percent of the Gross Domestic Product (GDP) on education annually.[6] Primary and secondary education are completely financed by tax revenues.[7] Post-secondary education is heavily subsidized by government grants to colleges and universities, which allow them to charge tuition fees that represent only a small percentage of the total cost of post-secondary education.[8]

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[5] The other two pillars are: income security (Employment Insurance, Welfare and Pension), and health care.

[6] In the most recent years, for which data are available, Statistics Canada (1995) reports that Canada's total expenditures on education in relation to GDP are those shown below.

Fiscal year	Expenditures on education ($'000)	Expenditures relative to GDP (%)
1990	48,679,626	7.3
1991	53,075,673	7.8
1992	55,760,340	8.1

[7] Private schools also receive some public funding. However, the funding levels vary widely among provinces.

[8] Vaillancourt (1995) reports the following private and public costs per student of three levels of education in Canada for the year 1985, these appear to be the most up-to-date calculation available:

School Level	Private Cost	Public Cost
Elementary	$100	$4,044
Secondary	$200	$5,391
College	$737	$7,001

Table 2 ***Public Expenditure as a Percentage of the Gross Domestic Product (GDP), Public Expenditure on Education as a Percentage of Total Public Expenditures, OECD Countries (1988)[a]***

Country	Expenditure (Percentage of GDP)	Expenditure (Percentage of Total Public Expenditure)
Australia	4.8	13.9
Austria	5.6	11.1
Belgium	6.1	10.5
Canada	6.4	14.4
Denmark	6.8	11.6
Finland	6.8	17.1
France	5.1	10.2
Germany	4.3	9.1
Ireland	5.8	11.5
Italy	4.8	9.4
Japan	3.8	11.7
Luxembourg	6.0	NA
Netherlands	6.3	10.9
Norway	6.6	12.4
Portugal	4.7	10.7
Spain	3.9	9.7
Sweden	5.7	9.6
Switzerland	5.1	14.7
UK	4.7	11.4
US	5.0	13.7

Source: OECD, 1992

[a] 1988 is the most recent year for which published international comparison data are available.

Table 3 Distribution of Employment by Sector, Canada, 1990

Industry	Share of Employment
construction	6
primary industries	6
finance and community services	6
education	7
public administration	7
transportation, communications, and utilities	8
health	9
manufacturing	16
other services	17
trade	18

Source: Economic Council of Canada, 1992a

The social welfare system of a country requires funding for its survival. The main source of this funding is governmental revenue. Beginning in the mid-1970s, the federal government of Canada started to incur a budget deficit.[9] The Conservative government, which was elected in 1984, had a mandate to lower the deficit. However, instead of reducing it, the government could only manage to rein in its rapid growth. The deficit had to be financed by government borrowing, and consequently the national debt grew. Just as the ratio of national debt to gross national product—the so called debt/GDP ratio—seemed to stabilize at around 0.60,[10] provincial governments began experiencing chronic deficits, which drove the overall government debt to GDP

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[9] The last overall budget surplus, that is, when the combined federal and provincial revenues exceeded expenditures, was recorded in 1974 (Canada, 1994).

[10] A debt/GDP ratio of 0.60 means that the amount of government debt is 60 percent of GDP, the goods and services produced in the country.

ratio close to 0.9 by 1993 (Lipsey, Purvis, & Courant, 1994). This is a burden of debt that only few advanced countries have exceeded during peacetime.[11] As a consequence, reducing the deficit remains an important objective of any elected government in Canada.

To meet the objective of deficit reduction, governments in Canada have resorted to massive cutbacks in their support of social programs. Most social programs have been subjected to various restructuring and cost-cutting measures. Public funding for education has been reduced and scrutinized.[12] The issues concerning public funding for education which have been raised in Canadian public as well as academic circles appear to revolve around the efficacy of the educational systems and the utility of large expenditures on education. Some of these issues are discussed below.

The first issue which calls into question the efficacy of the educational systems and the utility of large expenditures on education concerns the economic benefits of education. Concerns over the success of Canadian educational systems in meeting the public's expectations are frequently voiced in governmental circles as well as in the news media. A Government of Canada document (Canada, 1994) stated that "Canada

[11] By 1993, Canada's net foreign debt, owed jointly by the public and private sectors, had reached $313 billion, or 44 percent of GDP (Canada, 1994).

[12] Issues related to educational funding cutbacks have been frequently reported in the news media in recent years. For instance, the *Globe and Mail* featured an eight-part series examining how Canadian universities are responding to the continuing funding cutback (December 13, 1995 - December 20, 1995).

already spends relatively more on public education than almost all other advanced countries, but does not always have the results to show for it" (p. 41).

Anecdotal evidence about illiterate high school graduates and unemployed university graduates is plentiful (see, for instance, Osberg, 1994). Media and other reports of the public's disenchantment with the educational system encompass the views of students, parents, and educators. About a third of Canadians during the 1980s (compared with a tenth during the 1940s) perceived the quality of education to have deteriorated since they themselves attended school (Livingstone & Hart, 1991). About 40 percent of Ontario residents in 1990 believed the quality of elementary and secondary schooling to have deteriorated (Livingstone, Hart, & Davie, 1993). A recent Canadian Broadcasting Corporation (CBC) broadcast of the Maritime Noon program from Halifax (June 19, 1996) drew a majority of callers who held the view that universities in Canada have failed to prepare students for the labour market.

Governments and educators have responded to this general concern about the quality of education. The Prince Edward Island government, for example, stated that "to develop skills and attitudes related to the workplace" (Government of Prince Edward Island, 1989) is a central goal of education. Similarly, the Nova Scotia School Boards Association included "to acquire habits, attitudes, and intellectual skills that will be helpful in employment and in training for employment" as one of the aims of public education (Nova Scotia School Boards Association, 1988). Furthermore, the

Economic Council of Canada (Economic Council of Canada, 1990) called for research into "how Canada's education systems can prepare a high-quality, competitive work force, capable of adapting to a rapidly changing knowledge-based economy" (p. 20). Also, an information pamphlet published by Human Resources Development Canada (Canada, 1995) stated that one of the reasons that students attend college or university "may have been that people with post-secondary degrees usually get better jobs and earn more money." Moreover, the intent to forge closer and systematic links between the labour market and educational institutions through public policy is reflected in documents published by the present (Canada, 1994) and the former Government of Canada (Canada, 1991a). Assessing education's economic impact now appears to be a matter of national interest.

Another issue which concerns the efficacy of educational systems in Canada relates to the slowdown in the growth of labour productivity (Table 4) vis-à-vis a large share of public expenditure on higher education in Canada (Table 5).[13] A nation's productivity primarily determines its citizens' standard of living (Canada, 1994). If the present trend of declining productivity growth continues, the standard of living of Canadians will be adversely affected. Also, a declining trend in productivity growth

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[13] The Government of Canada (Canada, 1991) has stated that "[o]verall, public investments in education in Canada are high. Canadian taxpayers are among the most generous in the world in supporting elementary and secondary education ... We rank only midway in investing in higher education." (p. ix) However, it is observed that in Canada, expenditure on tertiary education as a proportion of total public education expenditure in 1988 was the highest among OECD countries.

may reduce the competitiveness of Canadian industries in the global market. In a 1994 publication (Canada, 1994), the Government of Canada emphatically stated that

Table 4 ***Productivity Performance in the Business Sector, Percentage Changes at Annual Rates, Selected OECD Countries***

Country	Labour Productivity[a]		
	1973-79	1979-90	1960-73
Belgium	1.5	1.4	5.2
Canada	0.8	0.2	2.8
Denmark	1.2	1.3	4.3
Finland	1.5	2.5	4.9
France	1.7	1.7	5.4
Germany	1.8	0.8	4.6
Italy	2.2	1.3	6.3
Japan	1.4	2.0	8.6
Netherlands	1.5	0.9	4.8
Sweden	0.3	0.9	4.1
Switzerland	-0.4	0.4	3.2
UK	0.6	1.6	3.6
US	-0.4	0.3	2.2

Source: OECD, 1991

[a] Labour productivity is the ratio of output to labour input. It normally measures output produced by an average worker.

"productivity growth is the foundation of economic progress and must therefore be the primary focus of economic policy" (p.16). A number of empirical studies, discussed in the next chapter, have identified education as a major source of productivity growth. Declining labour productivity growth in Canada, therefore, calls into question the efficacy of educational systems and also the practical wisdom of devoting a significant proportion of public resources to education, in the minds of some.

Table 5 ***Expenditure on Tertiary Education as a Proportion of Total Public Educational Expenditures, 1988[a] (Percentages)***

Country	Tertiary (post-secondary)
Australia	32.7
Austria	19.7
Canada	34.8
Denmark	29.8
Finland	16.7
France	13.6
Germany	22.3
Ireland	19.4
Italy	14.8
Japan	9.5
Luxembourg	3.5
Netherlands	28.8
Norway	16.0
Portugal	17.3
Spain	14.0
Sweden	16.1
Switzerland	19.8
UK	19.2
US	26.8

Source: OECD, 1992

[a] The shares of public expenditure allocated to tertiary education in Luxembourg and Japan are relatively small among the OECD countries. However, it is observed that most higher education students in Luxembourg are enrolled in the surrounding countries, whereas in Japan substantial parts of the cost of tertiary education are privately financed.

A third issue concerning the wisdom of allocating a significant portion of public funding to education relates to the beneficiaries of education. The same document mentioned above (Canada, 1994), stated:

> ... while society gains collectively from the skills of its citizens, the greatest beneficiaries of investments in human capital are individuals themselves, in terms both of lifetime financial return and potential for personal development (p. 41).

This line of argument appears to lend support to cutting public spending on education. However, it obscures the numerous non-economic and economic benefits of education accrued to society which have been discussed in the literature. Weisbrod (1964), Haveman and Wolfe (1984), and Bruce (1995), for instance, have all discussed some of the non-economic benefits of education. These non-economic benefits include, among other things, lower mortality rates, and lower crime rates.[14] The potential economic benefits of education which are accrued to society include improved productivity of the labour force as well as that of physical capital, and increases in employment and wage rates.[15] While many Canadian studies have analyzed private and total rates of return to education, researchers have also pointed out the ways in which future studies may be conducted to investigate these important labour and capital market benefits.[16]

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[14] Some may argue that lower crime rates confer economic benefits; however, they are often classified as non-economic benefits in the literature.

[15] This point is discussed at length in Chapter 2.

[16] Although the recent study by Vaillancourt (1995) acknowledged some of these additional benefits, it did not quantify them. Bruce (1995) has noted the lack of research on these additional benefits of education in Canada.

A fourth issue which is related to the efficacy of educational systems concerns the displacement of labour by technology. For instance, in a recent publication, Foot and Stoffman (1996) note that the Conference Board of Canada reported in 1995 that firms had been adding machines instead of labour, because the cost of labour was considerably higher than the cost of machines and that technology continued to destroy more jobs than it created. The Conference Board of Canada report confirmed the widely held fear of the "spectre of technological unemployment".[17] Technological improvement may be viewed as a by-product[18] of the continuing growth in the educational attainments of the Canadian labour force, which was presented in Table 1. However, to date the labour displacement effect of technological change has not been systematically investigated in Canada.

All of the issues discussed above are relevant in the debate over the efficacy of the educational systems and the utility of large-scale public spending on education in Canada. However, very few studies have presented a systematic analysis of the role of education in the Canadian economy. In particular, a direct estimate of the changes in industrial output, in employment and in production inputs resulting from changes in the educational attainments of the work force is lacking. By providing a quantitative

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[17] However, this conclusion is different from Mincer's (1988) U.S. study which concluded that technological change, on average, reduced unemployment in the long run and did not increase unemployment in the short run. Mincer (1989) noted that the fear of the "spectre of technological unemployment", that is, the fear of being displaced by sophisticated machines, is widely held.

[18] Miller (1967), for example, argued that "[e]ducation aids in the preservation and increase of technological knowledge." (p.282)

analysis of the impact of education on output, as well as on productivity and employment, the present study helps to shed light on whether concerns over the efficacy of educational systems and the utility of large public investments in education are well founded.

Organization of the Study

In this study, the analysis of the economic effects of education differs somewhat from previous studies. The economic effects of education have been the subject of extensive theoretical and empirical research since the 1960s (Haveman & Wolfe, 1984). These effects include the contribution of education to economic growth (e.g., Schultz, 1961; Jorgenson, 1984); to economic development (e.g., Carnoy, 1977), to efficiency in consumption (e.g., Michael, 1972); to household productivity (e.g., Haveman & Wolfe, 1984); to health (e.g., Haveman & Wolfe, 1984); to agricultural productivity (e.g., Griliches, 1964); and to manufacturing productivity (e.g., Besen, 1968). The effect of education on labour market outcomes, such as decreases in the incidence of unemployment as the educational attainment of labour force increases (e.g., Osberg, 1994), and increases in earnings as a result of higher educational attainment, have also been identified as economically significant (e.g., Murphy & Welch, 1989). This study, however, is focused on the effects of education on industrial productivity; that is, the role of education in the production of goods and services in Canada. Two major research questions were addressed:

1. What are the magnitudes of the marginal contributions of workers with different levels of education in the production of goods and services?[19]

2. What impacts do workers with higher educational levels have on the employment and productivity of workers with lower educational levels, and what impact do they have on the use and price of physical capital in industry?

A quantitative assessment of the role of education in the Canadian economy was conducted within the framework of human capital theory. According to human capital theory education increases the productivity of individuals and, therefore, also industrial output and economic growth. To estimate the magnitude of the contribution of education to industrial output and its impact on employment and productivity of capital and labour in Canada, a production function was estimated. A production function describes the relationships between outputs and the various inputs used in producing goods and services.[20] The inputs relevant to the present study were capitals, and labour, disaggregated by four levels of education. Two sets of data representing the years 1980 and 1990 were used to compute two separate sets of estimates. Data on the number and average earnings of employed workers with different levels of education in all major Canadian industries, located in all ten provinces, were cross-tabulated based on 1981 and 1991 Canadian Population Census microdata files. Data

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[19] Marginal contribution of a production input measures the additional output that can be produced by one more unit of that particular input while holding all other inputs constant.

[20] A detailed discussion of production functions is provided in Chapter 3.

on capital stock for the major industries located in the ten Canadian provinces were obtained from Statistics Canada Investment and Capital Stock Division microdata file, through a special request. Data on value added[21] for each industry in each province were obtained from Statistics Canada (1994a).

The present study is organized into five chapters. Chapter 2 provides a review of the theoretical and empirical literature. In this review, the development of human capital theory, with its reference to the economic role of education, is examined first. This examination is followed by a review of the three major approaches used to measure the economic effects of education, namely, the earnings function approach, the production function approach, and the cost function approach. This review of the theoretical and empirical literature led to the decision to use human capital theory as the theoretical framework and the production function as the empirical tool for this study. A discussion of the rationale for this decision concludes Chapter 2.

Chapter 3 provides a discussion of the methodology used in the study. The concept of a production function, its use in estimating the marginal contribution of inputs, the concepts of substitution and complementarity among inputs in a production

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[21] Value added is the Gross Domestic Product calculated by using the "valued added" approach. The "value added" approach entails subtracting intermediate inputs from gross output for each industry. This allows not only for the computation of total economic production but also the industrial position and origin of the economic production (Statistics Canada. 1994a).

function, and the test of weak separability are first introduced. This is followed by the specification of the production function, econometric considerations, and data sources.

Chapter 4 presents six sets of estimates separately. The first set represents estimates of the Canadian production function for the entire economy for the year 1980; the second set, for the year 1990. The third and fourth sets represent estimates for the Canadian production function for the service sector for the years 1980 and 1990, respectively. The fifth and the sixth sets represent estimates for the goods sector for the years 1980 and 1990, respectively. Where appropriate, these results are compared with other studies. Simulations were also conducted to present possible labour market consequences resulting from an increase in the number of workers with university education.

Finally, Chapter 5 summarizes the main findings of this study and discusses its contribution to the literature and to the ongoing debate on the role of education in Canada. The limitations of this study are also discussed.

CHAPTER 2: LITERATURE REVIEW

Many quantitative assessments of the impact of education on the economy have been conducted within the framework of human capital theory. According to this theory, education enhances an individual's productivity.[22] This chapter first traces the development of human capital theory, and specifically its reference to the economic role of education. Then it presents the two major approaches used in the literature to measure the economic contribution of education. Following the review of literature, the discussion concludes with a perspective on the usefulness of human capital theory and the production function as a tool for testing the theory.

The Economic Impact of Education: Human Capital Theory

Although T. W. Schultz has been identified as the founder of the theory of human capital due to the impact of his 1960 presidential address to the American Economic Association (Blaug, 1970), the concept of human capital did not begin with Schultz, but can be found in the writings of various economists of the seventeenth, eighteenth, and nineteenth centuries (Bowman, 1966; Kiker, 1966). In recognizing that the acquisition of skills and abilities through education and training incurs a cost and tends to increase workers' productivity, these economists concluded that these

[22] Early human capital theorists often referred to education's productivity-enhancing effect without directly using the word "productivity". For instance, Schultz (1960) argued that education improves "capabilities of a people as they work and manage their affairs" (p. 572)

acquired skills and abilities may be considered human capital. Adam Smith (1937), in discussing the concept of human capital, drew an analogy between man and machine:

> The acquisition of such talents, by the maintenance of the acquirer during his education, study, or apprenticeship, always costs a real expense, which is a capital fixed and realized, as it were, in his person. Those talents, as they take a part of his fortune, so do they likewise of that of the society to which he belongs. The improved dexterity of a workman may be considered in the same light as a machine or instrument of trade which facilitates and abridges labour, and which, though it costs a certain expense, repays that expense with a profit (pp. 259–260).

Senior (1939) expressly agreed with Adam Smith:

> The same remark applies to the acquired abilities which Adam Smith has properly considered a capital fixed and realized in the person of their possessor. In many cases they are the result of long previous exertion and expense on his own part; exertion and expense which might have been directed to the obtaining of objects of immediate enjoyment, but which have, in fact, been undergone solely in the hope of a distant reward. And in almost all cases they imply much expense, and consequently much sacrifice of immediate enjoyment on the part of parents or guardians. The maintenance of a boy during the first eight or nine years of his life is indeed an unavoidable burden, and therefore cannot be considered a sacrifice. But almost all that is expended on him after that age is voluntary. At nine or ten he might earn a maintenance in an agricultural, and more than a bare maintenance in a manufacturing employment, and at twenty-one obtain better wages than in any subsequent period of his life. But even the lowest department of skilled labour is in general inaccessible except at an expense very great, when we consider by whom it is to be borne; £15 or £20 is a low apprentice fee, but amounts to half the average annual income of an agricultural family. The greater part of the remuneration for skilled labour is the reward for the abstinence implied by a considerable expenditure on the labourer's education (p. 69).

List's (1928) view of the concept of human capital is akin to that of Senior. In arguing for protectionism, List contended that the skills and acquired abilities of human beings, which represent the most important elements of a nation's stock of capital, are to a great extent an inheritance from the labour and self-restraint of previous generations.

Von Thünen (1875) contended that skills and abilities are acquired at a cost and tend to increase the value of labour. He therefore regarded them as capital. His view was shared by other nineteenth century economists, such as Roscher (1878), Bagehot (1953) and Sidgwick (1901).

From this sampling of views expressed by various economists, it seems clear that the concept of human capital had received considerable attention in the eighteenth and nineteenth centuries. Marshall, the pre-eminent economic theorist of the late nineteenth and early twentieth centuries, also saw enough relevance in this concept to discuss it in his major work, *Principles of Economics*. From an abstract and mathematical point of view; Marshall (1961) saw human beings indisputably as capital; nonetheless, he didn't think it was practical to treat them as such. Marshall's pronouncement apparently discouraged further efforts to develop a theory of human capital and a lull ensued. Indeed, the prevailing view (Schultz, 1961; Kiker, 1966; Ricker, 1980) is that the reticence of economists on this subject in the first quarter of the twentieth century owed much to Marshall's objections (1961).[23] Nonetheless, it is worth noting that certain passages in *Principles of Economics* seem to suggest that Marshall's reluctance might have stemmed from the technical difficulties he foresaw

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[23] Marshall's influence extended well into the twentieth century. Shaffer's comment on Schultz's presidential address to the American Economic Association may be taken as a case in point: "Few U.S. scientists today will argue with the basic spirit of Marshall's statement that: 'There is no greater extravagance more prejudicial to the growth of national wealth than that wasteful negligence which allows genius that happens to be born of lowly parentage to expend itself in lowly work.' But Marshall did not utilize this realization to treat expenditures for education as 'investment in man' and neither should we." (1961: 23-24)

in the analysis of a capital of such complexity; and these same difficulties were destined to plague economists in the decades to come:

> The most valuable of all capital is that invested in human beings; ... and of that capital the most precious part is the result of the care and influence of the mother, ... This draws our attention to another aspect of the principle already noticed, that in estimating the cost of production of efficient labour, we must often take as our unit the family. At all events we cannot treat the cost of production of efficient men as an isolated problem; it must be taken as part of the broader problem of the cost of production of efficient men together with the women (pp. 469–470).

Since the 1970s, the contentious issues concerning the "production of efficient men," which have figured prominently in the theoretical debate and appeared as different variations on the theme of signalling theory, revolve around the cause of enhanced efficiency or productivity. Both genetic and environmental factors have been attributed as the cause of differences in productivity levels among individuals.

Apparently undaunted by Marshall's caveat about the impracticability of the concept of human capital, Walsh (1935) constructed a study to explore the cost-benefit relationship between education and human capital formation. In this study, Walsh noted that since Petty[24] the concept of human capital had been developed largely in general terms, and reference had been made "to *all* men as capital, and to *all* kinds of expenses in rearing and training as their cost" (1935: 255). His task was, however, to explore the relationship between private investment decisions and the returns on education. This line of inquiry was the first of its kind, and Walsh has since been

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[24] According to Kiker (1966), the seventeenth century mercantilist William Petty was one of the earliest economists who had considered human beings or their skills as capital.

credited (Bowman, 1966) as the first economist to question whether individuals behave in an economically rational manner with respect to their educational decisions—that is, do individuals incur educational expenditures with a view to increasing future earning streams? Walsh's pioneer work, however, did not attract immediate attention, as was the case with the later studies of Becker,[25] Schultz and others. And this, according to Bowman, was because "the time was not yet ripe" (1966: 121). It is understandable that in the gloomy days of the mid-1930s, while the twin spectres of economic and political turmoil were looming, Walsh's analysis was simply ill-timed and uninspiring, for the questions of investment and returns require projection into the future, and the future was precisely where uncertainty lay. Also, the concept of human capital formation was at odds with the pressing reality—there were extraordinary deflationary pressures which had resulted in massive cuts to educational spending. Walsh's study was destined to be discovered by economists of the next generation, not his contemporaries.

The Development of Human Capital Theory

It was not until after the Second World War that studies on investment in education began to receive widespread attention. In his 1960 presidential address to

[25] Bowman notes that Becker's 1960 studies which received "widespread reactions" were "essentially like Walsh's, except for one thing": instead of using an arbitrary rate of return (Walsh used 4%) to discount earning streams to estimate the present value of returns, Becker used internal rate of return to calculate the returns (1966: 122).

the American Economics Association, Schultz first took on the task of dispelling the notion that the consideration of human beings as capital debases humanity and is thus morally wrong. This notion, said Schultz, had created a stumbling block that impeded acceptance of the concept of human capital. Then he proceeded to put forward his solution to "the paradoxes and puzzles" of the post-Second World War economy. The "paradoxes and puzzles" to which Schultz referred were two phenomena which were inconsistent with micro-economic theory: first, the ratio of capital to labour income was declining as the postwar economy grew, and secondly, national income was rising relative to the amount of physical capital utilized in production. Also, the large increases in the real earnings of workers remained unexplained. Furthermore, the war-devastated countries had been able to recover faster than economists had anticipated. Schultz asserted that all these puzzles could be resolved once investment in human capital was taken into account.

One may well argue that Schultz's greatest contribution to the development of human capital theory lies in stating the economic role of education. As discussed earlier, the concept of human capital is to be found in the writings of the early economists, commencing with the seventeenth century mercantilist Petty, and therefore does not begin with Schultz. However, by pointing out that the unexplained increases in national income in the post-Second World War United States were attributable to increases in the educational attainments of the populace, Schultz advanced the concept from the simple notion of the earlier economists to a theory which could be tested by data. Based on his thesis that human capital plays an important role in the economy, Schultz proceeded to make policy recommendations. Among those was the suggestion that education be used as an effective and efficient means to attain income equality, and that it be used to assist underdeveloped countries to achieve economic growth. Schultz's address resulted in "a sudden acceleration of research ... and proliferation of publications" in the area of human capital (Blaug, 1968: 11).[26] This "re-birth" of the concept of human capital (Kiker, 1966) had an impact which extended beyond the academy.[27] In his comment on Schultz's address, Shaffer wrote:

> At present, the investment-in-human-capital concept appears to be gaining in favour among "liberals" who apparently intend to utilize it as a rationalization of federal aid to education (and, secondarily, other governmental investment-in-man expenditures). Walter Heller, Chairman of the Council of Economic Advisers to the President, for instance, refers to the human mind as America's greatest resource and points to the "vast implications for public policy" embodied in the development of the investment-in-human-capital concept (1961: 29).

The enthusiastic reception given Schultz's address gives rise to this question: why did it have such a profound impact? Attention must be directed to the immediate circumstances attending the address. Economists had been perplexed by the hitherto unexplained increases in national income in the United States,[28] and Schultz had

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[26] Blaug notes that his "annotated bibliography published in 1966 contained 800 items: the second edition of this bibliography, published in 1970, contained 1,350 items, and the third 1976 edition contains almost 2,000 items" (1976: 827).

[27] In its Second Annual Review, the Economic Council of Canada (1965) stated: "[t]he future benefits from increased efforts in education are very large, and the economic returns to the nation from increased investment in education are likely to exceed by a considerable margin those from other types of expenditures." (p. 121)

[28] Abramovitz adroitly termed this unexplained residual the "measure of our ignorance" (1957:11).

proposed an answer to questions about the so-called "residual factor" in the economy. The "residual" is the unexplained portion of economic growth, found by using traditional measures of man-hours worked and the value of physical capital. Schultz argued that investment in human beings provided not only an answer to the perplexing puzzles of the economy of the time, but also hope for prosperity and social equality.[29] Hence it was not surprising that policy makers received the concept of human capital with open arms; the "open sesame" potency of the concept was simply irresistible (Sobel, 1978: 282). Moreover, competition between the western countries and the Soviet Union, together with the launching of the Soviet satellite Sputnik, created a political climate conducive to new ideas.

In Canada the call for recognition of the concept of human capital in formulating educational policy was even more pressing, since in addition to the above, the "technological gap" created by a sharp fall in the post-war migration of skilled and professional workers from Great Britain and northern Europe made educational policy based on the concept of human capital at once necessary and politically expedient (Ricker, 1978). While Schultz's address succeeded in laying the foundation for a theory of human capital, the development and empirical testing of the theory in the

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[29] Schultz's faith in education's egalitarian efficacy seemed to echo Marshall's statement: "[t]he normal earnings of a carpenter and surveyor might be brought much nearer together than they are, by even so slight and easy an improvement on our present social arrangements as the extending to all persons of adequate natural ability the opportunity of receiving the training required for the higher ranks of industry." (1961: 214)

United States was made possible by the availability of more detailed census data which, after 1940, began to include earnings and information on educational attainments (Bowman, 1966). Canadian earnings-by-educational-attainment data, in contrast, have only been made available since 1967.

It is interesting to note that economists who have expounded upon the concept of human capital throughout the history of economic thought ostensibly couch the concept in terms of a positive theory, that is, theory conceived to explain how things are and not how things should be (Marshall & Briggs, 1989). Formulating human capital theory in terms of a positive theory, set it apart from normative prescription (the very concept of human capital was disagreeable to some on moral and practical grounds).[30] Indeed, before the 1960s, objections to the concept of human capital revolved around arguments that treating people as capital debased humanity, and considering education as an investment rather than cultural experience was narrow and uncouth (Schultz, 1963; Becker, 1993). Nonetheless, human capital theory gained acceptance in academic as well as political circles, despite the objectionable underlying assumption that the economic value of human beings is analogous to the value of physical capital.

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[30] Walras (1954), for instance, noted that the reluctance of economists to treat human beings as capital arose from moral and practical considerations.

Acceptance of human capital theory in the 1960s (see, for instance, Sobel, 1978), to a large extent, was due to Schultz's claim that it explained the "residual" of post-war economic growth. Nonetheless, its use as a tool of analysis did not go unchallenged, even during the 1960s, when enthusiasm for human capital theory was at its height. The challenge, however, was not aimed directly at the premise that education raises an individual's productivity. Rather, at issue was the use of earnings differentials between more-educated workers and their less-educated counterparts to estimate the magnitude of education's economic contribution. For instance, Vaizey (1962) noted:

> There is a multiple correlation between parental wealth, parental income, access to educational opportunity, motivation in education, access to the best jobs and 'success' in later life. Above all, there is sheer native wit and ability which will 'out' despite all educational handicaps. It follows, then, that all the statistics may go to show is that incomes are unequal, and that education is unequally distributed; there may be no necessary causal relationship between education and income (p. 45).

The issue Vaizey and others (e.g., Balogh and Streeten, 1963) raised is the appropriateness of ascribing earnings differentials exclusively to education vis-à-vis a host of genetic (e.g., innate ability) and environmental factors (e.g., access to educational opportunity and well-paid jobs). In response to these criticisms, the ability factor has been included in some empirical studies. Blaug (1976), for instance, noted that until the early 1970s "most investigators were content to follow Edward F. Denison by making the so-called 'two-thirds assumption' (also known as the alpha coefficient in the literature), that is, to attribute two-thirds of the earnings differentials associated with different amounts of education to the pure effect of schooling, ascribing the rest to some amalgam of genetic endowment and social origins" (p. 842). However, in his review of the empirically derived alpha coefficient Psacharopoulos (1975) reported that its value is more likely to be 0.9 and not 0.67 as Denison had proposed. Psacharopoulos therefore concluded that Denison's "two-thirds assumption" over-estimated non-educational influences on earnings differentials.

The Challenge to Human Capital Theory

Major challenges to human capital theory emerged in the 1970s in the wake of sluggish economic growth. The failure of large-scale increases in educational spending in the 1960s and early 1970s to sustain prosperity, as human capital theory predicted, called into question the efficacy of the theory. It is therefore not surprising that the main focus of human capital theory shifted from economic growth/aggregate productivity to earnings of individuals (Klee, 1991). The data on the aggregate economy did not lend support to human capital theory. Nevertheless, earnings differentials continued to exist in labour markets between the better-educated workers and their less-educated counterparts. Hence, many empirical studies conducted within the framework of human capital theory opted to use data on earnings differentials, rather than data on national economic output.

The lacklustre performance of the economy in the 1970s not only resulted in the change of the focus of research within the framework of human capital theory, but also had wide social implications (Lockhart, 1975). Education had come to be expected to deliver prosperity, and this was now called into question. The Economic Council of Canada, which advocated greater investment in education during the 1960s, revised its position and stated that "education for education's sake will always be a part of formal education (to the good of our culture), but there are limits on how much of this a country can afford at a given stage in its development" (1971: 223). A similar view was also found in the OECD 1976 report:

> The perceptibly growing public unwillingness to support seemingly endless increases in expenditure for education, especially in the face of new, perhaps even costlier, social tasks, is a warning that should be taken seriously. This unwillingness will continue to increase as long as the public is not given a clear understanding of the social goals of real importance that are to be achieved using this expensive educational enterprise. (p.102)

So also, human capital theory, upon which the great expectations for the economic benefits of education was built, was now seriously questioned. Large-scale expansion of education which, according to human capital theory, was to sustain prosperity, had failed miserably to meet expectations. The question arose, therefore, whether a central postulate of human capital theory, namely, that education increases an individual's productivity, was valid. The economic benefits of education had not been demonstrated in the aggregate economy in the form of increased output.

However, it may be plausibly argued that the slowdown in economic growth despite improved labour quality was a consequence of relatively low investment in physical capital. One notes that Canada's investment in machinery and equipment has been relatively low (Table 6).

Table 6 ***Investment in Machinery and Equipment, Annual Average as a Percentage of GDP, Selected OECD Countries***

Country	1960-89	1980-89
Canada	7.4	7.4
France	8.8	8.6
Germany	8.6	8.4
Italy	9.9	10.1
Japan	12.3	10.4
Sweden	7.7	8.2
UK	8.5	8.2
US	7.5	7.9

Source: OECD, as quoted in Crane (1992)

Indeed, Marshall had succinctly described the inter-dependency between labour and physical capital (1961):

> Their mutual dependence [capital and labour] is of the closest; capital without labour is dead; the labour without the aid of his own or someone else's capital would not long be alive. Where labour is energetic capital reaps a high reward and grows apace; ...The co-operation of capital and labour is as essential as that of the spinner of yarn and the weaver of cloth: there is a little priority on the part of the spinner; but that gives him no pre-eminence. The prosperity of each is bound up with the strength and activity of the other; though each may gain temporarily, if not permanently, a somewhat larger share of the national dividend at the expense of the other (p. 451).

Ironically, in the wake of the sluggish economy, human capital theorists turned to the widely observed positive relationship between education and earnings to support the theory, but it was precisely this persisting universal phenomenon that better-educated workers earn more than less-educated workers that gave credence to two alternative explanations of the positive relationship between education and earnings. These alternative explanations do not actually refute the theory of human capital. In fact, to a certain extent, they corroborate human capital theory.[31] Nevertheless, their presence obscures the effect of education in the formation of human capital, and renders the task of disentangling the relationship between education and productivity more difficult (Blaug, 1987).

The first alternative explanation is known in the economic literature as the screening hypothesis or signalling theory. Instead of interpreting the observed positive relationship between education and earnings as evidence for education's productivity-enhancing effect, the screening hypothesis suggests that education is primarily a screening/signalling/filtering device, that identifies individuals with innate ability and/or trainability.

Berg (1970) presented empirical evidence that, in the United States, within well-defined occupational categories, earnings were not correlated with physical productivity. The corollary was that the economic role of education was that of allocating a share of economic output: workers with more education were paid more

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[31] Empirical evidence presented by researchers who have pursued these alternative explanations invariably confirmed the existence of a positive relationship between education and earnings.

than their less-educated counterparts. Carnoy (1974) discussed the methodological problems in Berg's study. These problems included the lack of comparison of productivity between different occupations. Within well-defined occupational categories, differences in the level of productivity as a consequence of differences in educational attainment, were not reflected in the education variable. Yet within a single occupation workers tended to have a fairly wide range of educational attainments but fairly low income variance relative to the overall income variance in the labour force.

In their analysis of the relationship between productivity and education and training, Thurow and Lucas (1972) contended that education and training do not determine worker productivity. They argued that productivity is an attribute of jobs, not people, and the requisite skills for performing at the productivity level indicated by the job are learned through formal or informal training programs. Thus, they argued, employers are concerned with the trainability of workers, and use this as the criterion for recruiting. Those with more education—by virtue of their educational attainments—are considered to be more trainable, and therefore are assigned to the head of the "queue" for the best work. The role of education in the economy, then, is to send signals to employers informing them of the potential trainability of workers.

The same view was expressed in a separate study by Thurow (1972). This study described a job market where, instead of people looking for jobs, there were jobs looking for suitable people:

> In a labour market based on job competition, the function of education is not to confer skill and therefore increased productivity and higher wages on the worker; it is rather to certify his "trainability" and to confer upon him a certain status by virtue of this certification (p. 68).

Similarly, Arrow (1973), Spence (1973), and Stiglitz (1975) argued that education is used as a screening device for employers to select workers who possess the kinds of attributes they seek. Higher earnings are paid to workers with higher levels of education, but not on the basis of their cognitive abilities.

The contention that education is used as a screening or signaling device to facilitate recruiting, as discussed above, is sometimes identified as the weak version of the screening hypothesis (Psacharopoulos, 1979; Blaug, 1985). This version of the screening hypothesis differs from what some call the "strong" version, because employers use education simply as a proxy for potential productivity (Cohn & Geske, 1990). In the strong version, employers continue to pay higher wages to workers with more education, even after they have had an opportunity to evaluate their job performance. The strong version of the screening hypothesis is apparently less intuitively appealing than the weak version. Indeed, Psacharopoulos (1979) has posed the question: why would rational employers compound an initial hiring error by continuing to pay higher wages to workers who proved to be less productive?

Numerous studies have been conducted to test the validity of the screening hypothesis. Psacharopoulos (1979), for instance, devised a study using UK data from a competitive sector (suggesting a low probability of screening, since according to economic theory, employers in a competitive markets maximize profits by paying their employees according to the value of their marginal physical product[32]) and a non-competitive sector (suggesting a higher probability of screening, since in a non-competitive market it may not be crucial that employers pay their employees according to the value of their marginal physical product) to test both versions of the screening hypothesis. The tests showed that early-to-mid career earnings increased as amounts of education increased in both sectors, but increases in earnings were more pronounced in the competitive sector "where productivity matters" (p. 134).

Based on these findings, Psacharopoulos rejected the strong version of the screening hypothesis. Indeed, his findings appeared to confirm that education and productivity are positively related, at least in competitive sectors of the economy. But Psacharopoulos examined only the British economy; it would be necessary to examine others to repudiate the screening hypothesis. Cohn, Kiker, and Oliveira (1987) replicated Psacharopoulos' methodology in a study using cross-sectional data for the United States. They reported results generally consistent with his. The US study,

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[32] The value of marginal physical product is the value of additional output that can be produced by one more unit of a particular input while holding all other inputs constant. Hence, within the context of this example employers are more likely to pay employees according to the value of the goods and services these employees produce.

however, differed from the UK study in that the former showed that the returns to education in the public sector are generally higher than those in the private sector.

The Economic Council of Canada (1992) analyzed the rates of return to education based on human capital theory, and summarized its rationale for rejecting signalling theory[33] as follows. First, the Council argued that signalling theory implies that there are no private returns to education until graduation. However, comparisons of productivity rates[34] of drop-outs and graduates suggested that there are no significant differences. In some instances, the former even outperformed the latter.[35] Secondly, signalling theory suggests that diplomas are used as signals. The corollary is that private returns should decline with years of experience. However, studies of productivity rates suggested the opposite was true. Private returns, instead of declining with experience, actually increased with years of experience. This phenomenon seemed to suggest that education had long-term benefits. Lastly, argued the Council, if education is a mere signalling device, why are there no other less costly signalling devices to replace the expensive education system?

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[33] The Economic Council of Canada referred to the signaling theory as the "education-as-filter theory".

[34] The "productivity rates" are not defined by the Economic Council of Canada here. However, one may reasonably assume that wage rates are used as proxies for productivity rates.

[35] This Economic Council of Canada study did not refer to specific studies which provide empirical evidence for these assertions. However, references to such studies can be found in various literature surveys of screening, for instance, see Whitehead (1981).

To date, however, there is no test for validating the assertion that education does not also function as a signalling device.[36] At the same time, earnings differentials between better-educated workers and their less-educated counterparts persist. Given the fact that both developed and developing countries in the world have directed a considerable amount of resources to education,[37] it is difficult to argue that education is a mere signalling/screening/filtering device. However, it is interesting to note that in recent years education has been called upon to provide better labour market signals. For instance, in 1989, the Secretary of Labour's Commission on Workforce Quality (Commission on Workforce Quality and Labour Market Efficiency, 1989) urged schools in the United States to "develop easily understood transcripts which at the request of students, are readily available to employers" (p. 12). Also, during the 1992 election campaign, US President Clinton called for "*a national examination system* to measure our students' and schools' progress in meeting the national standards" (Clinton & Gore, 1992). The recognition of the importance of standardizing education to improve labour market efficiency is, to a certain extent, a recognition of the positive relationship between education and productivity.

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[36] In fact, it remains a common practice for employers to use educational qualifications as criteria for employment and wage rates of new recruits. In the parlance of recruitment, wages and salaries are "commensurate with qualifications." A casual survey of the employment section or most any newspaper confirms this. Interestingly, this common recruiting practice seems to support the view that educational qualifications are a valid indicator of an individual's productivity, but as noted above, employers may have other reasons for setting qualifications in the way they do.

[37] Canada, for instance, spends approximately seven percent of Gross Domestic Product (GDP) each year on education (Osberg, 1994).

A second alternative explanation has appeared in the form of reproduction theory. Proponents of this theory (e.g., Bowles, 1975; Gintis, 1971; Bowles & Gintis, 1976) contend that education is an institution which serves employers' class interests. Hence, the function of education is to perpetuate the socio-economic hierarchy by inculcating in students values, attitudes, and behaviour necessary for their future roles, which are largely determined by the socio-economic status of their parents. Proponents of reproduction theory tend to interpret empirical results in light of their ideology. For instance, the contention of Bowles and Gintis (1976) that the intergenerational transmission of social and economic status operates primarily via non-cognitive mechanisms. Their view was supported by empirical evidence, yet the evidence to which they referred was a correlation coefficient of childhood IQ in a normalized equation, a coefficient which was lower than the correlation coefficient of socio-economic background. There do not appear to be any studies verifying the validity of class reproduction theory versus human capital theory.[38] However, reproduction theory need not be seen as a refutation of human capital theory. Rather, it suggests that education has an impact on productivity by effecting behavioral changes in students which are useful for their future adult roles.

Given that the relationship between education and productivity is not directly observable, and to date has been inferred from the relationship between education and

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[38] Marshall, Carter & King (1976) argued that class reproduction theory is not amenable to empirical verification because it is founded on a dialectical interpretation of history.

earnings, it is not surprising that the theoretical debate continues. However, there seems to be a revival of faith in human capital as a means of promoting economic growth and productivity. In the Economic Council of Canada's last report, titled *Learning well ... Living well* (Canada, 1991), learning was identified as the "key to prosperity, competitiveness, good jobs and a good quality of life" (p.4). Also, the issue of investment in human capital figured prominently in a recent Canadian government publication (Canada, 1994) [39] as well as in the 1992 presidential election in the United States (Becker, 1993). In academic circles, a renewed interest in education's economic contribution is evidenced by a number of studies (e.g., Walters & Rubinson, 1983; Jorgenson, 1984; Fuller et al., 1986; Psacharopoulos & Velez, 1993; Liu & Armer, 1993).

The profit consequent to investment in human capital which Adam Smith noted more than two centuries ago is still widely observed today. Most empirical studies in the economics literature indicate that education contributes to both earnings and economic growth, and this evidence is considered by many to suggest that education contributes to worker productivity (Bruce, 1995). Nevertheless, many proponents of human capital theory no longer object to the suggestion that education may also have a

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[39] In this policy document the Canadian government affirms the important role of education in rehabilitating the nation's economy. However, it eschews responsibility for maintaining a constant level of public expenditure on education and rationalizes its action by arguing that "the greatest beneficiaries" of investment in human capital are individuals themselves (p. 41). The Canadian government's reluctance to maintain a constant level of financial support for education arguably reflects a tactical wisdom in the face of depleted coffers and mounting foreign debts.

signalling role. This seems to suggest that the signalling function of education is no longer perceived as a challenge to the validity of human capital theory. This new stance, however, is consistent with the tradition of being a positive theory: it perhaps better explains how things are. It would come as no surprise if signalling theory was eventually integrated into human capital theory.

Measuring the Economic Impact of Education

This section reviews the approaches used in the literature to obtain quantitative measures of the economic contribution of education. These approaches can be categorized into three groups,[40] namely, the earnings function approach, the production function approach and the cost function approach.

The Earnings Function Approach

According to Haveman and Wolf (1984), Mincer (1957) pioneered the concept and the use of earnings function.[41] An earnings function describes in mathematical terms the relationship between earnings and their determinants. In the original formulation (Mincer, 1957) the logarithm of an individual's earnings was expressed as

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[40] Bowen's (1963) categorization of the various methods measuring the economic contribution of education is often used in the literature (Bowman, 1966; Cohn, 1972; Sobel, 1978). These four general approaches are: (1) the simple correlation approach; (2) the residual approach; (3) the returns-to-education approach; and (4) the forecasting-manpower-needs approach. While Bowen's categorization relates to the specific purpose of the approach, the present study classifies the approaches according to the economic model used.

[41] Haveman and Wolfe (1984) used Bowen's classification and referred to the earnings function approach as the direct returns approach.

a function of years of schooling, years of labour market experience, and the square of years of labour market experience.[42] In later studies, Mincer (1962), and others (e.g., Griliches, 1970) added other variables to the original earnings function. These variables included gender, marital status, ethnic background, and ability measures (e.g., IQ scores).

To assess the economic contribution of education, the earnings function is used to analyze both private and social returns to educational investment. Private returns to education measure the net benefits of education (benefits minus costs) accrued to an individual receiving that education. The computation of these private benefits often involves estimating the incremental benefit in the stream of after-tax earnings of the individual, net of the increment in costs, as a result of acquiring additional years of schooling. Incremental after-tax lifetime earnings are measured based on parameter estimates of the earnings function that use annual after-tax earnings as the dependent variable.[43] Social returns to education measure the net benefits accrued to society when an individual acquires additional years of schooling. The computation of these social benefits involves estimating the incremental benefit in before-tax lifetime earnings

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[42] The logarithmic form of earnings is generally used as the dependent variable in order to avoid the econometric problem of heteroscedastic error terms. Error terms are heteroscedastic when their variance is not constant. The consequence of heteroscedastic error terms is that parameter estimates of the function to be estimated do not possess the minimum variance, thereby making their test of significance inaccurate. Detailed discussion of the assumptions regarding the distribution of error terms can be found in any standard econometrics text book, for instance, Koutsoyiannis (1977).

[43] After-tax lifetime earnings are calculated—using parameter estimates of earnings function—for each of the years after schooling has been completed. Lifetime earnings are usually assumed to span between the ages 25 and 65.

resulting from additional years of schooling. The reason for using the before-tax increment is that it is the individual's contribution to the nation's Gross Domestic Product (GDP). The incremental before-tax lifetime earnings are measured based on parameter estimates of the earnings function that use annual before-tax earnings as dependent variables. These incremental earnings are then subtracted from the incremental costs. The costs of educational investment which are considered in calculating private returns include the direct out-of-pocket costs to the individual as well as income foregone while attending school.[44] The costs which are considered in calculating social returns include private costs as well as social costs (e.g., tax-financed expenditure on education).

Recent Canadian estimates of private and social returns to investment in education using an earnings function approach are based on cross-sectional data. These estimates are reported in Table 7. Three interesting points emerge from the results presented in Table 7. First, private rates of return to educational investment exceed social rates of return. These findings lend support to the view that individuals who receive education are the greatest beneficiaries of education. Second, the results indicate that rates of return decline with the level of education achieved. This may support the view that more public funds should be allocated to lower levels of education. Finally, the results also indicate that

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[44] The direct costs include such out-of-pocket costs as tuition fees, books, supplies, etc..

Table 7 ***Some Recent Estimates of Rates of Returns to Education in Canada***

Study	Data	Educational Level	Estimates
Vaillancourt and Henriques (1986)	1982 Survey of Consumer Finance, individual microdata file	university	7% to 15%, (private) 6% to 10% (social)
Constantatos and West (1991)	1981 Census	elementary high school university	11.1% to 18.4% 7.5% to 13.1% 6.2% to 9.9% (all social)
Vaillancourt (1995)	1986 Census	secondary college university	18.6% to 38.5% (private) 6.1% to 9.1% (social) 6.6% to 17.3% (private) 2% to 5.4% (social) 8.3% to 18.8% (private) 4.3% to 8.4% (social)

over time, private returns to university education in Canada have risen, while social returns have fallen.

These results were all obtained, however, by using the earnings function approach and it does not consider the external effects of education. For example, a better-educated worker may have an impact on the productivity and employment of physical capital and workers with lower educational attainments. Some researchers (e.g., Bruce, 1995) have pointed to the possible existence of these external effects. A second difficulty with the earnings function approach relates to the issue of measurement. Estimates of returns to education are sensitive to the actual amount of costs and benefits used in the computation. Hence, it is not surprising that researchers have acknowledged that care must be taken in interpreting their estimates (see, for instance, Vaillancourt and Heniques, 1986; Constantatos and West, 1991). Furthermore, the functional form of the earnings function may also be a problem. For instance, a recent study, Akbari and Ogwang (1996), demonstrated that the logarithmic functional form does not solve the problem of heteroscedastic error terms[45] in earnings function estimation. A third shortcoming of the earnings function approach is that it relies on earnings as a proxy for productivity. The use of this proxy continues to be challenged (see, for instance, Vaizey, 1962; Klee, 1991). A fourth limitation relates to the issue of the inclusion of returns to physical capital in the computation of education's economic contribution. Since earnings include wages, salaries and self-employment income, a part of earnings represents returns to physical capital used by self-employed individuals.[46] To correct for this bias, it is necessary to exclude self-employed individuals from the computation. However, while this omission corrects for one bias, another serious bias is introduced, because individuals in certain professions, for instance, physicians and lawyers, are often self-employed. Vaillancourt (1995) argued that the bias introduced by the inclusion of self-employed income is small. However, no empirical evidence exists to confirm or deny this proposition. Hence, it is more useful to calculate education's economic contribution net of the effect of physical capital.

[45] See footnote 42 for a discussion.

[46] While wages and salaries are generally considered returns to labour, self-employed incomes reflect returns to both labour and physical capital invested.

The Production Function Approach

The production function approach entails the use, either explicitly or implicitly, of a production function. A production function is a mathematical expression which relates output of a production process to factors (inputs) included in the production process. The general production function can be expressed as

$$Y = f(K, L)$$

where Y is the output of the production process and K and L represent capital and labour inputs, respectively. The output of the production process is generally measured by its contribution towards Gross National Product (GNP), or its contribution towards value added. The capital input is generally measured by the value of capital stock, whereas the labour input is measured by either person-hours worked or by the number of workers employed.

As discussed earlier in this chapter, the empirical testing and the subsequent development of human capital theory began with economists' interest in education's contribution to economic growth. In the 1950s and the 1960s, researchers (e.g., Schultz, 1959; Denison, 1962) found that by taking into account the improved quality of the labour force consequent to rising educational attainments, a sizable portion of the "residual" of economic growth, could be explained.[47] These analyses of

[47] The "residual" is the unexplained portion of economic growth, calculated by using traditional measures of person-hours worked and the value of physical capital. A detailed account of sources of economic growth can be found in Denison (1974).

education's contribution to economic growth were based on the concept of an aggregate production function.

The studies which used a production function implicitly (e.g., Schultz, 1959; Denison, 1962) treated education as a labour-augmenting factor. Studies that used a production function explicitly (e.g., Griliches, 1963; Besen, 1968) used education as an explicit variable in the production function. The two approaches are discussed separately below.

Studies which explored the impact of education on economic growth by examining earnings differentials as a consequence of differences in educational levels were conducted within the framework of an implied production function. These studies have generally followed either the methodology developed by Schultz (1961), or the methodology developed by Denison (1962). Both methodologies used wage differentials by level of education to derive education's contribution to economic growth. Psacharopoulos (1984) noted that computational differences may arise in using the two methods because of discrepancies in considering physical increments of labour with given educational attainments (Denison's methodology), and the value invested in a particular level of education (Schultz's methodology). Schultz's methodology may be summarized in the following steps:[48]

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[48] This summary is based on the analysis of Cohn and Geske (1990).

1. Real labour income per person employed in a base year (0) and the subsequent year (t), given by LI_0 and LI_t is calculated. The difference in income between the two years represents growth in real labour income; an annual percentage change can also be computed.

2. LI^*_t, which is the level of real labour income that would have been observed in year t if each member of the labour force in year t earned the base-year income LI_0[49] is then calculated.

3. Next, the difference between actual labour income per person employed in year t, (LI_t), and the real labour income that would have been observed in year t, (LI^*_t) is calculated. The difference is ΔLI^*, representing the change in labour income during the period for which the labour force of year t would expect to earn, if the per person level of income has not changed between the base year and year t.

4. The increase in the stock of education for the period is then calculated. The stock of education for a given year (SE_t) is obtained by multiplying LF_t by the average number of school years completed per person in the labour force (YE_t), and multiplying the result by the price of an equivalent year of school in

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[49] The formula is $LI^*_t = \frac{LI_0}{LF_0} \times LF_t$, where LF_0 represents the number of workers in the labour force in the base year (0), and LF_t represents the number of workers in the labour force in year (t).

constant prices derived from data on the cost of schooling which also include foregone earnings (CE_t).[50]

5. Next, the portion of ΔSE that represents an increase in the educational level of the work force is calculated. This portion is computed by using the formula $\Delta SE^* = LF_t\ [(YE_t \times CE_t) - (YE_0 - CE_0)]$.

6. ΔSE^* is multiplied by the average rate of return on investment in education (r) to obtain the income attributable to the additional education (VE), where $VE = r\, \Delta SE^*$.[51]

7. Finally, the contribution of education to economic growth is expressed as the ratio $\frac{VE}{\Delta LI^*}$, representing the proportion of unexplained increase in economic growth due to education.

The maintenance of a given level of education for new members of the labour force may also be taken into account, that is, the cost of training workers in year t up to

[50] The formula for calculating the stock of education for a given year is $SE_t = LF_t \times YE_t \times CE_t$, where LF_t represents the number of workers in the labour force, YE_t represents the average number of school years completed per worker, and CE_t represents the cost of an equivalent year of school. The formula for calculating the total increase in the stock of education between the years 0 and t is $\Delta SE = SE_t - SE_0$.

[51] The notation r represents the average internal rate of return on investment in education. Schultz derived various average internal rates of return on education based on Becker's (1960) estimate of internal rate of return on investment in different levels of education

the level of training that workers received in year *0*. In addition to including the increase in labour income, one may include in ΔLI^* the increase in return to both capital and labour.

As noted above, Denison's methodology of computing education's contribution to economic growth differs from Schultz's. Denison's methodology does not take into account the maintenance of a given level of education for new members of the labour force, whereas Schultz's methodology does (Cohn and Geske, 1990). Denison's methodology may be summarized in the following steps:[52]

1. A weighting factor (W_e) that represents the earnings of workers with a given level of education relative to earnings of those with a base level of education is calculated. The base level used is eight years (W_8). Weights for additional classes of education under study are then calculated, using adjusted earnings of workers in the non-residential business sector (adjustments are made for various non-schooling factors, e.g., gender, age).

2. For each educational group, the full-time equivalent employment distribution of workers (P_e) is multiplied by the educational weights (W_e). The initial index is obtained by summing the product , $W_e \times P_e$ across all education groups. The

[52] This summary is based on the analysis of Cohn and Geske (1990).

same procedure is used to derive annual indexes for each time period under study.

3. Annual indexes for days per year and rates of attendance are then adjusted.[53]

4. Steps 1 through 3 are undertaken separately to obtain annual education indexes for both males and females. The final index for both sexes combined is obtained by either weighting total earnings, or by dividing each of the indexes by the index for a base year to standardize a final index.

5. Finally, the contribution of education to national economic growth is calculated by computing the increase in the quality of labour ascribed to education and multiplying it by the share of labour income in the national income.

Results of some of the studies estimating education's contribution to economic growth using an implicit production function are presented in Table 8. The estimates presented in Table 8 indicate that in the United States, education's contribution to economic growth was greater during the period 1929-48 than during the subsequent two decades period (1948-73). Education's contribution to Estimates of the contribution of education to economic growth in Canada using the implicit production

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[53] For instance, if a worker completed twelve years in a rural school where instruction was given only during 80 percent of the "normal" 180 school days, then it was assumed that the person obtained the equivalent of $0.8\times12 = 9.6$ years of schooling.

Table 8 ***Estimated Contribution of Education to National Economic Growth (Using an implicit Production Function)***

Study	Time Period	Country	Estimates
Schultz (1961)	1929-57	U.S.	36% (for average rate of return[a] on investment in education of 9%), 70% (for average rate of return on investment in education of 17.3%)
Psacharopoulos (1984)	1950s and 1960s	Argentina	16.5%
		Belgium	14.0%
		Brazil	3.3%
		Canada	25.0%
		Denmark	4.0%
		France	6.0%
		Germany	2.0%
		Italy	7.0%
		Japan	3.3%
		U.K.	12.0%
		U.S.	15.0%
Denison (1985)	1929-48	U.S.	36.1%
	1948-73		21.2%

[a] Schultz derived different average rates of return on investment in education. For a discussion of this, see footnote 51.

function approach have also been computed for various time periods. A summary of these estimates is presented in Table 9. economic growth in Canada was the largest among countries under study in the 1950s and 1960s.

Table 9 ***Contribution of Education to Economic Growth In Canada (Percentage of Total Growth)***

Study	1909-29	1929-57	1950-62	1962-73	1973-81	1981-88
Bertram (1966)	12.4	22.9				
Lithwick(1967)		11.9				
Walters (1970)			4.7			
Kendrick[a] (1981)				8.8	20.0	
Canada[b] (1985)				8.8	26.7	
CLMPC[c] (1989)						16.2

[a] Kendrick's estimates for the 1962-73 period refers to 1960-73, the 1973-81 period refer to 1973-79.

[b] This study was prepared for the Royal Commission on Canadian Economic Prospects (MacDonald Commission.).

[c] CLMPC stands for Canadian Labour Market and Productivity Centre.

Both Kendrick (1981) and the MacDonald Commission (1985) found that education's contribution to economic growth increased significantly during the 1960s and 1970s The Canadian Labour Market and Productivity Centre (CLMPC, 1989) attributed this to the significant increase in the number of persons completing higher levels of education during these two decades. Given that the educational levels of the population were used as weights to compute education's contribution to economic growth, the increase in education's contribution to economic growth may well reflect the increase in the educational attainment of the population during those time periods Structural factors such as the decline in youth population are, on the other hand largely responsible for the relatively low contribution of education to economic growth during the 1980s (CLMPC, 1989).

The shortcoming of the implicit production function approach is that in estimating education's contribution to economic growth it uses earnings differentials as a proxy for labour productivity differentials. This requires the assumption that labour markets are competitive. As Dean (1984) pointed out, criticisms of the implicit production function approach revolve around the appropriateness of the assumptions that workers are paid according to the value of their marginal product[54], and that factor and product markets are competitive. Bruce (1995) noted that, in Canada, markets are generally competitive. Only two examples of occupations in which employers have been found to exert a significant degree of monopsony power[55], namely, the market for nurses, and prior to the 1980s, the markets for professional athletes, such as baseball, hockey, football, and basketball players. In many markets, workers are paid according to the value of their marginal product, for instance, the salaries of hockey players (Jones & Walsh, 1988) and basketball players (Kahn & Sherer, 1988) have been found to match their marginal product. However, it is recognized in the literature that wage differentials between workers may not reflect their true marginal productivity differentials. For instance, as Ehrenberg and Smith

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[54] The marginal product of an input is the increase in the quantity of output resulting from an additional unit of that input used in the production process.

[55] Monopsony labour market structure results when there is a single buyer of labour.

(1988) noted, wage differentials between men and women reflect their marginal productivity differences as "perceived" by their employers.[56]

The Cobb-Douglas production function[57] is often used explicitly to obtain estimates of education's contribution to economic growth. In his analysis of education's contribution to productivity, Besen (1968), used cross-sectional data on the U. S. manufacturing industries to estimate the following Cobb-Douglas production function:

$X = AK^{\alpha} L^{\beta} E^{\gamma}$ ....(1)

X, K, L, are output, capital stock, and labour, respectively, and E is a measure of educational attainment. Estimated values of α, β, and γ, therefore, represent the effects of capital, labour, and education, respectively.[58] Despite its restrictive properties,[59] the Cobb-Douglas production function continues to be widely used,[60] perhaps due to the ease with which one can estimate the function, and also the fact that its parameters are

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[56] For instance, in Canada, it has been reported that women earn 30 percent less than men due to gender discrimination (Miller, 1987). In discrimination literature, employers are assumed to subjectively discount the productivity of female workers below that of male workers and consequently pay the latter less (e.g., Ehrenberg & Smith, 1988).

[57] A more detailed discussion on the Cobb-Douglas production function is provided in Chapter 3.

[58] The parameters α, β, and γ represent elasticity of output with respect to K, L, and E, respectively. Elasticity of output measures the percentage change in output resulting from the percentage change in a given input.

[59] A discussion of the restrictive properties of the Cobb-Douglas production is provided in Chapter 3.

[60] Recent studies, such as Hage, Garnier, and Fuller (1988), Liu and Armer (1993), Lee, Liu, and Wang (1994), are based on the Cobb-Douglas production function.

more readily interpretable.[61] The results of some of the studies using the Cobb-Douglas production function are presented in Table 10. Education's contribution to economic growth is obtained from estimating the value of γ in equation (1) presented above.[62] Liu and Armer (1993) estimated different levels of contribution to economic growth by incorporating different levels of education as separate variables. Griliches (1963, 1964), however, did not differentiate education by level.

Table 10 indicates that education's contribution to economic growth within US

Table 10 ***Education's Contribution to the Growth in Production (Using an Explicit Production Function)***

Study	Production Function	Time Period	Country	Estimates (Output Elasticity)
Griliches (1963)	Cobb-Douglas	1949	U.S. aggregate agriculture	0.431 (0.181)
Griliches (1964)	Cobb-Douglas	1954	U.S. aggregate agriculture	0.405 (0.161)
Liu and Armer (1993)	Cobb-Douglas	1953-85	Taiwan	primary 0.32 (0.13) junior high 0.32 (0.08) senior high 0.19 (0.16) college 0.14 (0.15)

Note: standard errors of output elasticities are reported in parentheses in last column.

[61] For instance, if the estimated value of γ is 0.4 in equation (1), then the output elasticity of education is 0.4. This means that a one percent increase in education will cause output to increase by 0.4 percent.

[62] The estimation is conducted by taking natural logarithms of equation (1) first, then using ordinary least squares regression to estimate the value of the parameters α, β, and γ.

agricultural industries was stable during the 1950s. Also, the magnitude of education's contribution to economic growth in Taiwan varied according to levels of education during the period 1953-85. The impact of education's contribution decreased as the level of education increased. In addition, Liu and Armer's study suggested that the estimates of the contribution of senior high and college education were not statistically significant, whereas the estimates of the contribution of primary and junior high education were statistically significant.[63]

As noted above, the explicit production function approach differs from the implicit production function approach by measuring the impact of education's input on output directly. Weisbrod (1967) considered the former approach "superior to" the latter approach "in principle" (p.379). However, the explicit approach also has its limitations. For instance, Cohn and Geske (1990) noted that the Cobb-Douglas production function is restrictive in its assumption that the elasticity of substitution between any pair of inputs is constant and is always equal to unity; that is, a given percentage change in relative input prices causes the same percentage change in relative input quantities. A detailed discussion of the restrictive properties of the Cobb-Douglas production function and the Constant Elasticity of Substitution (CES) production function is presented in Chapter 3.

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[63] A discussion of the implications of statistical significance is presented in Chapter 4.

Recent studies (e.g., Chinloy, 1980; Jorgenson, 1984) have developed more advanced techniques to measure the sources of economic growth. Jorgenson(1984), for instance, developed a methodology based on another explicit model of production, namely the Transcendental Logarithmic (translog) production function. A detailed discussion of the translog production function is presented in Chapter 3. The translog production function allows for the computation of both main effects and interaction effects of labour quality components.[64] Jorgenson found that during the period 1948-1973, the main effect of education was to increase labour quality by an average annual rate of 0.67 percent. However, the interaction effects between education and other components of labour quality were negative (-0.21), thereby reducing education's net effect on labour quality to 0.36. Table 11 presents Jorgenson's and one other recent study which estimated education's interaction effects as well as its main effect.

Table 11 ***Estimated Contribution of Education to Economic Growth (Main Effect and Interactive Effect)***

Study	Production Function	Time Period	Country	Estimates
Chinloy (1980)	translog	1947-1974	U.S.	main effect 0.61 interactive effect -0.27 net effect 0.34
Jorgenson (1984)	translog	1948-73	U.S.	main effect 0.67 interactive effect -0.21 net effect 0.36

[64] The labour quality components used include education, gender, age, employment class, and occupation.

The tables presented above (Tables 7 through 11) illustrate some findings of empirical studies done on human capital theory. These findings are consistent. Education makes a contribution to economic growth; however, the magnitude of that contribution varies over time and space.

The Cost Function Approach.

While many studies have used production functions to estimate education's contribution to economic growth, other studies have employed the cost function approach. A cost function is a mathematical function that describes the relationship between output and inputs in terms of the costs of that production process. The necessary assumptions for estimating a cost function are that factor prices are exogenous variables and that the criterion for the selection of an input bundle is cost-minimization for any given level of output. Various studies have used the cost function approach to examine the extent to which different groups of labour, disaggregated by educational attainments are substitutes for, or complements of, each other.[65]. As mentioned above, a cost function assumes factor prices are exogenous variables.

The appropriate measure of the extent to which inputs are substitutes is the Allen partial elasticity of substitution, σ_{ij}, which measures the effect on the quantities

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[65] If two inputs are substitutes an increase (decrease) in the demand for one would lead to an decrease (increase) in the demand for the other. Conversely, if two inputs are complements an increase (decrease) in the demand for one would lead to the increase (decrease) in the other. A detailed discussion is provided in Chapter 3.

of input i of a change in the price of input j, holding output and other input prices constant. Input i and j are substitutes in production if $\sigma_{ij} > 0$, and are complements in production if $\sigma_{ij} < 0$ (Hamermesh & Grant, 1979). Table 12 presents the estimates of the extent to which different groups of labour disaggregated by educational level are substitutes for, or complements of, each other.

Since all estimates of Allan partial elasticity of substitution in the three studies presented in Table 12 are positive, they indicate that labour groups disaggregated by educational levels are substitutes for each other in production. However, it is interesting to note that to date, studies which examined the extent to which different labour groups are disaggregated by educational levels have not extended their analysis to include the overall role of education in economic production.

Indeed, both the production function and the cost function can be used to estimate the marginal contribution of education as well as the impact of education on the production of economic output—that is, the extent to which education affects both the use and the price of capital and the employment and wage rates of labour with different levels of educational attainment. A production function assumes that factor quantities are exogenous variables, whereas a cost function assumes factor prices are exogenous variables. Thus the choice of production function or cost function may also depend on whether the objective of the analysis is to determine the effect of a change in employment levels (quantities) on wage rates (prices), or the effect of a change in wage rates on employment levels. In the last analysis, the choice of production function or cost function often depends on the availability of data.[66]

Table 12 Studies of Labour Substitution (Disaggregated by Education)

Study	Data & Method	Types of Labour	σ_{ij} (Labour-Labour)
Welch (1970)	U.S., States, Census of Agriculture, 1959; CES	college vs. high school four years or less	1.41
Dougherty (1972)	U.S., States, Census of Population, 1960; CES	more than 9 years vs. less than 8 years	3.3
Grant (1979)	U.S., SMSAs[a], Census of Manufactures, 1969; translog	8 years or less vs. 9-12 years	0.77
		8 years or less vs. 12 years or more	0.21
		9-12 years vs. 12 years or more	1.16

[a] SMSA stands for Standard Metropolitan Statistics Area

The discussion above shows that both the explicit production function approach and the cost function approach are useful tools for analyzing education's economic contribution, especially since both approaches allow for estimates of the effect of education on the use and the price of capital and the employment and wage rates of labour. However, these approaches are not without shortcomings. One of the

[66] It should be noted that production and cost functions are dual in theory, and that Shephard's Lemma facilitates estimation of the effect of a change in quantities on prices using a cost function, as well as estimation of the effect of a change in prices on quantities using a production function. For a detailed discussion of the correspondence between production and cost functions see Shephard (1970).

shortcomings of the production function arises from the restrictive underlying assumptions of some of the functional forms. For instance, the Cobb-Douglas production function assumes that the elasticity of substitution between any pair of inputs is unity; that is, if output remains unchanged, a given percentage change in relative input prices causes the same percentage change in relative input quantities. This objection can be remedied. A number of less restrictive functional forms are available. For instance, neither the CES production function nor the translog production function requires the underlying assumption of unity. Another shortcoming of the production function approach stems from its underlying assumption of profit maximization. Some economists assert that real world firms do not have sufficient information at their disposal to maximize profits.[67] However, the assumption that firms organize productive inputs in such a way as to maximize profits remains generally acceptable in the literature.

Perspective

This review of the literature on the development of human capital theory indicates that the theory has significantly contributed to an explanation of both economic growth and earnings differentials. The empirical studies of the last two decades have shown education is not limited to imparting marketable skills and knowledge—it contributes more fundamentally to the economy in ways which human

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[67] For a detailed discussion of the controversy over the profit maximization hypothesis. see Nicholson (1978).

capital theorists specified in their writings in the 1960s (e.g., Schultz, 1960; Becker, 1964).

Perhaps some of the alternative explanations for earnings differentials between better-educated workers and their less-educated counterparts might not have been advanced if the early proponents of human capital theory had made an effort to explicate fully the process by which education enhances an individual's economic productivity. Miller (1967), for instance, noted that research within the framework of human capital theory suffered in this respect:

> Surprisingly, no single contemporary economist has stated with much detail and scope just why he thinks education advances economic development. Without such a statement, most contemporary economists interested in education and economic growth delve into the task of statistical measurement and show great imagination in efforts to substitute order for chaos (p. 280).

One may perhaps reasonably argue that during the 1960s proponents of human capital theory did not see the need to explain the theory in detail and scope, since the facts of post-war economics neatly fit the requirements of the theory, i.e., better-educated workers earned more than their less-educated counterparts, and physical capital worked miracles only in countries with a more-educated populace. Even the contentious issue of ability did not appear to repudiate the validity of the theory.

To a certain extent it was the slowdown of economic growth in the 1970s that paved the way for the emergence of alternative explanations, and it was only after the emergence of these alternative explanations that proponents of human capital theory began to expound the relationship between education and the economy, as opposed to concentrating on measuring the magnitude of education's economic contribution. In defending the validity of human capital theory, Whitehead (1981) wrote:

> ... education is a productivity-augmenting process in the sense that it produces skills and abilities in the individual which previously did not exist, or develops productive characteristics which would otherwise remain largely dormant (p. 241).

Psacharopoulos (1984) pointed to education's function of producing attitudinal and behaviour changes to facilitate economic growth:

> One of the prime indirect ways in which education contributes to economic growth is that it enhances the adoption and efficient use of new inputs. Whether the argument is cast in terms of the allocative efficiency of farmers (Schultz, 1964) or the general ability to "deal with disequilibria" (Schultz, 1975), the literature is full of evidence that schooling acts as a catalyst in behavioural change conducive to growth (p. 341).

Acceptance of the premise that education enhances the economic productivity of labour does not preclude the vital role of physical capital in the economy. In their enthusiasm for the discovery of the importance of human capital through education, proponents of human capital theory paid little attention to the importance of physical capital. Indeed, Johnson (1964) pointed out that concentration on the role of human capital is as restrictive as an emphasis on investment in physical capital, and proposed "a more comprehensive formulation of economic development problems in terms of a broadly conceived concept of capital formulation" (p. 35). Johnson's approach was not favoured by Schultz (1970), because although "this approach may be paved with good economic logic, it is in fact a rough road with many detours" (p. 301). However, as noted earlier, given the mutual dependence between capital and labour (Marshall, 1961), the slowdown in economic growth in Canada despite increases in the educational attainments of Canadians may be attributable to the relatively low level of investment in physical capital. Hence, economic analysis may be more fruitful if both human capital and physical capital formation are taken into account.

Human capital theory provides a useful theoretical framework for a quantitative analysis of the economic contribution of education. As to the empirical tool for such an analysis, the review of literature in this chapter shows that either the explicit production function approach, or the cost function approach is appropriate. Given that one of the objectives of the present study is to determine the impact of workers possessing higher levels of educational attainments on the employment and wages of workers with lower levels of education, it is more appropriate to use the explicit production function approach, which utilizes a non-restrictive production function. The reason for this will be stated more fully in Chapter 3. Further discussion of the merits of estimating a production function is presented in the next chapter, following a discussion of the relationships among inputs of production.

CHAPTER 3: METHODOLOGY AND THE ECONOMETRIC MODEL

The review of theoretical and empirical literature in the previous chapter has shown that human capital theory provides a useful general framework for empirical analysis of the economic contribution of education. Using this framework, one can specify a production function. Econometric estimation of this production function permits quantitative assessment of the impact of education on industrial output and the employment level of productive factors.

The primary purpose of this chapter is to present the econometric model—that is, the production function—used in this study. This includes a discussion of the production function concept, returns to scale, three commonly used functional forms of the production function, the possible relationships between pairs of inputs in a production function, and the merits of the translog production function. The specification of the particular translog form of the production function used in this study is also discussed, as are econometric issues relating its estimation and the econometric technique used to estimate its parameters. Following this discussion, the data sets used to estimate the production function are described. Finally, the role of education in the production process, as specified by human capital theory, is discussed.

The Econometric Model

The Production Function

A production function describes the technical relationship of the output of a production process with the various inputs used.[68] It provides quantitative estimates of the maximum output that can be produced by various combinations of inputs at a given level of technology[69]. Economists generally aggregate inputs into two homogeneous categories, namely, labour and capital. Outputs are usually measured by national products (e.g., Gross National Product, Gross Domestic Product, Value Added, etc.). Labour inputs are usually measured by hours worked or persons employed, and capital inputs are usually measured by capital stock, which is comprised of building construction, engineering construction, machinery and equipment. A production function specified in this manner has been used to analyze various social and economic issues (Liu and Armer, 1993).

Returns to Scale

In a production function, the response of output to changes in inputs used in its production is called returns to scale. A production function is said to exhibit increasing returns to scale if, as inputs rise in a given proportion, the output rises by a greater

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[68] Mathematically, a two-input production function is written as $Q = (X_1, X_2)$, where Q is the level of output of a production process. X_1 and X_2 are the quantities of inputs employed to produce Q.

[69] The given technology with which one input may be substituted for another input in the productive process while holding output constant.

proportion. Thus, for example, if all inputs are doubled, the output will be more than doubled. Normally, a firm's production function exhibits increasing returns to scale during the initial stages of expansion, when a division of tasks takes place on the basis of specialization. Decreasing returns to scale refer to production processes in which an increase in inputs in a given proportion results in an increase of output by a smaller proportion. Normally, a firm's production function exhibits decreasing returns to scale when the firm has expanded its scale of operation so much that there is a loss of managerial control over its operations. Finally, constant returns to scale normally occur at a stage where increasing and decreasing returns to scale tend to cancel each other out. During this stage, increases in inputs in a given proportion increase output by the same proportion. Thus, if all inputs are doubled, the output will also be doubled.

Major Forms of Production Functions

A production function can be specified mathematically. As noted in Chapter 2, the three most common forms are: the Cobb-Douglas production function, the Constant Elasticity of Substitution (CES) production function, and the translog production function.[70] These forms are based on the realization that in their production decisions firms will seek to choose the combination of inputs which will minimize production costs. In their search for such a combination of inputs, firms may substitute one input for another. The forms of production functions differ from one another in

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[70] A detailed discussion on various forms of the production function can be found in Berndt (1994).

their assumptions about the *extent* to which pairs of inputs used in the production of a given output level can be substituted for one another.

The extent to which pairs of inputs are substitutable is reflected by the ***elasticity of substitution***. The elasticity of substitution between inputs *i* and *j* measures the effect on their relative quantities ($\frac{X_i}{X_j}$) of changes in their relative prices ($\frac{P_i}{P_j}$) when output is held unchanged. The higher the value of the elasticity of substitution, the greater the extent of substitutability between inputs in producing a given output level.

As noted earlier, in estimating the Cobb-Douglas production function,[71] it is assumed that the elasticity of substitution between any two inputs is unity, i.e., it is assumed that a given percentage change in relative input prices causes the same percentage change in relative input quantities, output remaining unchanged. The CES production function[72] is less restrictive than the Cobb-Douglas form: the elasticity of substitution between any two inputs is allowed to be of any value. However, it is assumed that the elasticity of substitution between any given pair of inputs is constant. If a CES production function uses three inputs, say blue collar workers, white collar workers and physical capital, then the elasticity of substitution between blue and white collar workers is assumed to be the same as that between blue collar workers and

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[71] The Cobb-Douglas production function was introduced by C. W. Cobb and P. H. Douglas. For a detailed discussion. see Douglas (1934).

[72] The CES production function was developed by Arrow et al. (1961).

physical capital, and that between white collar workers and physical capital. For a CES production function with more than two inputs, the degree of substitution between any two inputs is always assumed to be the same.

The translog production function is the most flexible of the three most commonly used forms of production functions.[73] No assumptions are made with respect to the *extent* of substitution between pairs of inputs; therefore it is useful for analyzing varying substitution possibilities across different industries. It is precisely this property of the translog production function that makes it an appropriate choice for the present study, because an objective of the present study is to include an assessment of the kind of relationship between various inputs used in Canadian production. The following section discusses the kinds of relationships that are possible between pairs of inputs used in a production process.

<u>Possible Relationships between Inputs Used in Production: Substitutes or Complements in Production.</u>

In a production process, if other input quantities are held constant, changes in the quantity of any given input alter the quantity produced of the final product. This means that the demand for other productive inputs may also change. As noted earlier, if there are more than two inputs used in a production process, these two inputs can be either *substitutes in production* or *complements in production*. For example, suppose

[73] This functional form was first presented by Christensen, Jorgenson and Lau (1973), and since has been classified as the *flexible functional form* in the literature (Hamermesh and Grant, 1979).

there are three inputs used in a production process: capital, skilled labour, and unskilled labour. Each of the two categories of labour will have a demand curve that slopes downward, that is, the quantity demanded decreases as the wage rate increases. If skilled and unskilled labour are *substitutes in production*, this means that a higher level of employment of one group can compensate for a lower level of employment in another group. In this case, an increase in the wage rates of one group of labour can either increase or decrease the demand for the other group.[74] If an increase in the wage rates of one group decreases the demand for the other group, the *scale effect* has dominated the *substitution effect* and these two groups of labour are *gross complements*. Conversely, if an increase in the wage rates of one group increases the demand for the other group, the *substitution effect* has dominated and these two groups of labour are *gross substitutes*.[75] If skilled and unskilled labour are *complements in production*, this means that they must be used together. Hence, a decrease in the level of employment in one group of labour implies a reduction in the level of employment in the other labour group. In this case, there is only a scale effect and no substitution effect, and the two inputs must be gross complements.

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[74] This means that the demand curve for the other may shift either to the left or to the right.

[75] When the price of an input rises, two effects take place simultaneously. One is the *scale effect*, which means that the firm tends to reduce its output level for a given expenditure since the cost of production has risen. The other effect is the *substitution effect*, which means that the firm will produce any given output level by substituting the input whose price has risen with another (now relatively cheaper) input. Eventually what happens to the employment of the input whose price has risen will depend upon whether the scale effect is greater or the substitution effect is greater.

To illustrate, consider the example of a snow-removing firm in which skilled and unskilled workers are substitutes in production.[76] Snow can be removed either by skilled workers (who use snow plows) or by unskilled workers (who use shovels). Other things being equal, if the supply of skilled workers increases, the wages of these workers will fall. As a consequence, the firm would want more skilled workers than before, and fewer of the now relatively more expensive unskilled workers, to remove any given quantity of snow. To the extent that this substitution effect dominates any scale effect, the demand for skilled workers would rise. In this case, skilled and unskilled workers are gross substitutes. On the other hand, if the increase in the scale of output results in increased use of unskilled workers, even though skilled workers are being substituted for unskilled workers in the production process, skilled and unskilled workers are considered gross complements.

In the firm discussed above, snow plows and skilled workers are complements in production. If the price of these snow plows rise, the firm would cut back on their use, which would result in a reduced demand for, at each wage level, the skilled workers who use the snow plows. As stated earlier, inputs that are complements in production are always gross complements. By investigating the *kind* of relationship between pairs of inputs one can also determine the effect of an increase in the quantity of a given input on the employment and wage rates of other inputs. Thus, in the

[76] Hamermesh and Rees (1996) have used a similar example in their study. In this example, the amount of snow removed during a given time period is considered the output of the production process. The inputs used in the production process are skilled workers, unskilled workers, snow plow and shovel.

context of the present study, if the production function analysis shows that workers with higher educational attainments and workers with lower educational attainment are substitutes in production, then it means that any increase in the supply of workers with higher educational attainments will result in a displacement of workers with lower educational attainments in production. At the same time, the wage rates of workers with lower educational attainments will decrease since demand for their services will fall. On the other hand, if workers with higher educational attainments and workers with lower educational attainments are complements in production, any increase in the supply of workers with higher educational attainments will result in increased employment of workers with lower educational attainments. At the same time, the wage rates of workers with lower educational attainments will rise since demand for their services will increase.

The Merits of Estimating a Production Function

As shown in the previous chapter, both the earnings function and the production function have been used in the literature to assess the economic contribution of education. For the present study, however, there are at least four advantages of estimating a production function instead of an earnings function.

First, the production function permits a direct assessment of the impact of education on industrial output. The alternative, earnings function, assesses education's economic impacts on industries only *indirectly*, that is, the assessment is conducted by estimating educational returns for individuals.

Secondly, by including physical capital stock as one of the inputs in production, the production function permits a direct assessment of education's contribution to production, net of the use of physical capital. According to Hamermesh and Grant (1979), estimates of labour-labour substitution are biased if labour is not *separable* from capital, i.e., if the relationship between any two groups of labour is not independent of the amount of capital used. The translog production function enables one to test for input separability. An earnings function does not include the effect of physical capital on output and thereby ignores the effect of substitution towards capital in the event labour costs rise. As a result, estimates of own-price elasticities of demand tend to be downwardly biased.[77]

Thirdly, the production function permits a direct assessment of the relationship between workers with different levels of educational attainment as well as their relationship with physical capital in any given industry. Estimates of production function parameters can be used to compute the all important factor price elasticities which indicate the extent to which two groups of workers are substitutes or

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[77] Vaillancourt (1995) has also noted out this particular shortcoming of earnings function. The downwardly biased estimates are the result of ignoring the impact of capital stock.

complements in production.[78] Estimates of factor price elasticity provide useful information for public policy makers to gauge the reverberation of a change in a given production input in the related markets. A detailed discussion of the concept of factor price elasticity and its computation is provided in a later section of this chapter.

Finally, as some observers (e.g., Bruce, 1995) have noted, the impact of education on economic output is not only reflected in changes in earnings. A more detailed analysis of such impact requires an assessment of how workers endowed with various educational levels are related to each other and to capital stock in production. The production function permits such an assessment.

Specification of the Econometric Model

The present study follows Welch (1970) and Grant (1979), and disaggregates labour by educational levels. The production of goods and services in the major industries in Canada is summarized in the following production function:

$$Q = f(P,S,T,U,K) \qquad (1)$$

where the output and the input variables are given below:

[78] The factor price elasticity between inputs i and j measures the percentage change in the price of input i caused by a percentage change in the quantity of input j. Further discussion of factor price elasticity is presented later in this chapter.

Q	value added in an industry
P	employed persons in an industry with grade eight or less education
S	employed persons in an industry with grades nine to thirteen education
T	employed persons in an industry with post-secondary non-university education
U	employed persons in an industry with university education
K	end-year gross capital stock in an industry

An econometric estimation of the above function requires the imposition of a functional form. In the present study, the translog form is chosen for its non-restrictive property.[79] The specific form of this function is:

$$
\begin{aligned}
\ln Q = {} & \ln\alpha_0 + \alpha_p \ln P + \alpha_s \ln S + \alpha_t \ln T + \alpha_u \ln U + \alpha_k \ln K \\
& + \frac{1}{2}[\gamma_{pp}(\ln P)^2 + \gamma_{ss}(\ln S)^2 + \gamma_{tt}(\ln T)^2 + \gamma_{uu}(\ln U)^2 + \gamma_{kk}(\ln K)^2] \\
& + \frac{1}{2}[\gamma_{ps}(\ln P)(\ln S) + \gamma_{pt}(\ln P)(\ln T) + \gamma_{pu}(\ln P)(\ln U) + \gamma_{pk}(\ln P)(\ln K) \\
& + \gamma_{st}(\ln S)(\ln T) + \gamma_{su}(\ln S)(\ln U) + \gamma_{sk}(\ln S)(\ln K) \\
& + \gamma_{tu}(\ln T)(\ln U) + \gamma_{tk}(\ln T)(\ln K) + \gamma_{uk}(\ln U)(\ln K)] \\
& + \frac{1}{2}[\gamma_{sp}(\ln P)(\ln S) + \gamma_{tp}(\ln P)(\ln T) + \gamma_{up}(\ln P)(\ln U) + \gamma_{kp}(\ln P)(\ln K) \\
& + \gamma_{ts}(\ln S)(\ln T) + \gamma_{us}(\ln S)(\ln U) + \gamma_{ks}(\ln S)(\ln K) \\
& + \gamma_{ut}(\ln T)(\ln U) + \gamma_{kt}(\ln T)(\ln K) + \gamma_{ku}(\ln U)(\ln K)]
\end{aligned}
\qquad \text{.................(2)}
$$

where α_0, α_p, α_s, α_t, α_u, α_k, γ_{pp}, γ_{ss}, γ_{tt}, γ_{uu}, γ_{kk}, γ_{ps}, γ_{pt}, γ_{pu}, γ_{pk}, γ_{sp}, γ_{tp}, γ_{up}, γ_{kp}, γ_{st}, γ_{su}, γ_{sk}, γ_{tu}, γ_{tk}, γ_{uk}, γ_{st}, γ_{us}, γ_{ks}, γ_{ut}, γ_{kt} and γ_{ku} are the parameters to be estimated. These parameters are determined by the technology in use.[80]

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[79] As was discussed earlier, the translog form of a production function does not require any à priori assumptions about the relationship between pairs of inputs in the production process.

[80] The technology in use determines whether or not one input can be substituted for another input in the production process, and also to what extent they can be substituted for each other.

The parameters of the translog production function specified above can be directly estimated using the Ordinary Least Squares (OLS) regression technique. However, gains in efficiency of the estimated parameters can be realized first by transforming equation (2) into factor share equations, and then estimating the parameters from the factor share equations.[81] Grant (1979) observed that only the very early studies directly estimated the translog production function. Existence of multicollinearity among the exogenous variables affects the standard error of such estimates. Lack of requisite data on capital and lack of good nonlinear estimation techniques were possibly responsible for the prevalent use of the indirect estimation method[82].

Grant's notion that multicollinearity poses a serious potential problem for the direct approach seems to stem from his knowledge of an earlier study by Byron (1977). In that study, Byron conducted a series of Monte Carlo[83] experiments to compare the merits of the direct and the indirect estimation approaches. Based on the differences in the quality of the results produced by the two approaches, Byron, cited in Grant (1979), concluded:

> What does emerge from the results is that the direct approach is markedly inferior to the indirect approach... and it appears that the poor results of the direct estimates are simply due to multicollinearity between the regressor variables resulting from the presence of quadratic terms in the estimated equation (p. 58).

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[81] Details of this indirect method follow anon.

[82] A discussion of this indirect method follows anon.

[83] A Monte Carlo study is a simulation exercise designed to shed light on the small-sample properties of estimators, for a given estimation problem, the analytical small-sample properties of which are difficult to derive. For a detailed discussion, see, Kennedy (1985).

Based on the evidence presented by the two studies cited above, the present study opted for the indirect estimation method, which entails the transformation of equation (2) into a system of factor share equations. These factor share equations are obtained by taking the partial derivatives of equation (2) with respect to input quantities. In order to obtain an estimable form of the share equations certain assumptions had to be made. These assumptions are discussed following the statement of the partial derivatives for equation (2), below:

The partial derivatives of equation (2) with respect to each input quantity are written thus:

$$\frac{\partial \ln Q}{\partial \ln P} = \alpha_p + \gamma_{pp} \ln P + \frac{1}{2}(\gamma_{ps} \ln S + \gamma_{pt} \ln T + \gamma_{pu} \ln U + \gamma_{pk} \ln K) + \frac{1}{2}(\gamma_{sp} \ln S + \gamma_{tp} \ln T + \gamma_{up} \ln U + \gamma_{kp} \ln K) \quad \text{.....(3a)}$$

$$\frac{\partial \ln Q}{\partial \ln S} = \alpha_s + \gamma_{ss} \ln S + \frac{1}{2}(\gamma_{sp} \ln P + \gamma_{st} \ln T + \gamma_{su} \ln U + \gamma_{sk} \ln K) + \frac{1}{2}(\gamma_{ps} \ln S + \gamma_{ts} \ln T + \gamma_{us} \ln U + \gamma_{ks} \ln K) \quad \text{.....(3b)}$$

$$\frac{\partial \ln Q}{\partial \ln T} = \alpha_t + \gamma_{tt} \ln T + \frac{1}{2}(\gamma_{tp} \ln P + \gamma_{ts} \ln S + \gamma_{tu} \ln U + \gamma_{tk} \ln K) + \frac{1}{2}(\gamma_{pt} \ln P + \gamma_{st} \ln S + \gamma_{ut} \ln U + \gamma_{kt} \ln K) \quad \text{.....(3c)}$$

$$\frac{\partial \ln Q}{\partial \ln U} = \alpha_u + \gamma_{uu} \ln U + \frac{1}{2}(\gamma_{up} \ln P + \gamma_{us} \ln S + \gamma_{ut} \ln T + \gamma_{uk} \ln K) + \frac{1}{2}(\gamma_{pu} \ln P + \gamma_{su} \ln S + \gamma_{tu} \ln U + \gamma_{ku} \ln K) \qquad \text{(3d)}$$

$$\frac{\partial \ln Q}{\partial \ln K} = \alpha_k + \gamma_{kk} \ln K + \frac{1}{2}(\gamma_{kp} \ln P + \gamma_{ks} \ln S + \gamma_{kt} \ln T + \gamma_{ku} \ln U) + \frac{1}{2}(\gamma_{pk} \ln P + \gamma_{sk} \ln S + \gamma_{tk} \ln T + \gamma_{uk} \ln U) \qquad \text{(3e)}$$

In order to re-write the system of equations (3a) - (3e) in estimable form, three assumptions are made. First, it is assumed that the parameters of the production function are symmetric. This assumption means that in the above system of equations, $\gamma_{ps} = \gamma_{sp}$, $\gamma_{pt} = \gamma_{tp}$, $\gamma_{pu} = \gamma_{up}$, $\gamma_{uk} = \gamma_{ku}$, $\gamma_{st} = \gamma_{ts}$, $\gamma_{su} = \gamma_{us}$, $\gamma_{sk} = \gamma_{ks}$, $\gamma_{tu} = \gamma_{ut}$, $\gamma_{tk} = \gamma_{kt}$, $\gamma_{uk} = \gamma_{ku}$. These restrictions reduce the number of parameters to be estimated from 30 to 20:

$$\begin{aligned}
\frac{\partial \ln Q}{\partial \ln P} &= \alpha_p + \gamma_{pp} \ln P + \gamma_{ps} \ln S + \gamma_{pt} \ln T + \gamma_{pu} \ln U + \gamma_{pk} \ln K \\
\frac{\partial \ln Q}{\partial \ln S} &= \alpha_s + \gamma_{ps} \ln P + \gamma_{ss} \ln S + \gamma_{st} \ln T + \gamma_{su} \ln U + \gamma_{sk} \ln K \\
\frac{\partial \ln Q}{\partial \ln T} &= \alpha_t + \gamma_{pt} \ln P + \gamma_{st} \ln S + \gamma_{tt} \ln T + \gamma_{tu} \ln U + \gamma_{tk} \ln K \\
\frac{\partial \ln Q}{\partial \ln U} &= \alpha_u + \gamma_{pu} \ln P + \gamma_{su} \ln S + \gamma_{tu} \ln T + \gamma_{uu} \ln U + \gamma_{uk} \ln K \\
\frac{\partial \ln Q}{\partial \ln K} &= \alpha_k + \gamma_{pk} \ln P + \gamma_{sk} \ln S + \gamma_{tk} \ln T + \gamma_{uk} \ln U + \gamma_{kk} \ln K
\end{aligned}$$

Secondly, the production function is assumed to be homogeneous of degree one in input quantities. This means that if all inputs are increased by a given proportion, the output will also rise by the same proportion.[84] This assumption allows one to impose the following restrictions on the parameters:

$$
\begin{aligned}
\alpha_k &= 1-(\alpha_p+\alpha_s+\alpha_t+\alpha_u) \\
\gamma_{kk} &= -(\gamma_{pk}+\gamma_{sk}+\gamma_{tk}+\gamma_{uk}) \\
\gamma_{pk} &= -(\gamma_{pp}+\gamma_{ps}+\gamma_{pt}+\gamma_{pu}) \\
\gamma_{sk} &= -(\gamma_{sp}+\gamma_{ss}+\gamma_{st}+\gamma_{su}) \\
\gamma_{tk} &= -(\gamma_{tp}+\gamma_{ts}+\gamma_{tt}+\gamma_{tu}) \\
\gamma_{uk} &= -(\gamma_{up}+\gamma_{us}+\gamma_{ust}+\gamma_{uu})
\end{aligned}
$$

The above restrictions reduce the number of free parameters to 14 from 20. Finally, it is assumed that firms purchase inputs in competitive markets. This means that firms must pay the market wage to inputs and determine the employment of inputs by equating the wage rate with the value of an input's marginal product[85]. This assumption allows one to transform the left hand side of equations (3a) - (3e) as follows:

$$\frac{\partial \ln Q}{\partial \ln X} = \frac{\partial Q}{\partial X}\frac{X}{Q} \qquad (4)$$

[84] As discussed earlier, a production function possessing this property is said to exhibit constant returns to scale in production. Wicksell (1946) has pointed out that while a homogeneous production function could not be expected to apply over the whole range of output within a plant, each firm under perfect competition would tend to carry its scale of output to a point where neither increasing nor decreasing returns to scale apply, rather where the returns to scale are constant. Since industries are aggregates of firms, and the economy as a whole is an aggregate of industries, a constant returns to scale production function is presumed to be true of society as a whole.

[85] The value of an input's marginal product is the value of the extra output produced by the additional worker hired.

where $X = P, S, T, U, K$. Also, $\frac{\partial Q}{\partial X}$ is the value of the marginal product of X. In a competitive market, firms equate market wage with the value of marginal product. Hence, $\frac{\partial Q}{\partial X} = W_x$, where W_x is the wage of input X. Therefore, equation (4) can be rewritten as:

$$\frac{\partial \ln Q}{\partial \ln X} = \frac{W_x X}{Q} = S_x,$$

where S_x is the share of the input X in the output Q. The three assumptions discussed above allow the system of share equations to be written as follows:

$$\begin{aligned}
S_p &= \alpha_p + \gamma_{pp}\ln P + \gamma_{ps}\ln S + \gamma_{pt}\ln T + \gamma_{pu}\ln U - (\gamma_{pp} + \gamma_{ps} + \gamma_{pt} + \gamma_{pu})\ln K \\
S_s &= \alpha_s + \gamma_{sp}\ln P + \gamma_{ss}\ln S + \gamma_{st}\ln T + \gamma_{su}\ln U - (\gamma_{sp} + \gamma_{ss} + \gamma_{st} + \gamma_{su})\ln K \\
S_t &= \alpha_t + \gamma_{tp}\ln P + \gamma_{ts}\ln S + \gamma_{tt}\ln T + \gamma_{tu}\ln U - (\gamma_{tp} + \gamma_{ts} + \gamma_{tt} + \gamma_{tu})\ln K \\
S_u &= \alpha_u + \gamma_{up}\ln P + \gamma_{us}\ln S + \gamma_{ut}\ln T + \gamma_{uu}\ln U - (\gamma_{up} + \gamma_{us} + \gamma_{ut} + \gamma_{uu})\ln K \\
S_k &= 1 - (\alpha_p + \alpha_s + \alpha_t + \alpha_u) - (\gamma_{pp} + \gamma_{ps} + \gamma_{pt} + \gamma_{pu})\ln P - (\gamma_{sp} + \gamma_{ss} + \gamma_{st} + \gamma_{su})\ln S \\
&\quad -(\gamma_{tp} + \gamma_{ts} + \gamma_{tt} + \gamma_{tu})\ln T - (\gamma_{up} + \gamma_{us} + \gamma_{ut} + \gamma_{uu})\ln U - (\gamma_{pp} + \gamma_{ss} + \gamma_{tt} + \gamma_{uu} \\
&\quad +2\gamma_{ps} + 2\gamma_{pt} + 2\gamma_{pu} + 2\gamma_{st} + 2\gamma_{su} + 2\gamma_{tu})\ln K
\end{aligned}$$

In order to estimate the share equations empirically, it is necessary to specify an appropriate stochastic framework. Empirical researchers usually add a random disturbance term ε_i to each of the share equations, and then assume that the resulting disturbance vector $\varepsilon=\{\varepsilon_p, \varepsilon_s, \ldots\}$ is normally distributed with mean zero and constant covariance matrix. The stochastic specification[86] accounts for random errors. These random errors may result from various causes. One of the possible causes is the error made by firms in choosing profit maximizing input bundles. The system of equations to be estimated can be written as follows:

$$S_p = \alpha_p + \gamma_{pp} \ln P + \gamma_{ps} \ln S + \gamma_{pt} \ln T + \gamma_{pu} \ln U + \gamma_{pk} \ln K + \varepsilon_p \quad \text{(5a)}$$

$$S_s = \alpha_s + \gamma_{sp} \ln P + \gamma_{ss} \ln S + \gamma_{st} \ln T + \gamma_{su} \ln U + \gamma_{sk} \ln K + \varepsilon_t \quad \text{(5b)}$$

$$S_t = \alpha_t + \gamma_{tp} \ln P + \gamma_{ts} \ln S + \gamma_{tt} \ln T + \gamma_{tu} \ln U + \gamma_{tk} \ln K + \varepsilon_t \quad \text{(5c)}$$

$$S_u = \alpha_u + \gamma_{up} \ln P + \gamma_{us} \ln S + \gamma_{ut} \ln T + \gamma_{uu} \ln U + \gamma_{uk} \ln K + \varepsilon_u \quad \text{(5d)}$$

$$S_k = \alpha_k + \gamma_{kp} \ln P + \gamma_{ks} \ln S + \gamma_{kt} \ln T + \gamma_{ku} \ln U + \gamma_{kk} \ln K + \varepsilon_k \quad \text{(5e)}$$

The estimated coefficients obtained from the factor share equations (5a) - (5e) are used to compute the *marginal contributions* of each input in the production of industrial output, as well as *factor price elasticities* between pairs of inputs. The factor price elasticities provide information about the *extent* and the *kind* of relationship between inputs in production.[87] The concepts of marginal contribution and factor price elasticity are discussed in the next two sub-sections.

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[86] Estimation of all econometric models is based on stochastic specification. For a further discussion on the rationale for stochastic specifications, see Berndt (1991).

[87] As discussed earlier, there are two possible kinds of relationships between inputs: inputs are either substitutes for, or complements of, each other.

Marginal Contribution of an Input Towards Output

The marginal contribution of an input towards output is computed as the additional output produced by an additional unit of that particular input while holding constant the quantities of all other inputs. Mathematically, this is expressed as $\frac{\partial Q}{\partial X}$, where Q represents output, and X represents P, S, T, U, K.[88] The value of $\frac{\partial Q}{\partial X}$ is computed as the product of $\frac{\partial \ln Q}{\partial \ln X}$ and $\frac{Q}{X}$. The value of $\frac{\partial \ln Q}{\partial \ln X}$ in turn is computed by using the parameter estimates obtained from the system of equations (5a) - (5d) and the averages of the right hand side variables *lnP, lnS, lnT, lnU, lnK*, in the system of equations (3a) - (3e). The value of $\frac{Q}{X}$ is based on averages of Q, P, S, T, U, and K.

Factor Price Elasticity.

Factor price elasticity measures the impact of a change in an input's quantity on its *own* price (own-factor price) or on the price of another input (cross-factor price). A

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[88] $\frac{\partial Q}{\partial P}$ measures the marginal contribution of workers with grade 8 or less education: $\frac{\partial Q}{\partial S}$ measures the marginal contribution of workers with grades 9-13 education: $\frac{\partial Q}{\partial T}$ measures the marginal contribution of workers with post-secondary non-university education: $\frac{\partial Q}{\partial U}$ measures the marginal contribution of workers with university education, and $\frac{\partial Q}{\partial K}$ measures the contribution of physical capital.

factor X_i's own price elasticity is expressed as $\frac{\partial \ln P_i}{\partial \ln X_i}$, and its cross price elasticity with respect to factor X_j is expressed as $\frac{\partial \ln P_i}{\partial \ln X_j}$.

In terms of the parameters of the translog production function, the above definitions can be converted into the following formulae:[89]

$$\frac{\partial \ln P_i}{\partial \ln X_j} = S_j \frac{\gamma_{ij} + S_i S_j}{S_i S_j},$$

$$\frac{\partial \ln P_i}{\partial \ln X_i} = S_i \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2}.$$

In addition to providing information on the magnitude of the impact of a change in an input's quantity on its own or on another input's price, factor price elasticity is also used to investigate what *kind* of relationship exists between inputs i and j, i.e., whether they are substitutes or complements in production. Thus, if the sign of cross factor price elasticity is negative, the inputs are *substitutes* in production. Conversely, if the sign of cross factor price elasticity is positive, the inputs are *complements* in production.[90]

[89] For a detailed discussion of the derivation of these formulae see Sato and Koizumi (1973).

[90] A positive sign indicates there is a positive relationship between the two factors under study and that an increase in the quantity of one factor results in the price of the other factor to rise. Conversely, a negative sign indicates that the two factors under study are substitutes for each other, and that an increase in the quantity in one factor results in the price of the other to fall.

Test of Separability.

The translog production function specified in this study also allows for tests of weak separability among inputs. Weak separability implies that the marginal rates of substitution between pairs of inputs within the group are independent of the extent to which those inputs outside the group are used[91] (Hamermesh & Grant, 1979). That is, if an input is separable from other inputs used in a production function, then the production relationships between inputs in the separable subset are independent of the quantity of that input used. Grant (1979) has expanded the Denny-Fuss proposition of weak separability conditions for the three-input translog production function.[92] Following Grant's expanded Denny-Fuss proposition of weak separability for the five-input translog production function, the four groups of labour inputs specified in the present study are jointly separable from physical capital, provided the following conditions are met:

$$\frac{\alpha_p}{\alpha_s}=\frac{\gamma_{pk}}{\gamma_{sk}},\frac{\alpha_p}{\alpha_t}=\frac{\gamma_{pk}}{\gamma_{tk}},\frac{\alpha_p}{\alpha_u}=\frac{\gamma_{pk}}{\gamma_{uk}},\frac{\alpha_s}{\alpha_t}=\frac{\gamma_{sk}}{\gamma_{tk}},\frac{\alpha_s}{\alpha_u}=\frac{\gamma_{sk}}{\gamma_{uk}},\frac{\alpha_t}{\alpha_u}=\frac{\gamma_{tk}}{\gamma_{uk}}$$

Furthermore, the imposition of linear homogeneity implies that the above conditions may be expressed as a set of three resultant constraints:

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[91] Marginal rates of substitution in production measure how much more of one factor of production must be used to compensate for the use of one less unit of another factor of production if production is to be held constant.

[92] The Denny-Fuss proposition (1977) states that the translog production function is a quadratic approximation to any arbitrary weakly separable production function $\ln Q = f(b(\ln x_1, \ln x_2), \ln x_3)$ if $\frac{\alpha_1}{\alpha_2}=\frac{\gamma_{13}}{\gamma_{23}}$.

$$\alpha_p = \frac{\alpha_s(\gamma_{pp} + \gamma_{ps} + \gamma_{pt} + \gamma_{pu})}{\gamma_{ps} + \gamma_{ss} + \gamma_{st} + \gamma_{su}}, \quad \alpha_t = \frac{\alpha_s(\gamma_{pt} + \gamma_{st} + \gamma_{tt} + \gamma_{tu})}{\gamma_{ps} + \gamma_{ss} + \gamma_{st} + \gamma_{su}},$$

$$\alpha_u = \frac{\alpha_s(\gamma_{pu} + \gamma_{su} + \gamma_{tu} + \gamma_{uu})}{\gamma_{ps} + \gamma_{ss} + \gamma_{st} + \gamma_{su}}.$$

In the present study, a weak separability test was conducted to determine whether or not the four groups of labour inputs are jointly separable from physical capital. If the test result showed that the four groups of labour inputs were jointly separable, this would imply that whether any pair of labour inputs were substitutes or complements was independent of the amount of physical capital input. In other words, the quantity of physical capital stock did not affect the demand for labour with any particular educational level. If this was the case, then the capital stock variable may be omitted from the labour share equations (5a) - (5d). Conversely, if the test showed that the four groups of labour inputs were not jointly separable from physical capital, this would imply that whether any pair of labour inputs were substitutes or complements depended upon the amount of physical capital input. Hence, the capital stock variable should not be omitted from the labour share equations.

By conducting the separability test, information can be obtained as to whether or not the quantity of physical capital used in the production of goods and services in Canada had an impact on labour-labour substitution. In other words, the separability test can shed light on whether or not the level of investment in physical capital affects the employment and wage rates of labour with different levels of education.

Econometric Issues Relating to the Estimation of the System of Share Equations

There are two issues concerning the simple OLS estimation of the system of equations (5a) - (5e) which are relevant to the present study. First, since all shares sum to unity, variations in any one input share will affect all other shares. This causes the error terms (U_i's) to be dependent across the equations, thereby rendering the OLS parameter estimates of the system of equations inefficient. This is a violation of one of the properties of Best Linear Unbiased Estimators (BLUE) of parameters.[93] As a consequence, the parameter estimates obtained from the OLS regression will not be efficient. Several estimation techniques have been suggested in the econometric literature so as to avoid this problem of loss of efficiency in a simultaneous equation system.[94] Secondly, the system of equations (5a) - (5e) possesses a special property that for each observation the sum of the dependent variables (the shares) for all

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[93] These properties are discussed in Kennedy (1985). In econometric terms, the elements of the variance-covariance matrix of the error terms are no longer constant when these error terms are correlated across equations. A variance-covariance matrix of the disturbance terms is a matrix of T rows and T columns, where T is the number of observations used for estimation of the equation system. The matrix is arranged in such a manner that the diagonal elements are the variances of the disturbance associated with one of the sample observations (i.e., the first diagonal term gives the variance of the disturbance associated with the first observation, and the last diagonal term gives the variance of the disturbance associated with the last observation). Each off-diagonal element of the variance-covariance matrix provides the covariance between the disturbances associated with two of the sample observations (i.e., the elements in the second column and the fifth row provide the covariance between the disturbance associated with the second observation and the disturbance associated with the fifth observation).

[94] Details of these procedures can be obtained from Pindyck and Rubinfeld (1991) and Berndt (1991).

equations is always equal to unity. Hence, if there are five share equations as in (5a) - (5e), only four are linearly independent. This means that for each observation the sum of the disturbances (U_i's) across equations must always be equal to zero. The econometric implication of this property is that it is impossible to compute the parameter estimates for the system of equations.[95]

Econometric Technique to be Used in Estimation of Share Equations

As discussed in the previous section, the imposition of first-degree homogeneity constraints on the factor share equations results in two computational problems. The first problem is that the error terms of the system of share equations are correlated across the equations. This suggests that it is appropriate to use Seemingly Unrelated Regression Estimation (SURE) model to estimate this system of factor share equations. The SURE model is used both in business and economic analyses. It requires writing the set of individual equations as one giant equation, allowing for contemporaneous correlation between the error terms across equations.

Zellner (1962) suggested using generalized least squares to estimate the parameters of the SURE model. Following his approach, the five equations in the system of share equations are written as one combined equation which is estimated using generalized least squares. This increases efficiency because there are 5N degrees

[95] In econometric terms, this means that the variance-covariance matrix of the disturbance term is singular. In a singular matrix, at least two columns are dependent. Thus its inverse cannot be computed since the determinant is zero.

of freedom with which to estimate the coefficients instead of N. N represents the number of observations. As a practical matter, the SURE estimation is a two-stage estimation procedure. In the first stage, the OLS method is used to estimate each single equation, and the corresponding residuals are used to estimate the cross-equation variances and covariances. In the second stage, generalized least-squares parameters are obtained.

The second problem is that the imposition of first-degree homogeneity restrictions renders the system of share equations singular. Hence, it is necessary to exclude one equation from the system for solution. Barten (1969) has shown that maximum likelihood estimates of share equation coefficients are invariant with respect to which equation is deleted. Hence, it is instructive to compare Zellner's estimation with maximum likelihood estimation. Indeed, Kmenta and Gilbert (1968) have compared these two methods and found that iteration of the Zellner estimation procedure, until convergence results, is equivalent to maximum likelihood estimation. The implication, according to Grant (1979), is that parameter estimates obtained from the Zellner estimation are consistent and asymptotically efficient.

In the present study, it is convenient to exclude capital's factor share equation (equation (5e)) from the system, since capital's share cannot be computed due to lack of appropriate price data. The estimation equations are as follows:

$$S_p = \alpha_p + \gamma_{pp} \ln(\frac{P}{K}) + \gamma_{ps} \ln(\frac{S}{K}) + \gamma_{pt} \ln(\frac{T}{K}) + \gamma_{pu} \ln(\frac{U}{K}) + \varepsilon_p \text{ .... (6a)}$$

$$S_s = \alpha_s + \gamma_{sp} \ln(\frac{P}{K}) + \gamma_{ss} \ln(\frac{S}{K}) + \gamma_{st} \ln(\frac{T}{K}) + \gamma_{su} \ln(\frac{U}{K}) + \varepsilon_s \text{ .... (6b)}$$

$$S_t = \alpha_t + \gamma_{tp} \ln(\frac{P}{K}) + \gamma_{ts} \ln(\frac{S}{K}) + \gamma_{tt} \ln(\frac{T}{K}) + \gamma_{tu} \ln(\frac{U}{K}) + \varepsilon_t \text{ .... (6c)}$$

$$S_u = \alpha_u + \gamma_{up} \ln(\frac{P}{K}) + \gamma_{us} \ln(\frac{S}{K}) + \gamma_{ut} \ln(\frac{T}{K}) + \gamma_{uu} \ln(\frac{U}{K}) + \varepsilon_u \text{ .... (6d)}$$

Once the parameters of the other four factor share equations are computed, the parameters of the capital share equation and the share of capital in value added can in turn be determined from the first-degree homogeneity constraints with the following equations:

$$\alpha_k = 1 - (\alpha_p + \alpha_s + \alpha_t + \alpha_u)$$
$$\gamma_{kk} = -(\gamma_{pk} + \gamma_{sk} + \gamma_{tk} + \gamma_{uk})$$
$$\gamma_{pk} = -(\gamma_{pp} + \gamma_{ps} + \gamma_{pt} + \gamma_{pu})$$
$$\gamma_{sk} = -(\gamma_{sp} + \gamma_{ss} + \gamma_{st} + \gamma_{su})$$
$$\gamma_{tk} = -(\gamma_{tp} + \gamma_{ts} + \gamma_{tt} + \gamma_{tu})$$
$$\gamma_{uk} = -(\gamma_{up} + \gamma_{us} + \gamma_{utr} + \gamma_{uu})$$

The standard errors of these estimated parameters are needed to perform tests of significance, e. g., t-tests. A t-test is performed by computing the t-ratios which are the ratios of the estimated coefficients to their standard errors. A computed t-ratio that exceeds 1.96 suggests that the corresponding coefficient is statistically significant at the 0.05 level for a two-tailed test, using large samples. The computation of the standard errors of the estimated coefficient is built-in to the computer software that was used to estimate the share equations. However, the standard errors of the coefficients of the capital share equation must be computed separately, since this equation was excluded from SURE.

Estimation of the standard errors of these six coefficients can be done with the following formulae:

$$Var(\alpha_k) = Var(\alpha_p) + Var(\alpha_s) + Var(\alpha_t) + Var(\alpha_u) + 2Cov(\alpha_p \alpha_s) + 2Cov(\alpha_p \alpha_t)$$
$$+2Cov(\alpha_p \alpha_u) + 2Cov(\alpha_s \alpha_t) + 2Cov(\alpha_s \alpha_u) + 2Cov(\alpha_t \alpha_u)$$

$$Var(\gamma_{pk}) = Var(\gamma_{pp}) + Var(\gamma_{ps}) + Var(\gamma_{pt}) + Var(\gamma_{pu}) + 2Cov(\gamma_{pp}\gamma_{ps}) + 2Cov(\gamma_{pp}\gamma_{pt})$$
$$+2Cov(\gamma_{pp}\gamma_{pu}) + 2Cov(\gamma_{ps}\gamma_{pt}) + 2Cov(\gamma_{ps}\gamma_{pu}) + 2Cov(\gamma_{pt}\gamma_{pu})$$

$$Var(\gamma_{sk}) = Var(\gamma_{sp}) + Var(\gamma_{ss}) + Var(\gamma_{st}) + Var(\gamma_{su}) + 2Cov(\gamma_{sp}\gamma_{ss}) + 2Cov(\gamma_{sp}\gamma_{st})$$
$$+2Cov(\gamma_{sp}\gamma_{su}) + 2Cov(\gamma_{ss}\gamma_{st}) + 2Cov(\gamma_{ss}\gamma_{su}) + 2Cov(\gamma_{st}\gamma_{su})$$

$$Var(\gamma_{tk}) = Var(\gamma_{tp}) + Var(\gamma_{ts}) + Var(\gamma_{tt}) + Var(\gamma_{tu}) + 2Cov(\gamma_{tp}\gamma_{ts}) + 2Cov(\gamma_{tp}\gamma_{tt})$$
$$+2Cov(\gamma_{tp}\gamma_{tu}) + 2Cov(\gamma_{ts}\gamma_{tt}) + 2Cov(\gamma_{ts}\gamma_{tu}) + 2Cov(\gamma_{tt}\gamma_{tu})$$

$$Var(\gamma_{uk}) = Var(\gamma_{up}) + Var(\gamma_{us}) + Var(\gamma_{ut}) + Var(\gamma_{uu}) + 2Cov(\gamma_{up}\gamma_{us}) + 2Cov(\gamma_{up}\gamma_{ut})$$
$$+2Cov(\gamma_{up}\gamma_{uu}) + 2Cov(\gamma_{us}\gamma_{ut}) + 2Cov(\gamma_{us}\gamma_{uu}) + 2Cov(\gamma_{ut}\gamma_{uu})$$

$$Var(\gamma_{kk}) = Var(\gamma_{pk}) + Var(\gamma_{sk}) + Var(\gamma_{tk}) + Var(\gamma_{uk}) + 2Cov(\gamma_{pk}\gamma_{sk}) + 2Cov(\gamma_{pk}\gamma_{tk})$$
$$+2Cov(\gamma_{pk}\gamma_{uk}) + 2Cov(\gamma_{sk}\gamma_{tk}) + 2Cov(\gamma_{sk}\gamma_{uk}) + 2Cov(\gamma_{tk}\gamma_{uk})$$

In the above formulae, the right hand side variances are computed by squaring the standard errors obtained directly from the SURE. The covariances are also obtained directly from SURE. Once the variances of these six omitted coefficients are computed by using the above formulae, the corresponding standard errors can be obtained by taking the square root of these variances. These standard errors are important for use in a test of significance of these coefficients.[96]

In addition to testing the significance of the translog coefficient, it is also important to test the statistical significance of the elasticity coefficients. Since the elasticities are based on the translog parameter estimates and fitted shares which have their own variances and covariances, they also have stochastic distributions.[97] As Berndt (1991) has noted, this has made estimation of variances and hence standard errors of elasticities difficult to obtain. Many studies have used the standard errors of the estimated translog coefficients to perform significance tests on elasticities (e.g., Grossman, 1982). Some (e.g., Akbari & Devoretz, 1992) have used the following formula which takes into account the stochastic distributions of the computed elasticities: $\left(\frac{Var\gamma_{ij}}{S_i^2 S_j^2}\right)^{\frac{1}{2}}$.

Finally, many studies have reported significance test results based on both sets of standard errors (Grant & Hamermesh, 1981). In all such studies, standard errors based on the above formula are large enough to make the elasticity coefficients statistically insignificant. Since the issue of which standard error should be used for testing the statistical significance of estimated elasticities remains unsettled in the

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[96] Many statistical software packages include Zellner's two-stage estimation procedure for SURE models. For the present study, SHAZAM was used.

[97] The formulae for elasticity coefficients have been provided earlier.

literature, the present study will report test results based on both sets of standard errors. However, conclusions will be drawn only on the basis of estimated magnitudes of elasticities. Other studies have also based their conclusions on the magnitudes of elasticities (e. g., Grant & Hamermesh, 1981). Additional discussion of this issue can be found in Toevs (1980), Krinsky and Robb (1986).

Data Used in This Study

The quantitative estimates of the impact of education on Canadian production were based on the econometric estimates of the system of equations (6a) - (6d). As suggested in the previous section, Zellner's SURE technique was used to estimate the system of equations.

Cross-sections of pooled industry-provincial data for Canada for the years 1980 and 1990 were used. Based upon data availability, fifteen major industries, which encompassed the entire Canadian economy for the year 1980, and sixteen major industries, which encompassed the entire Canadian economy for the year 1990, were considered. For the year 1980, the value added data on federal government service industries and other government service industries were combined into one category, "government service industries," in order to match the corresponding labour force data, in which government service industries were aggregated. A list of these industries is provided in Appendix A and in Appendix B, respectively.[98] Ten observations were made for each industry—one observation for each province[99]. Thus the total number of observations for estimating the system of share equations for the year 1980 was 150, and for the year 1990 160.

The Industrial Output Data

Each industry's output in this study was measured by value added in production. Other measures of industrial output such as GNP and GDP at market value could also have been used. However, value added is a more appropriate representation of the output contribution produced in a particular industry, since it subtracts from the value of an industry's production the contribution of other industries. Furthermore, the use of value added as a measure of output is consistent with the methodology of many other production function studies.[100]

The major source of industrial data was Statistics Canada (1988, 1994a). Statistics Canada provides annual data on value added for each industry in each

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[98] Statistics Canada assigns a two-digit code to each industry to distinguish it from a three-digit code which is a narrower break down of each industrial classification.

[99] For the year 1980. the labour force data on Prince Edward Island were aggregated with data on Yukon and Northwest territories. For the year 1990. the labour force data on Prince Edward Island stood alone.

[100] See. for instance. Grossman (1982). If the value added concept of output is used. then it is not necessary to include raw material as an input in the production function. because it is not a primary input. In technical terms. this means that a weak separability is assumed to exist between an aggregate of primary input and raw material. That is. the amount of any primary inputs used in a production process is independent of the quantity of raw material used. For a further discussion of this issue. see Akbari and DeVoretz (1992).

province.[101] Provincial value added by industry data were obtained by allocating the national value added estimates for a given industry across provinces/territories in order to ensure consistency between the two sets of data (Statistics Canada, 1994a).

Statistics Canada uses several approaches to derive the provincial value added by industry data (Statistics Canada, 1994a). Among these approaches, the net output approach is the preferred method. This approach consists of subtracting provincial intermediate inputs[102] and net indirect taxes from provincial gross output[103] to yield provincial current dollar value added estimates for each industry. The intermediate inputs are subdivided into material and service input commodities. Net indirect taxes consist of indirect taxes less subsidies. However, provincial data are not available for all of the required elements, namely, material and service inputs, indirect taxes and gross output. Where provincial data on intermediate inputs were not available, provincial intermediate inputs were allocated across provinces under the assumption that these inputs vary proportionally with gross output. Indirect taxes were allocated provincially as part of service inputs. In addition, subsidies and royalties were derived from the information published in Public Accounts for the federal, provincial and municipal governments and also from other related sources.

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[101] See Catalogue No. 15-203.

[102] Intermediate inputs are goods and services used as inputs into a further stage of production.

[103] Gross output is the total of goods and services produced.

In instances when the net output approach cannot be used, either the gross output approach or an approach based on selected factor incomes may be used as a proxy approach. The gross output approach entails allocating national gross output and value added for a particular industry, based on the provincial distribution of gross output. The approach based on selected factor incomes entails allocating national gross output and value added for a particular industry based on the sum of selected factor incomes, such as provincial wages and depreciation estimates of capital stock, or provincial wages and net income of unincorporated businesses.

Data on provincial value added for agricultural and related services industries, other primary industries, total manufacturing industries, construction industries, government service industries, education service industries, health and social service industries, accommodation and food service industries for the year 1980 were obtained from Statistics Canada. Data on the other seven major industries for the year 1980 were not available.[104] To construct 1980 data for the missing industries for each province, provincial industry weights were computed for the closest year, which was 1984. These weights were applied to the 1980 provincial data.[105]

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[104] Richard Martel of Provincial Industry Measures Section, Industry Measures and Analysis Division, Statistics Canada in Ottawa has confirmed that full coverage of the entire two digit industries began in 1984. Data on provincial value added by industry for the period before 1984 only include selected two digit industries.

[105] Provincial industry weights for the years 1984 - 1986 are presented in Appendix C. These provincial industry weights for the three-year period (1984 -1986) appear to be generally consistent. Hence the provincial industry weights for the year 1984 were used as proxies for the provincial industry weights for 1980.

Provincial value added data for the year 1990 were obtained from Statistics Canada (1994a). The 1980 data encompassed the entire Canadian economy. The 1990 data excluded Yukon and the Northwest territories.

For the year 1980, labour force data included religious organizations in *health and welfare service industries*, whereas value added data and capital stock data included religious organizations in other service industries. However, the impact of this aggregation variation appear to be insignificant, because the value added produced by religious organizations in 1980 was $725,800,000 (Statistics Canada, 1992), which accounted for only 0.256 percent of the entire economy.

Capital Stock Data

Through a special request, data on capital stock for the sixteen industries located in the ten Canadian provinces for the years 1980 and 1990 were obtained from the Statistics Canada Investment and Capital Stock Division microdata file. Capital stock includes fixed tangible capital stock that has been produced by human effort with the capacity to produce goods and services in the future. Capital stock is comprised of building construction, such as plants and offices, engineering construction, such as roads and dams, and machinery and equipment used in the production process. End of year gross stock data were used.

To compile industrial capital stock data, Statistics Canada uses information obtained from the Actual Survey of Capital and Repair Expenditures.[106] The survey provides census coverage for the public sector. In the private sector, there are approximately 900,000 businesses. The survey covers 25,000 of these. Gross capital stock is the sum of annual capital expenditures less the annual discards[107] of worn out fixed assets.

Labour Force and Earnings Data

Data on the number of persons in different educational categories who were employed in different industries in 1980 and 1990 as well as the corresponding data on the wages and salaries of these individuals were obtained from the 1981 and 1991 Statistics Canada Population Census micro data files on individuals. These data files contained demographic as well as labour market information on each individual for the year prior to the census year. Information on the province of residence in Canada is also included. These data represented two percent and three percent of the Public Use Sample drawn from the 1981 and 1991 Canadian Population Census, respectively.

[106] Capital and Repair Expenditures Survey is conducted quarterly to obtain the "intended" and the actual expenditures from business establishments every year. For details, see Statistics Canada Catalogue No. 61-205.

[107] Discards are the segments of earlier gross fixed capital formation that have reached the end of their useful life, while assets may be discarded at the end of their service life. To reflect the variation in the age at which identical assets are removed from the stock, a discard function is used. Detailed discussion of the estimation of discards is provided in Statistics Canada Catalogue No. 13-568.

For the purpose of this study, cross-tabulations of data by industry and province were constructed from the census data for employed individuals who were aged fifteen years or older, and reported a positive receipt of wages and salaries for 1980 and 1990. The average wages and salaries of these individuals were also cross-tabulated. Wages and salaries were defined as gross wages and salaries before deduction for such items as income taxes, unemployment insurance and pension funds. Directors' fees, bonuses, commissions, gratuities, piece-rate payments, and taxable allowances are also included in this category. All income in kind, such as free board and lodging, was excluded.[108] Similarly, employers' contributions to pensions, group insurance, and other benefits which were of monetary value were also excluded.

Limitation of Cross-Sectional Data and Their Effect on the Present Study

The use of cross-sectional data has several limitations. The first limitation is perhaps the most obvious one: since cross-sectional data reflect economic conditions at one point in time—in the present study two years—these conditions may be anomalous and therefore not representative of normal conditions. Consequently, inferences based on such data may be biased.

As mentioned earlier, the 1981 and 1991 census data used in the present study represent information for the years 1980 and 1990, respectively. To determine whether

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[108] For further details see Statistics Canada Population Census micro data file document.

economic conditions in 1980 and 1990 were anomalous, the Gross Domestic Product (GDP) for the years 1979 - 1982 and 1989 - 1992 was reviewed.[109] The GDP statistics, are presented in Table 13.

Table 13 GDP at Factor Cost, 1986 Price

Year	GDP (millions of dollars)
1979	418,328
1980	424,537
1981	440,127
1982	425,970
1989	505,050
1990	504,787
1991	498,932
1992	503,638

Source: Statistics Canada, 1992

GDP in 1986 prices for the four-year period 1979-82 was approximately $427,240,000,000, which is close to the GDP for the year 1980. Similarly, the average GDP in 1986 prices for the four-year period 1989-92 was approximately $503,102,000,000, which is close to the GDP for the year 1990. Hence, neither 1980 nor 1990 may be viewed as a year with abnormal economic conditions.

Another potential problem for cross-sectional data, which can also affect time-series data, concerns differences over time among industries or between regions in the

[109] The Gross Domestic Product (GDP) is normally used as a proxy for economic conditions.

relative quality of education within a particular category of labour (Hamermesh & Grant, 1979). If quality of education differs within a particular category of labour, then this category of labour cannot be considered homogenous. With respect to provincial differences in educational quality in Canada, there is mixed evidence. On the one hand, an Educational Testing Service (ETS) study (cited in Economic Council of Canada [1992b]) demonstrated provincial differences in average test scores in mathematics and science for thirteen-year-olds in 1991 (Table 14).

Table 14 ***Average Provincial Test Scores in Mathematics, Science, Educational Testing Service, Age 13, Canada, 1991***

Province	Average Math Score (%)	Average Science Score (%)
Quebec	68.4	71.2
British Columbia	66.2	72.4
Alberta	64.0	74.1
Saskatchewan	62.2	69.9
Nova Scotia	59.7	68.7
Newfoundland	58.9	66.1
New Brunswick	58.7	65.4
Manitoba	58.5	68.4
Ontario	58.1	66.7

Economic Council of Canada, 1992b

On the other hand, two other studies have concluded that there are no qualitative differences in education across Canadian provinces. Osberg (1992) argued that in Canada, despite the absence of established national standards, voluntary harmonization has produced de facto educational standards. In an empirical analysis using 1991

Survey of Consumer Finances data, Akbari (1996) also found no evidence of qualitative differences in education among the Canadian provinces. Thus, the issue of provincial differences in educational quality remains unresolved.

Education and the Production Function

The econometric model used in this study is a production function, which expresses industrial output as a function of capital and labour endowed with different educational levels. Estimates of the production function were used to show the effect of capital and labour endowed with different educational levels on industrial output in Canada. Human capital theory explains how education influences the productivity of workers. According to the theory, workers with higher levels of educational attainment have higher productivity and therefore contribute more to output. Accordingly, workers with university education were predicted to have the highest marginal contribution towards industrial output. The marginal contribution to output was predicted to decline as the level of educational attainment decreased.

By having a direct impact on industrial output and hence growth, workers in different educational groups also influenced the use and price of physical capital as well as the employment and wage rates of workers in other educational groups. Thus, for example, workers who have university level education may either be substitutes for, or complements to, physical capital, as well as for workers with other levels of education. Hence, any changes in the supply of workers in a given educational group will influence the employment and wages of other workers as well as the use and price of physical capital. By allocating public funds to various levels of education in Canada, governments control the supply of workers endowed with different educational levels. It is important to assess relationships among workers of different educational attainments and their relationship with physical capital stock to determine the employment and earnings effects of educational policy in Canadian labour markets. The translog production function specified in this chapter made such an analysis possible.

CHAPTER 4: PRESENTATION OF RESULTS

In order to obtain some quantitative estimates of the role of education in Canadian production, a translog production function was specified in Chapter 3. The present chapter discusses estimates of the translog production function based on the 1981 and the 1991 census data. Separate estimates of the production function for the goods and service sectors are also discussed. Finally, this chapter concludes with a presentation of simulated results of labour market consequences resulting from a ten percent increase of workers with university education. This simulation is based on 1991 census data for the entire Canadian economy.

As discussed in the previous chapter, the 1980 data included 150 observations obtained from fifteen major Canadian industries in the ten provinces. The 1990 data included 160 observations obtained from sixteen major Canadian industries in the ten provinces. The translog production function was estimated from the system of factor share equations (equations (6a) - (6d)), with symmetry and linear homogeneity restrictions imposed. Zellner's Seemingly Unrelated Regression Estimation (SURE) was performed to estimate the factor share equations. To avoid the problem of singularity, the share equation for capital was excluded from the system of equations to be estimated.[110] This means that fourteen coefficients were obtained directly from the

[110] Details of the rationale for this approach are provided in Chapter 3.

equation system, and the remaining six coefficients were determined from the linear homogeneity constraints.

The Total Economy

This section presents estimates of the translog production function based on 1980 and 1990 data for the entire Canadian economy.

Averages of Variables, 1980 and 1990.

The average output shares of capital stock, and those of employed workers possessing different levels of education, are reported in Table 15. The average output share of the employed workers possessed grade eight or less education was the lowest among all factor shares for both years under study. In addition, the average output share of these workers experienced the largest decline over the span of one decade. The average output share of capital was the highest among all factor shares for both

Table 15 Averages of Output Share, Total Economy, 1980 and 1990

Productive Inputs	Average Share	
	1980	1990
employed workers with grade eight or less education (S_p)	0.07	0.03
employed workers with grade nine to thirteen education (S_s)	0.22	0.20
employed workers with post-secondary non-university education (S_t)	0.21	0.16
employed workers with university education (S_u)	0.19	0.20
capital stock (S_k)	0.31	0.41

years. However, given that the factor shares of capital were the residual shares—they are derived from the total value added minus labour's factor shares—it is possible that these estimates of capital's shares are biased. Furthermore, labour's shares were under-estimated because they do not include employers' contributions to pensions, group insurance, medical insurance, and other fringe benefits which are of monetary value.

Table 16 presents the average number of employed workers with different

Table 16 Averages of Labour Quantity Disaggregated by Educational Level, Total Economy, 1980 and 1990

Educational Levels	Quantity	
	1980	1990
employed persons with grade eight or less education	7,820	5,531
employed persons with grade nine to thirteen education	24,252	32,216
employed persons with post-secondary non-university education	19,013	21,382
employed persons with university education	14,713	21,610

levels of education employed in an industry within a province. These averages were obtained by dividing the total number of workers possessing a given level of education by the total number of observations in each year. It is observed that the average number of employed workers with grade nine to thirteen education was the highest for both years. The average number declined for workers with the lowest level of education and rose for all other educational groups.

The average amount of capital stock used in an industry within a province was also computed by dividing the total amount of capital stock available by the total number of observations in each year. The average amount of capital stock used in Canadian industries within each province was $11,221,000,000 in 1980, and $9,809,000,000 in 1990. The average value added produced in each industry within each province was $1,698,800,000 in 1980, and $3,520,458,100 in 1990.

The average number of employed workers with post-secondary, non-university education included the average number of employed individuals who had attended a post-secondary, non-university institution, whether they had completed their studies or not. There were large variations between industries with respect to the size of the labour force disaggregated by education, capital stock used, and value added produced, in both years. These variations were especially noticeable for the year 1980: the total number of employed workers with grade eight or less education ranged from 0 to 156,650, the total number of employed workers with grade nine to thirteen education ranged from 450 to 108,250, the total number of workers with post secondary non-university education ranged from 100 to 116,400, the total number of workers with university education ranged from 0 to 169,100; capital stock used varied from $200,000 to $59,247,000,000; value added produced ranged from $11,100,000 to $26,902,700,000.

Table 17 presents the translog coefficients and their corresponding standard errors. As discussed in Chapter 3, fourteen of the twenty coefficients as well as their standard errors were obtained directly from the Seemingly Unrelated Regression Estimation (SURE). The remaining six coefficients (α_k, γ_{pk}, γ_{sk}, γ_{tk}, γ_{uk}, γ_{kk}) were determined from the first-degree homogeneity constraints. Standard errors for these six coefficients were computed by using the formulae presented in Chapter 3. It is observed in Table 17 that five of the estimated translog coefficients based on the 1980 data and six coefficients based on the 1990 data are not statistically significant at the 0.05 level of significance.[111] The negative value of the constant term in the capital share equation (α_k) for the year 1980 is anomalous. This may be partly attributed to data problem. As noted earlier in this chapter, the size of industries across provinces varied widely, especially for the year 1980. In addition, the linear homogeneity constraints of the production function may also be responsible for this result. It is also to be noted that this anomalous term is statistically insignificant at the 0.05 level, implying that the share of capital in the total industrial production would be insignificant when other inputs are held constant at unity.

[111] A t-ratio is calculated as the ratio of the coefficient to standard error. A t-ratio which is less than 1.96 suggests that the corresponding coefficient is not statistically significant at the 0.05 level. i.e., not significantly different from zero for a Two-Tailed Test.

Table 17 ***Estimated Translog Coefficients (Standard Errors in Parentheses), Total Economy, 1980 and 1990***

Coefficients	Value	
	1980	1990
α_p	0.2135 (0.112)*	0.0973 (0.017)*
α_s	0.3715 (0.141)*	0.2198 (0.055)*
α_t	0.4296 (0.262)*	0.2712 (0.051)*
α_u	0.5374 (0.253)*	0.3213 (0.061)*
α_k	-0.5520 (0.406)	0.0904 (0.098)
γ_{pp}	0.0426 (0.003)*	0.0311 (0.001)*
γ_{ps}	-0.0173 (0.003)*	-0.0094 (0.002)*
γ_{pt}	-0.0081 (0.004)*	-0.0119 (0.002)*
γ_{pu}	-0.0229 (0.003)*	-0.0087 (0.001)*
γ_{pk}	-0.0105 (0.007)	-0.0010 (0.003)
γ_{ss}	0.1506 (0.006)*	0.1308 (0.005)*
γ_{st}	-0.0480 (0.006)*	-0.0439 (0.004)*
γ_{su}	-0.0588 (0.004)*	-0.0702 (0.003)*
γ_{sk}	-0.0265 (0.010)*	-0.0073 (0.007)
γ_{tt}	0.0978 (0.120)	0.1396 (0.007)*
γ_{tu}	-0.0285 (0.008)*	-0.0743 (0.004)*
γ_{tk}	-0.0294 (0.017)	-0.0095 (0.008)
γ_{uu}	0.1296 (0.009)*	0.1606 (0.004)*
γ_{uk}	-0.0194 (0.013)	-0.0073 (0.006)
γ_{kk}	0.0858 (0.024)*	0.0251 (0.013)

* denotes that the corresponding coefficient is statistically significant at the 0.05 level, i.e., the corresponding coefficient will be different from zero in the sample used.

Estimated Magnitude of Marginal Contribution of Inputs, Total Economy, 1980 and 1990

Table 18 reports the estimated marginal contributions of labour disaggregated by levels of education towards the production of goods and services in Canada for the years 1980 and 1990. The marginal contributions are defined as the changes in the value of goods and services produced resulting from an additional employed worker possessing a given level of education, while all other inputs quantities are held constant. Mathematically , the marginal contribution of an input X is computed by using the equation $\frac{\partial Q}{\partial X} = \frac{\partial \ln Q}{\partial \ln X} * \frac{Q}{X}$

Table 18 ***Wages and Estimated Marginal Contributions of Labour Disaggregated by Levels of Education, Total Economy, 1980 and 1990, in Constant (1986) Prices***

Educational Levels	1980			1990		
	Wages	Sample	Value of Marginal Product	Wages	Sample	Value of Marginal Product
grade eight or less education	$16,670	1,172,950	$22,629	$13,364	884,903	$15,998
grade nine to thirteen education	$17,075	3,787,800	$23,975	$16,228	5,154,497	$18,289
post-secondary non-university education	$20,760	2,852,000	$26,592	$18,785	3,421,167	$22,045
university education	$24,878	2,206,950	$32,645	$21,815	3,457,571	$27,265

The value of $\frac{\partial \ln Q}{\partial \ln X}$ is obtained directly from SURE.[112]

[112] For a detailed discussion of this see Chapter 3.

Since census data were used and they were expressed in current prices, it was necessary to convert the marginal contribution estimates into constant prices for the purposes of comparison of value for the years 1980 and 1990. The conversion was based on Consumer Price Indices (CPI) provided by Statistics Canada (1994c).[113]

As seen in Table 18, there was a positive relationship between labour's educational attainment and its marginal contribution to output in both years. That is, as labour's educational attainment increased, its marginal contribution to output also increased. This finding appears to support the prediction of human capital theory that education enhances an individual's productivity. However, it is to be noted that the indirect estimation method used in this study to compute the marginal contributions assumed that workers are paid according to the value of their marginal contribution to output. This implies that the differences in workers' marginal contributions reported above may only be reflecting the wage differentials accorss educational levels. The discrepancy between wages and marginal contributions reported in Table 18 may be attributed to the stochastic error terms.

Table 18 also indicates that the estimated magnitudes of labour's marginal contribution in each educational group declined between 1980 and 1990, whereas the estimated magnitude of capital stock's contribution increased. The decline in the

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[113] To convert the 1980 estimates into constant 1986 prices, these estimates were divided by 0.672, the 1980 value of the CPI using 1986 as the base year. The 1990 estimates were divided by 1.195, the 1990 value of the CPI using 1986 as the base year, to be converted into constant 1986 prices.

marginal contributions of workers in all educational groups, also reflected in their real wage rate decline, is puzzling and needs more detailed investigation. Some possible reasons for this decline are: an increase in the proportion of part-time workers in the labour force between 1980 and 1990,.[114] and an increase in the proportion of women in the labour force during the same period.[115] The wages of women are generally lower than their male counterparts, partly due to discrimination (Miller, 1987), partly due to the fact that many women work only part-time, and those who do work full-time, work 5 hours less per week, on average, than men (Bruce, 1995).

The marginal contribution of capital stock was $69,839 for the year 1980, and $123,137 for the year 1990, (in constant 1986 prices). These estimates represented the change in the total value of goods and services produced resulting from an additional one million dollars' worth of capital stock used in production, while the quantities of workers in all educational categories remained the same.

Estimated Factor Price Elasticities, Total Economy, 1980 and 1990.

Tables 19 and 20 present estimated own- and cross-factor price elasticities.

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[114] The percentage of part-time workers in the employed labour force increased from 13 in 1980 to 15 in 1990 (computation was based on employed labour force data obtained from Statistics Canada Catalogue No. 11-210).

[115] The percentage of women in the employed labour force increased from 40 in 1980 to 44 in 1990 (computation was based on employed labour force data obtained from Statistics Canada Catalogue No. 11-210).

Table 19 ***Estimated Factor Price Elasticity[a], Total Economy, 1980 (Standard Errors in Parentheses and Brackets)***

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.35 (0.003)* [0.55]	-0.005 (0.003) [0.18]	0.11 (0.004)* [0.25]	-0.05 (0.003)* [0.21]	0.04 (0.007)* [0.30]
S	-0.01 (0.003)* [0.18]	-0.09 (0.006)* [0.12]	-0.002 (0.007) [0.14]	-0.09 (0.004)* [0.09]	0.13 (0.010)* [0.015]
T	0.33 (0.004)* [0.25]	-0.002 (0.007) [0.14]	-0.33 (0.12)* [0.25]	0.06 (0.008)* [0.19]	0.12 (0.017)* [0.48]
U	-0.12 (0.003)* [0.21]	-0.08 (0.004)* [0.09]	-0.06 (0.008)* [0.19]	-0.13 (0.009)* [0.25]	0.13 (0.013)* [0.13]
K	0.16 (0.007)* [0.30]	0.18 (0.010)* [0.15]	0.16 (0.017) [0.48]	0.20 (0.013)* [0.13]	-0.41 (0.100)* [0.02]

[a] Factor price elasticity measures the percentage change in the price of input i, given a change in the quantity of input j, (i = row, j = column). Elasticities on the diagonal are the own-price elasticities.

* denotes the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz (1992) which assumes that factor shares are stochastic.

Own-price elasticities are reported on the diagonal of the table. These elasticities measure the long-run price adjustment resulting from an exogenous change in the quantity of a given input included in the production function specification.[116] As

[116] Such exogenous changes can create short-run imbalances in the labour market which require changes in wages to clear the market. The short-run imbalances may be reflected in the employment changes of the inputs. These employment changes are discussed in a later section.

discussed in Chapter 3, cross-factor price elasticities are computed as the percentage change in the price of input *i* resulting from one percent change in the quantity of input

Table 20 ***Estimated Factor Price Elasticity[a], Total Economy, 1990 (Standard Errors in Parentheses and Brackets)***

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.05 (0.001)* [0.86]	-0.01 (0.002)* [0.29]	-0.04 (0.002)* [0.35]	-0.01 (0.001)* [0.14]	0.03 (0.003)* [0.22]
S	-0.08 (0.002)* [0.29]	-0.14 (0.005)* [0.12]	-0.69 (0.004)* [0.12]*	-0.16 (0.003)* [0.07]*	0.18 (0.007)* [0.09]*
T	-0.18 (0.002)* [0.35]	-0.06 (0.004)* [0.12]	-0.03 (0.006)* [0.22]	-0.21 (0.004)* [0.12]	0.14 (0.008)* [0.12]
U	-0.05 (0.001)* [0.14]	-0.16 (0.003)* [0.07]*	-0.26 (0.004)* [0.12]*	-0.03 (0.004)* [0.10]	0.18 (0.006)* [0.08]*
K	0.38 (0.003)* [0.22]	0.37 (0.007)* [0.09]*	0.35 (0.008)* [0.12]*	0.37 (0.006)* [0.08]*	-0.53 (0.013)* [0.08]*

[a] Factor price elasticity measures the percentage change in the price of input *i*, given a change in the quantity of input *j*, (*i* = row, *j* = column). Own-price elasticities are reported on the diagonal.

* denotes the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz (1992) which assumes that the shares are stochastic.

j. A positive cross-factor price elasticity between two inputs indicates that the two inputs under consideration are complements of each other. Conversely, a negative cross-factor price elasticity between two inputs indicates that the two inputs under consideration are substitutes for each other. If two inputs are complements, an increase (decrease) in the quantity of one input causes the price of the other input to rise (fall). On the other hand, if two inputs are substitutes, then an increase (decrease) in the quantity of one input causes the price of the other input to fall (rise). Put another way, if two inputs are substitutes, then a given increase in the amount of one input used in production is associated with a decrease in the marginal product of the other input. To perform the test of significance on elasticity coefficients, two sets of standard errors of elasticity coefficients are presented in Tables 19 and 20. The first set, reported in parentheses, treats factor shares as non-stochastic and considers the estimated standard errors of translog coefficients and those of elasticity coefficients to be the same. The second set, reported in square brackets, treats factor shares as stochastic and is computed using the formula $\left(\frac{Var\gamma_{ij}}{S_i^2 S_j^2}\right)^{\frac{1}{2}}$, where $Var\ \gamma_{ij}$ is the estimated variance of the translog coefficient γ_{ij}, obtained from SURE, and S_i and S_j are the estimated shares of inputs i and j. The present study has presented both sets of standard errors because the issue of which set of standard errors is appropriate to use is unsettled in the literature.[117]

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[117] Chapter 3 alluded to this debate in the literature.

As shown in Tables 19 and 20, the two sets of standard errors provide different results of significance tests. If the standard errors presented in the square brackets are considered, none of the own- and cross-price elasticity estimates for 1980 was statistically significant, and only a few estimates for 1990 were statistically significant. This implies that all capital and labour inputs were neither complements of, nor substitutes for, each other in 1980. Furthermore, only a few labour groups and capital were complements of each other, all other capital and labour inputs were neither complements of, nor substitutes for, each other in 1990. However, it is to be noted that almost all studies which reported significance tests based on the formula (presented above) to compute these standard errors have resulted in mostly insignificant results (e.g., Grant & Hamermesh, 1981; Akbari & DeVoretz, 1992). Interpretation of results in those studies has been based on the estimated magnitudes of the elasticities.

If one considers the standard errors in parentheses, then in 1980, changes in the quantity of workers with grade nine to thirteen education would have no statistically significant effect on either the wage rates of workers possessing grade eight or less education or workers possessing post-secondary non-university education. Similarly, changes in the quantity of workers with post-secondary non-university education would have no effects on the wage rate of workers who possessed grade nine to thirteen education. All the remaining estimates of own- and cross-price elasticity were statistically significant, based on the estimated standard errors reported in the parentheses..

The magnitudes of own-factor price elasticities of labour inputs, reported on the diagonal of the table, suggest that generally there was an inverse relationship between own-factor price elasticity and education. As workers' educational attainment increased, their wage rates became less sensitive to changes in the employment level of workers in the same educational category. Thus, a given percentage change in quantity employed induced a relatively smaller percentage change in the wages of workers with higher levels of educational attainment than those of workers with lower levels of educational attainment. These results differ from those reported by Grant (1979) for the US, but appear to be consistent with Riddell's (1994) findings that suggested that, in Canada, between 1980 and 1993, there had been large changes in the educational composition of employment and moderate changes in the relative earnings of workers with different levels of educational attainment, and that workers who possessed grade eight or less education had experienced the largest decline in both employment levels and relative earnings, while workers who had completed post-secondary education had experienced the largest increase in employment level as well as relative earnings.

The magnitudes of cross-factor price elasticities between capital and labour groups do not exhibit any consistent patterns. Nonetheless, since these price elasticities were all positive, it is concluded that capital (*K*) was complementary with all labour groups disaggregated by educational attainment (*P*, *S*, *T*, *U*). That is, an increase in the amount of capital used was associated with an increase in the marginal product of labour of all educational categories. These findings are consistent with those of Grant's US study (1979). Grant also found that as workers' educational attainment level increased, a given percentage increase in the amount of capital used was associated with a larger percentage increase in wage rates, and that a given percentage increase in the level of employment of workers was associated with larger percentage increases in the price of capital.[118] While the results in the present study do not show such a consistent pattern, they do indicate that workers who possessed university education were most complementary with capital for both years under study. That is, a given percentage increase in the amount of capital used was associated with the largest percentage increase in the wage rates of workers who had university education, and a given percentage increase in the quantity of workers who had university education was associated with the largest percentage increase in the price of capital.

The results of cross-factor price elasticities between labour groups also suggest that, in 1980, workers with post-secondary non-university education were complements of workers with grade eight or less education, as well as with workers with grade nine to thirteen education. However, in 1990, all labour groups were substitutes for one another. The results from 1980 are somewhat similar to those found in Grant's US study. By disaggregating the employed labour force into three

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[118] In other words, capital-labour complementarity increased with education.

educational groups, Grant found that labour with 0 to 8 years of education was complementary with labour possessing 9 to 12 years of education, and with labour possessing 12 or more years of education.

Empirical studies estimating substitutability between labour disaggregated by levels of educational attainment usually do not include capital in the model specification.[119] Therefore Grant's study which included capital stock variable in the regression model, provides a useful frame of reference for the present study, although the results of the present study and his are not directly comparable as the two differ not only in terms of labour disaggregation criteria, but also in terms of the time and location. While the present study used pooled industry-provincial data for major Canadian industries for the years 1980 and 1990, Grant's study used a sample of 84 Standard Metropolitan Statistical Areas (SMSAs) for the manufacturing industry across the United States for the year 1969.

The results of the present study indicate that, in Canada, labour-labour substitution in 1980 was different from that in 1990. In 1980, some labour groups were complements of other labour groups. However, in 1990, all labour groups were substitutes for one another. Furthermore, although capital and labour were complements for each other for both years under study, there was no definitive

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[119] In other words, such studies assume capital and labour are separable without testing for the same. Lack of capital stock data may be the reason for this assumption. Griliches (1969) and Grossman (1982), for instance, have commented on the problem of lack of physical capital data.

relationship between education level of workers and the extent of labour-capital complementarity.[120] In addition, workers who possessed university education were most complementary with capital.

Separability Tests.

In this section, the results of the labour-capital weak separability test are presented. These tests investigate whether the relationships (labour-labour complementarity or substitution) between workers of two different educational attainments are independent of the amount of capital used. As discussed in Chapter 3, labour is separable from capital if the ratio of the constant terms of the share equations for each pair of labour inputs equals the ratio of the capital labour interaction coefficient of each one of that pair. These results are presented in Table 21. They show that the weak separability conditions as expressed in the equations presented in Chapter 3 are not met, because the ratio of the constant terms of each pair of labour inputs and the ratio of the corresponding capital-labour interaction coefficients of the pair, presented in the same cells, are not the same. These results suggest that the marginal rates of substitution between pairs of inputs within the labour group are not

[120] It is to be noted if the negative value of α_k is interpreted in light of its statistical insignificance, then its value is zero. The implication of this is that the capital share would be larger. Furthermore, since all capital and labour inputs were estimated to be complements using the negative value of α_k, by assigning α_k the value of zero, the cross-price elasticities between capital and the four labour groups would retain their positive signs. Hence, capital and all labour inputs would still be complements for each other, if the value of α_k, was zero.

independent of the quantity of capital used. In other words, labour-labour substitution results were related to the level of capital used. This result is consistent with that of

Table 21 Separability Ratios of Coefficients

Coefficients	Ratio	
	1980	1990
$\frac{\alpha_p}{\alpha_s}$	0.5851	0.5188
$\frac{\gamma_{pk}}{\gamma_{sk}}$	0.4782	0.2297
$\frac{\alpha_p}{\alpha_t}$	0.4669	0.5134
$\frac{\gamma_{pk}}{\gamma_{tk}}$	0.4368	0.2151
$\frac{\alpha_p}{\alpha_u}$	0.6216	0.3970
$\frac{\gamma_{pk}}{\gamma_{uk}}$	0.7562	0.3695
$\frac{\alpha_s}{\alpha_t}$	0.7981	0.8720
$\frac{\gamma_{sk}}{\gamma_{tk}}$	0.9133	0.9367
$\frac{\alpha_s}{\alpha_u}$	1.0624	0.7652
$\frac{\gamma_{sk}}{\gamma_{uk}}$	1.5812	1.6086
$\frac{\alpha_t}{\alpha_u}$	1.3311	0.8775
$\frac{\gamma_{tk}}{\gamma_{uk}}$	1.7312	1.7173

Grant (1979) which also indicated that US labour disaggregated by education was not separable from capital. An important implication of this result is that in estimating Canadian labour demand functions, capital stock variable should not be omitted. Finally, given that capital and labour were not separable, it is noted that by including capital in this study, the present study may have avoided introducing a bias into estimates of the production function parameters describing substitution between labour groups.[121]

Sectoral Analysis

The above results were economy-wide. When one considers the employment growth of various industrial sectors in Canada, significantly different growth patterns of employment are observed. For instance, as reported in Economic Council of Canada (1990), in the 1980s employment in the service sector grew at an average annual rate of 3.2 percent, while in the goods sector, employment growth averaged around only 0.9 percent.

Correlated with the employment growth was the growth in output, Table 22 shows that in 1990, the Gross Domestic Product (GDP) increased by 1.9 percent in the service sector, whereas it declined by 2.5 percent in the goods sector. Within the service sector, the only industries to report outright declines in 1990 were the service

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[121] Berndt (1980) demonstrated that when labour-capital separability is inappropriately assumed. the resulting cross-price elasticities of demand for factors are over-estimated and the own-price elasticities of demand are under-estimated.

industries which provide service to goods-producing industries. The wholes industry, the retail industry, and the transportation and storage industries experien declines in GDP, with the largest decline occurring in the wholesale industries retail industries (Statistics Canada, 1994a). Given a rising trend in the educatio attainments of the Canadian labour force and the differential economic growth various sectors, an investigation of any differential sectoral impact of education Canada is warranted. In the following two sections the role of education is investiga separately for the service and goods sectors. This was done by estimating production function separately for the two sectors.

Table 22 Annual Growth in GDP at Factor Cost, 1986 Prices by Industry

Economy	Annual Percentage Change			
	1987	1988	1989	199
Total economy	4.4	4.6	2.6	0.3
Goods sector	4.0	4.8	1.1	-2.
Service sector	4.5	4.5	3.5	1.9

Source: Statistics Canada, 1994a

Service Sector

Averages of Variables, Service Sector, 1980 and 1990

Production function estimates for the service sector were obtained using 1 data for eleven major service industries, and 1990 data for twelve major ser industries. These industries included transportation and storage industr communication and other utility industries, wholesale trade industries, retail industries, finance, insurance, and real estate industries, business service industries, federal government service industries, other government service industries, education service industries, health and social service industries, accommodation, food and beverage service industries, and other service industries. The 1981 census provided data only for the category "government service industries". Separate information on federal government service industries and other government service industries were not available. Hence, when data were grouped by ten Canadian provinces, the 1980 sample of service industries included only 110 observations, while the 1990 sample included 120 observations. The SURE procedures used for the total economy were also used for estimating the production function for the service sector.

Estimates of the average output shares of capital and labour inputs in the service sector for the years 1980 and 1990 are presented in Table 23. In general, the average output shares of labour and capital stock inputs in the service sector appear to

Table 23 Averages of Output Share, Service Sector, 1980 and 1990

Productive Inputs	Average Share	
	1980	1990
employed workers with grade eight or less education (S_p)	0.08	0.03
employed workers with grade nine to thirteen education (S_s)	0.22	0.20
employed workers with post-secondary non-university education (S_t)	0.21	0.18
employed workers with university education (S_u)	0.18	0.19
capital stock (S_k)	0.31	0.40

be similar to those in the entire economy. Estimates of the average number of employed workers in the service sector who possessed various educational levels are presented in Table 24. These averages were computed by dividing the total number of workers of a given level of education by the total number of observations each year. As was the case with the entire economy, the quantity of workers with grade eight or less education declined

Table 24 Averages of Labour Quantity, Service Sector, 1980 and 1990

Educational Levels	Quantity	
	1980	1990
employed persons with grade eight or less education	6,408	3,831
employed persons with grade nine to thirteen education	21,865	29,796
employed persons with post-secondary non-university education	17,857	21,243
employed persons with university education	16,186	24,431

significantly from 1980 to 1990. This implies that the decline in the demand for workers who possessed grade eight or less education sector was significant in the service sector.

The average amount of capital stock used in Canadian industries was computed by dividing the total amount of capital stock by the total number of observations. The average amount of capital stock used was $10,897,000,000 in 1980, and $9,203,000,000 in 1990.

The translog coefficients are reported in Table 25. It is observed that seven of the estimated coefficients based on the 1980 data and six based on the 1990 data are not statistically significant at the 0.05 level of statistical significance.[122] As was the case with the entire economy, the value of the constant term on the capital share equation (α_k) for the year 1980 was negative, and this term is statistically insignificant at the 0.05 level. As discussed earlier, this anomalous result may be due to the large variations in the size of industries across provinces, and the assumption of linear homogeneity of the production function. However, its statistical insignificance does not warrant any more attention in the present analysis.

[122] As discussed earlier in this chapter, a t-ratio which is less than 1.96 suggests that the corresponding coefficient is not statistically significant at the 0.05 level, and therefore may be considered not significantly different from zero.

Table 25 ***Estimated translog Coefficients, Service Sector (Standard Errors in Parentheses)***

Coefficients	Value	
	1980	1990
α_p	0.2609 (0.402)	0.1128 (0.021)*
α_s	0.4459 (0.134)*	0.2174 (0.065)*
α_t	0.5587 (0.140)*	0.2493 (0.059)*
α_u	0.4197 (0.109)*	0.2841 (0.068)*
α_k	-0.6852 (0.456)	0.1364 (0.11)
γ_{pp}	0.0440 (0.004)*	0.0357 (0.002)*
γ_{ps}	-0.0166 (0.003)*	-0.0113 (0.002)*
γ_{pt}	0.0106 (0.006)	-0.0126 (0.003)*
γ_{pu}	-0.0259 (0.004)*	-0.0099 (0.002)*
γ_{pk}	-0.0121 (0.009)	-0.0017 (0.004)
γ_{ss}	0.1449 (0.007)*	0.1307 (0.005)*
γ_{st}	-0.0471 (0.008)*	-0.0419 (0.005)*
γ_{su}	-0.0557 (0.004)*	-0.0700 (0.003)*
γ_{sk}	-0.0253 (0.010)*	-0.0074 (0.007)
γ_{tt}	0.0822 (0.015)*	0.1323 (0.008)*
γ_{tu}	-0.0181 (0.010)	-0.0696 (0.005)*
γ_{tk}	-0.0277 (0.019)	-0.0079 (0.011)
γ_{uu}	0.1157 (0.011)*	0.1542 (0.005)*
γ_{uk}	-0.0160 (0.016)	-0.0046 (0.007)
γ_{kk}	0.0811 (0.029)*	0.0216 (0.016)

* denotes that the corresponding coefficient is statistically significant at the 0.05 level.

Estimated Magnitudes of Marginal Contribution of Labour Disaggregated by Education, Service Sector

Table 26 presents the wages and the estimated marginal contributions of labour disaggregated by educational levels in the service sector. It is observed that there

Table 26 ***Wages and Estimated Marginal Contributions of Labour Disaggregated by Levels of Education, Service Sector, 1980 and 1990, in Constant (1986) Prices***

Educational Levels	1980			1990		
	Wage	Sample	Value of Marginal Product	Wage	Sample	Value of Marginal Product
grade eight or less education	$16,216	594,850	$22,131	$13,167	459,735	$17,350
grade nine to thirteen education	$16,657	2,543,750	$22,237	$16,324	3,575,533	$17,846
post-secondary non-university education	$20,110	1,964,300	$24,559	$18,714	2,549,167	$23,780
university education	$24,088	1,817,350	$27,033	$22,266	2,931,802	$23,942

was a positive relationship between workers' marginal contribution and their educational attainment. That is, as workers' educational attainment increased, their marginal contribution also increased. This result is consistent with that reported for the entire Canadian economy in Table 18. However, as noted earlier, the marginal contributions of workers dissaggregated by education were computed using the indirect estimation method which assumed that workers are paid according to the value of their marginal contribution to output. This implies that the differences in the workers marginal contributions may only reflect the wage differentials between workers possessing different levels of education.[123]

The magnitudes of the marginal contribution of capital were also computed for the two years. The marginal contribution of capital stock rose from $57,632 in 1980 to $104,034 in 1990, in constant 1986 prices. These estimates represented, for the given quantities of workers, the change in the total value of goods and services produced resulting from an additional one million dollars' worth of capital stock used in production..

Estimated Factor Price Elasticity, Service Sector

Tables 27 and 28 report the estimated own- and cross-factor price elasticities for the service sector for the years 1980 and 1990, respectively. Own-price elasticities are reported on the diagonal of the table. These elasticities were computed using the estimates of the translog production function for the service sector reported in Table 27. Again, as was the case with the entire economy, if one considers the standard errors presented in the brackets which assume the factor shares to be stochastic, then. none of the estimates of own- and cross-price elasticity is significantly different from zero.[124] Hence, the production relations between capital and labour inputs were

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[123] As noted earlier, the discrepancy between wages and marginal contributions reported in Tables 26 and 28 may be attributed to the stochastic error term.

[124] As noted earlier, most studies which assume factors to be stochastic found insignificant elasticities.

Table 27 ***Estimated Factor Price Elasticity[a], Service Sector, 1980 (Standard Errors in Parentheses and Brackets)***

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.39 (0.004)* [0.56]	0.009 (0.003)* [0.21]	0.13 (0.006)* [0.33]	-0.06 (0.004)* [0.26]	0.04 (0.009)* [0.35]
S	0.02 (0.003)* [0.21]	-0.12 (0.007)* [0.14]	-0.004 (0.008) [0.08]	-0.09 (0.004)* [0.15]	0.14 (0.010)* [0.16]
T	0.34 (0.006)* [0.33]	-0.004 (0.008) [0.08]	-0.40 (0.015)* [0.33]	0.11 (0.010)* [0.26]	0.12 (0.019)* [0.30]
U	-0.13 (0.004)* [0.26]	-0.07 (0.004)* [0.15]	0.10 (0.010)* [0.26]	-0.18 (0.011)* [0.33]	0.13 (0.016)* [0.29]
K	0.16 (0.009)* [0.35]	0.19 (0.010)* [0.16]	0.20 (0.019)* [0.30]	0.22 (0.016)* [0.29]	-0.43 (0.029)* [0.31]

[a] Factor price elasticity measures the percentage change in the price of input *i*, given a change in the quantity of input *j*, (*i* = row, *j* = column).Own-price elasticities are reported on the diagonal.

* denotes the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz (1992) which assumes that the factor shares are stochastic.

Table 28 ***Estimated Factor Price Elasticity[a], Service Sector, 1990 (Standard Errors in Parentheses and Brackets)***

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.05 (0.002)* [1.28]	-0.02 (0.002)* [0.24]	-0.04 (0.003)* [0.47]	-0.01 (0.002)* [0.27]	0.04 (0.004)* [0.28]
S	-0.09 (0.002)* [0.24]	-0.15 (0.005)* [0.12]	-0.06 (0.005)* [0.15]	-0.17 (0.003)* [0.07]*	0.18 (0.007)* [0.09]*
T	-0.16 (0.003)* [0.47]	-0.04 (0.005)* [0.15]	-0.02 (0.008)* [0.30]	-0.21 (0.005)* [0.16]	0.14 (0.011)* [0.16]
U	-0.07 (0.002)* [0.27]	-0.16 (0.003)* [0.07]*	-0.24 (0.005)* [0.16]	-0.02 (0.005)* [0.14]	0.18 (0.007)* [0.10]
K	0.36 (0.004)* [0.28]	0.37 (0.007)* [0.09]*	0.35 (0.011)* [0.16]*	0.38 (0.007)* [0.10]*	-0.54 (0.016)* [0.09]*

[a] Factor price elasticity measures the percentage change in the price of input *i*, given a change in the quantity of input *j*, (*i* = row, *j* = column). Own-price elasticities are reported on the diagonal

* denotes the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz (1992) which assumes the factor shares are stochastic.

neither complementary nor substitutional for the years 1980 and 1990. However, if the standard errors presented in the parentheses are considered, then only the production relations between workers with grade nine to thirteen education and those with post-secondary non-university education in 1980 were statistically insignificant. In other words, changes in the quantity of workers with grade nine to thirteen education had no statistically significant effect on the wages of workers who had attained post-secondary education, and vice versa. All the remaining relations were statistically significant.

Examination of the results of own-price elasticity suggests that, in general, there was an inverse relationship between own-factor price elasticity and education for the year 1990. That is, as workers' educational attainment increased, their wage rates became less sensitive to changes in the quantity of workers in the same educational category. In other words, education appeared to guard against wage decreases resulting from increases in the supply of labour. This result is consistent with that found for the total economy.

The results of cross-factor price elasticity between labour groups show that, in 1980, workers with grade eight or less education were complements of workers with grade nine to thirteen education as well as workers with post-secondary non-university education. In addition, workers with post-secondary non-university education were complements of workers possessing university education. Workers in all other labour groups were substitutes for one another. In 1990, workers disaggregated by education were substitutes for one another. These results are in contradiction with those found for the total economy where all labour inputs were found to be substitutes for one another.

Estimated cross-factor price elasticities between capital and labour groups show that capital and all labour groups were complementary inputs in production in both years under study. However, there was no definitive relationship between education and the extent of capital complementarity.[125]. In addition, as was the case with the entire economy, capital and workers possessing university education were the most complementary in both years in the service sector. In other words, a given percentage increase in the amount of capital used in production was associated with the largest percentage increase in the wages of workers who possessed university education. A given percent increase in the quantity of workers employed was associated with the largest percentage increase in the prices of capital.

Goods Sector

Estimates of the production function for the goods sector were computed based on pooled provincial data for the four major industries in the goods sector obtained separately for the years 1980 and 1990. These industries include agriculture and related service industries, other primary industries, total manufacturing industries, and construction industries. The SURE estimation procedures were also used for

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[125] It is to be noted if the negative value of α_k is interpreted in light of its statistical insignificance, then its value is zero. This implies that the capital share would be larger than the one reported in Table 29. Furthermore, since all capital and labour inputs were estimated to be complements using the negative value of α_k, by assigning α_k the value of zero, the cross-price elasticities between capital and the four labour groups would retain their positive signs. Hence, capital and labour disaggregated by education would still be complements for each other, if the value of α_k, was zero.

production function estimation in this sector. The sample size was 40 for both years under study.

Averages of Variables, Goods Sector

Table 29 presents the average output shares of capital and labour inputs for the

Table 29 Averages of Output Shares, Goods Sector, 1980 and 1990

Productive Inputs	Quantity	
	1980	1990
employed workers with grade eight or less education (S_p)	0.08	0.05
employed workers with grade nine to thirteen education (S_s)	0.22	0.21
employed workers with post-secondary non-university education (S_t)	0.21	0.18
employed workers with university education (S_u)	0.17	0.16
Output share of capital stock (S_k)	0.32	0.40

goods sector. The output share of workers possessing grade eight or less education was larger in the goods sector than their shares in the entire economy and the service sector.

The average labour input quantities are reported in Table 30. The computation of the averages was discussed earlier. Again, as was the case with the entire Canadian economy and the service sector, the average number of employed workers with grade eight or less education declined over the 1980-1990 period. However, compared to the entire economy and the service sector, the average number of these workers was the highest in the goods sector. The average amount of capital stock in the goods sector was $12,113,000,000 in 1980, and $11,628,000,000 in 1990. The total quantity of

Table 30 Averages of Labour Input Quantity, Goods Sector, 1980 and 1990

Educational Levels	Quantity	
	1980	1990
employed persons with grade eight or less education	13,453	10,629
employed persons with grade nine to thirteen education	32,301	39,474
employed persons with post-secondary non-university education	22,193	21,800
employed persons with university education	9,740	13,144

capital stock used in the goods sector was $4,84,522,000,000 in 1980, and $465,116,000,000 in 1990, respectively.

Table 31 reports the estimated translog coefficients for the goods sector. Eight of the translog coefficients based on the 1980 data and ten coefficients based on the 1990 data were not statistically significant. As was the case with the entire economy and the service sector, the value of the constant term on the capital share equation (α_k) for the year 1980 was negative. Again, this anomalous result may be due to the large variations in the data and the assumption of linear homogeneity of the production function. This term was statistically insignificant at the 0.05 level.

Table 31 ***Estimated Translog Coefficients (Standard Errors in Parentheses), Goods Sector***

Coefficients	Value	
	1980	1990
α_p	0.3024 (0.097)*	0.1479 (0.047)*
α_s	0.4535 (0.182)*	0.1854 (0.109)
α_t	0.5911 (0.279)*	0.2119 (0.101)*
α_u	0.3495 (0.162)*	0.1273 (0.101)
α_k	-0.6965 (0.463)	0.3274 (0.185)
γ_{pp}	0.0426 (0.008)*	0.0433 (0.005)*
γ_{ps}	-0.0153 (0.006)*	-0.0114 (0.006)
γ_{pt}	0.0080 (0.011)	-0.0100 (0.006)
γ_{pu}	-0.0202 (0.008)*	-0.0181 (0.004)*
γ_{pk}	-0.0151 (0.016)	-0.0038 (0.010)
γ_{ss}	0.1451 (0.012)*	0.1266 (0.011)*
γ_{st}	-0.0563 (0.016)*	-0.0475 (0.010)*
γ_{su}	-0.0490 (0.008)*	-0.0636 (0.006)*
γ_{sk}	-0.0245 (0.022)	-0.0040 (0.017)
γ_{tt}	0.0734 (0.029)*	0.1280 (0.016)*
γ_{tu}	-0.0026 (0.019)	-0.0660 (0.009)*
γ_{tk}	-0.0278 (0.039)	-0.0045 (0.021)
γ_{uu}	0.0788 (0.020)*	0.1413 (0.009)*
γ_{uk}	-0.0123 (0.029)	-0.0064 (0.014)
γ_{kk}	0.0797 (0.057)	0.0059 (0.033)

* denotes that the corresponding coefficient is statistically significant at the 0.05 level.

Estimated Magnitude of Marginal Contribution of Inputs, Goods Sector

Table 32 presents the estimated marginal contributions of the five productive inputs. As was the case with the entire Canadian economy and the service sector,

Table 32 Wages and Estimated Marginal Contribution of Labour Disaggregated by Education, Goods Sector, in Constant (1986) Prices

Educational Levels	1980			1990		
	Wage	Sample	Value of Marginal Product	Wage	Sample	Value of Marginal Product
grade eight or less education	$18,025	578,100	$23,246	$13,954	425,168	$15,078
grade nine to thirteen education	$18,226	1,244,050	$26,568	$15,938	1,578,964	$20,257
post-secondary non-university education	$22,546	887,700	$28,989	$18,997	872,000	$21,443
university education	$25,767	389,600	$34,216	$20,459	525,769	$30,590

these results also indicate that there was a positive relationship between workers' educational attainment and their marginal contribution to output. That is, as workers' educational attainment increased, their marginal contribution to output also increased. Hence, these results support the view of human capital theory that education enhances individuals' productivity. However, as noted earlier, these results were obtained by using the indirect estimation method which assumed that workers are paid according to their marginal contribution to output. This implies that the differences in the workers' marginal contributions reported above may only reflect the wage differentials of workers with different levels of education.[126] Nonetheless, it is also observed that the estimated marginal contribution of workers was higher in the goods sector than in the service sector. In addition, the differences in the marginal contribution of workers

[126] As noted earlier, the discrepancy between wages and marginal contributions reported in Table 32 may be attributed to the stochastic error term.

with differing educational levels were more pronounced in the goods sector than in the service sector.

The marginal contribution of capital stock increased from $69,839 in 1980 to $134,258 in 1990, in constant 1986 prices. These estimates represented the change in the total value of goods and services produced resulting from an additional one million dollar's worth of capital stock used in production, while the quantities of workers in all educational categories remained the same.

Estimated Factor Price Elasticity, Goods Sector

Tables 33 and 34 report the estimated own- and cross-factor price elasticities for the goods sector. Again, own-price elasticities are reported on the diagonal. As was the case with the entire economy as well as the goods sector, if the standard errors presented in the square brackets are considered, then none of the estimates of own- and cross-price elasticity is statistically significant. Hence, the production relations between capital and labour inputs appeared to be neither complementary nor substitutional in the goods sector for the years 1980 and 1990. However, if the standard errors presented in the parentheses are considered, then changes in the quantity of workers with grade nine to thirteen education would have no statistically significant effect on the wage rates of workers possessing post-secondary non-university education and vice versa in 1980. In 1990, changes in the quantity of

Table 33 Estimated Factor Price Elasticity[a], Goods Sector, 1980 (Standard Errors in Parentheses and Brackets)

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.44 (0.008)* [0.96]	0.03 (0.006)* [0.28]	0.12 (0.011)* [0.50]	-0.03 (0.008)* [0.52]	0.04 (0.016)* [0.68]
S	0.07 (0.006)* [0.28]	-0.15 (0.012)* [0.21]	-0.002 (0.016) [0.28]	-0.06 (0.008)* [0.20]	0.14 (0.022)* [0.35]
T	0.33 (0.011)* [0.50]	-0.002 (0.005) [0.28]	-0.45 (0.019)* [0.50]	0.25 (0.019)* [0.47]	0.14 (0.039)* [0.61]
U	-0.06 (0.008)* [0.52]	-0.04 (0.008)* [0.20]	0.18 (0.019)* [0.47]	-0.36 (0.020)* [0.72]	0.12 (0.029)* [0.66]
K	0.10 (0.016)* [0.68]	0.17 (0.022)* [0.35]	0.15 (0.039)* [0.61]	0.20 (0.029)* [0.66]	-0.43 (0.057)* [0.78]

[a] Factor price elasticity measures the percentage change in the price of input *i*, given a change in the quantity of input *j*, (*i* = row, *j* = column).

* denotes that the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz(1992).

workers with grade nine to thirteen education as well as those possessing post-secondary non-university education would have no statistically significant impact on the wage rates of workers possessing grade 8 or less education. In addition, changes in the quantity of workers with university education would also have no impact on the

Table 34 Estimated Factor Price Elasticity[a], Goods Sector, 1990 (Standard Errors in Parentheses and Brackets)

Price of	With Respect to Quantity of				
	P	*S*	*T*	*U*	*K*
P	-0.05 (0.005)* [2.18]	-0.007 (0.006)* [0.59]	-0.008 (0.006) [0.69]	-0.06 (0.004)* [0.51]	0.04 (0.010)* [0.55]
S	-0.03 (0.006)* [0.59]	-0.19 (0.011)* [0.25]	-0.06 (0.010)* [0.26]	-0.19 (0.006)* [0.17]	0.20 (0.017)* [0.20]
T	-0.03 (0.006)* [0.69]	-0.05 (0.010)* [0.26]	-0.11 (0.016)* [0.49]	-0.23 (0.016)* [0.31]	0.17 (0.021)* [0.30]
U	-0.22 (0.004)* [0.51]	-0.14 (0.006)* [0.17]	-0.21 (0.016)* [0.31]	-0.006 (0.009) [0.34]	0.18 (0.014)* [0.22]
K	0.32 (0.010)* [0.55]	0.38 (0.017)* [0.20]	0.38 (0.021)* [0.30]	0.44 (0.014)* [0.22]*	-0.58 (0.033)* [0.20]

[a] Factor price elasticity measures the percentage change in the price of input *i*, given a change in the quantity of input *j*, (*i* = row, *j* = column).

* denotes that the corresponding coefficient is statistically significant at the 0.05 level.

Note: the first number in parentheses is the standard error on γ_{ij}, which underlies the calculation of the own- and cross-price elasticities. The second number in brackets is the estimated standard error based on the formula presented in Akbari and DeVoretz (1992).

wage rates of workers in the same educational category. All the remaining production relations were statistically significant. The inverse relationship between own-factor price elasticity and education held as in the case of the total economy and the service sector. Therefore, as workers' educational endowment increased, their wages became less sensitive to changes in the educational composition of the work force.

The estimated magnitudes of cross-price elasticity show that, in 1980, workers with grade eight or less education were complements of workers who had grade nine to thirteen education as well as workers with post-secondary non-university education. This result is the same as that for the service sector. Workers possessing post-secondary non-university education were also complements of workers possessing university education employed in the goods sector. Workers in other labour groups were substitutes for one another. In 1990, however, all labour groups were substitutes for each other. In addition, the magnitudes of own-price elasticities appeared to be larger in 1990 than in 1980.

The complementarity between capital and labour inputs which prevailed in the entire economy, as well as in the service sector, also held in the goods sector. It is to be noted if the negative value of α_k is to be interpreted in light of its statistical insignificance, then its value is zero. The implication of this is that the capital share would be larger. Furthermore, since all capital and labour inputs were estimated to be complements using the negative value of α_k, by assigning α_k the value of zero, the cross-price elasticities between capital and the four labour groups would retain their positive signs. Hence, capital and labour inputs would still be complements for each other, if the value of α_k, was zero. In addition, workers with university education were most complementary with capital in the goods sector, as was the case with the entire economy.

Summary of Results

The following is a summary of the results presented above.

(1) Labour with different educational levels were substitutes for each other, in general. Some complementarity between these labour inputs was found when separate analyses were conducted for the service sector and the goods sector.

(2) Capital and labour disaggregated by education were complementary inputs.

(3) Workers with university education were the most complementary with capital.

(4) Workers' wages became less sensitive to the changes in the quantity of workers as their educational attainment rose, in general.

(5) The marginal output contribution of workers as reflected in their wages, rose with educational attainment. This result was consistent across the entire economy, the service sector and the goods sector

Furthermore, with the exception of workers with grade eight or less education, the number of workers in all educational categories increased in absolute terms during the 1980-90 period. Hence, it is instructive to examine the changes during the same period in relative terms. The following tables present the educational composition of the labour force. Table 38 indicates that the educational composition of the labour force changed from 1980 to 1990. The percentages of workers with grade nine to

Table 35 ***Educational Composition of Labour Force[a], 1980 and 1990 (in percentage)***

Educational Levels	Total Economy		Service Sector		Goods Sector	
	1980	1990	1980	1990	1980	1990
grade 8 or less education	12	6	9	5	19	12
grade 9 to 13 education	38	40	37	38	40	46
post-secondary non-university education	28	27	28	27	29	26
university education	22	27	26	30	12	16

[a] These percentages are based on Tables 16, 24, 30.

thirteen education and of those with university education increased from 1980 to 1990, while those percentages decreased for workers who possessed grade eight or less education and for those who had post-secondary non-university education. Considering the entire economy, the increase in the employment of workers with university education was most noticeable. This reflects a rise in the demand for workers with university education during the period.

Given that workers in all educational categories were found to be substitutes for one another in 1990, it is useful to investigate the changes in the wage rates and quantities of workers in different education groups resulting from an increase in the number of workers holding university education. The results of this simulation exercise will provide educational policy makers some quantitative measures of the impact of educational policy changes that affect the labour supply of a particular educational category. The following section considers this impact by performing a simulation using the production function estimates based on the 1990 data for the entire economy.

Simulated Results of an Increase in University-Educated Workers

To perform the simulation, the impact of a ten percent increase in the number of workers holding university education in the labour force is considered. As presented in the previous section, both the absolute number and the share of workers with university in the work force increased notably from 1980 to 1990. Hence, it is instructive to gauge the effect of an increase in the number of workers with university education on the employment and wages of other groups of labour disaggregated by lower educational levels, and on the use and price of physical capital. The simulation exercise is based on Johnson (1980).[127]

In this simulation, the long-run and the short-run impacts of a ten percent increase in workers with university education is considered. In the short run, wages of workers with grade eight or less education is likely to be downwardly inflexible, due to institutional and other reasons.[128] When wages are downwardly inflexible, adjustment occurs through an increase in unemployment. In the long run, however, all wages are downwardly flexible. Adjustment is thus made through wage changes.

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[127] Johnson's simulation model has been used in other studies, including Grant and Hamermesh (1980), Grossman(1981), and Mahmood (1990).

[128] Detailed reasons for rigid wages are provided in Bruce (1995).

Assuming, as before, the major Canadian industries have a constant returns to scale production function, the rule of minimization of input cost is to set the marginal product of an input i, F_i (P,S,T,U,K), equal to the wage, W_i, for all inputs. The endowments of inputs are exogenous to the economy. Differentiating these conditions, we obtain

$$dW_i - F_{ip}dP - F_{is}dS - F_{it}dT - F_{iu}dU - F_{ik}dK = 0, i = p,s,t,u,k \text{ ....(1)}$$

In the short run, when the wages of workers holding grade 8 or less education are downwardly inflexible, the solution to the above equation is

$$\frac{dP}{dU} = \frac{-F_{pu}}{F_{uu}} \text{ ....(2)}$$

$$\text{and } \frac{dW_i}{dU} = \frac{-F_{ip}F_{pu} + F_{iu}F_{pp}}{F_{pp}}, i = s,t,u,k \text{ ....(3)}$$

By multiplying equation (2) by $\frac{U}{P}$ and equation (3) by $\frac{U}{W_i}$, and using the properties of the constant-returns-to-scale production function that

$$F_{ij} = \frac{W_i W_j C_{ij}}{Q}$$[129],

$$\text{and } X_i = \frac{QS_i}{W_i},$$

the following can be derived

$$\frac{d\ln P}{d\ln U} = \frac{-S_u C_{pu}}{S_p C_{pp}} \quad \text{......(4)}$$

and

$$\frac{d\ln W_i}{d\ln U} = \frac{S_u(-C_{ip}C_{pu} + C_{iu}C_{pp})}{C_{pp}}, i = s,t,u,k \quad \text{......(5)}$$

When the wages are flexible, the changes in wages of all other labour groups, and in price of capital resulting from a ten percent increase in workers with university education are calculated by

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[129] C_{ij} is defined as the proportional change in relative wage for factor i given a proportional change in facto j's endowment. holding the output price and other input quantities constant. Mathematically, it can be defined as $C_{ij} = \frac{FF_{ij}}{F_i F_j}$, where F_i is the first derivative of the production function F with respect to factor i and F_{ij} is a second derivative. In terms of the translog coefficients, $C_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}$, and $C_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i}$.

$$\frac{d\ln W_i}{d\ln X_j} = S_j C_{ij}, i = p,s,t,u,k,$$

and the change in wage of workers with university education as a consequence of a ten percent increase in the number of workers in the same group is calculated by

$$S_u \frac{r_{uu} + S_u^2 - S_u}{S_u^2} \times 10$$

The simulation results of a ten percent increase in the number of workers with university education were based on estimated parameters obtained from the 1990 data on the entire Canadian economy. They are presented in Tables 36 and 37. Table 36

Table 36 ***Simulation Results of Wages of Workers with Grade 8 or less Education Downwardly Inflexible (the Effect of a 10% Increase of Workers with University), based on 1990 Data***

Labour Group	% Change in Wage/Price	% Change in Employment
Workers with grade 8 or less education		-12.7
Workers with grade 9 to 13 education	-1.2	NA[a]
Workers with post-secondary non-university education	-2.1	NA
Workers with university education	-0.1	NA
Capital	1.4	NA

[a] NA stands for not applicable.

presents the short-run scenario when, due to minimum wage law, the wages of workers with grade eight or less education are downwardly inflexible, while the wages of all other labour groups are downwardly flexible. Although wage rigidity applies to wages of *all* workers, the lower bounds of wage rates of workers in other educational categories normally exceed minimum wage. Minimum wage law would not cause the wages of workers in other educational categories to be downwardly inflexible. Adjustments in the markets are reflected in the changes in the employment of workers with grade eight or less education, and the changes in the price of capital and wages of all other labour groups. Since workers with university education and workers in all other labour groups are substitutes, a ten percent increase in the number of workers with university education would result in a decrease of 12.7 percent in the employment of workers with grade eight or less education. The wages of workers with grade nine to thirteen education and workers with post-secondary non-university educate would fall by 1.2 percent and 2.1 percent, respectively. The wages of workers with university education would fall by 0.1 percent. However, since workers with university education and physical capital are most complementary, the price of physical capital would rise by 1.4 percent.

Table 37 presents the long-run scenario, when all wages are flexible. Adjustments in the markets are made through changes in wages. These results indicate that a ten percent increase in the number of workers with university education would cause the wages of workers with grade eight or less education to fall by 0.6 percent. It would also cause the wages of workers with grade nine to thirteen education and of those with post-secondary non-university education to fall by 3.7 percent and 2.6 percent, respectively. In addition, it would result in the wages of workers with university education falling by 0.3 percent, and the price of capital rising by 3.7 percent.

Table 37 ***Simulated Results (the Effect of a 10% Increase of Workers with University Education), based on 1990 Data, All Wages Flexible***

Labour Groups	% Changes in Wage/Price
Workers with grade 8 or less education	-0.6
Workers with grade 9 to 13 education	-3.7
Workers with post-secondary non-university education	-2.6
Workers with university education	-0.3
Capital	3.7

The simulation results suggest that a ten percent increase in workers with university education would have considerable impact on the employment of workers with grade eight or less education. That is, a loss of 12.7 percent employment would occur, if the wages of workers with grade eight or less education are downwardly rigid, while wages of other groups are flexible. The impact on the wages of workers with grade nine to thirteen education and those with post-secondary non-university would be relatively small, while the impact on wages of workers with university education would be the smallest (-0.1 percent). The price of capital, however, would rise. On the other hand, if all wages were flexible, then the impact on the wage rates of different groups would be relatively small. Hence, it may be concluded that if wage rates of all labour groups remain flexible, an influx of workers with university education would have relatively smaller impact on the wage rates of the labour force than on the price of capital stock.

CHAPTER 5: CONCLUSION

This study examined the role of education in the production of industrial output in Canada.. To this end, the impact of workers possessing a given level of education on the use and wages of labour with other levels of education, and on the use and price of physical capital was assessed. The marginal contribution of workers possessing different levels of education to the production of goods and services was also analyzed. These quantitative assessments were conducted within the framework of human capital theory, according to which education affects the productivity of individuals and, therefore, also industrial output and economic growth. A translog production function was estimated using cross-sectional industrial data grouped by provinces for the years 1980 and 1990. The relevant inputs were capital and labour, the latter being disaggregated by four levels of education. Three sets of estimates were obtained separately for the years 1980 and 1990; one for the entire Canadian economy, one for the service sector, and one for the goods sector. This gave for the entire Canadian economy, 150 observations for the year 1980, and 160 observations for 1990. Data from Statistics Canada were used.

The following results were obtained:

1. Workers disaggregated by levels of educational attainment were substitutes for one another, in general.

2. Capital and all labour groups disaggregated by education were complements.

3. Workers with university education were the most complementary with capital.

4. As educational attainments increased, wages became less sensitive to changes in the quantity of workers in the same labour group, in general.

5. If wages are true reflections of marginal productivity, then workers with higher levels of education were found to contribute more to industrial output than their counterparts with lower levels of education.

The first result, that workers disaggregated by levels of educational attainment were substitutes for one another, also differs from Grant's (1979) US study. Grant found that labour possessing grade eight or less education was complementary with all labour with higher levels of education, while labour possessing grade nine to twelve education and labour possessing more than grade twelve education were substitutes. The labour-labour substitution results indicate that better-educated workers and their less-educated counterparts are competing inputs in Canadian production function. As noted in Chapter 4, over the 1980s there was a decline in the employed labour force of the least educated group. Hence, the labour-labour substitution found in this study could reflect employers' preference for better-educated workers. This result could be viewed as consistent with signalling theory.

The second result, that all labour groups disaggregated by education were complements of physical capital in production, is consistent with the findings of Grant's (1979) US study. As noted in Chapter 2, the lack of physical capital data has been a common complaint among researchers. Among the few studies which have examined labour substitution by educational groups (e.g., Welch, 1970; Dougherty, 1972), Grant's analysis appears to be the only one that included physical capital as a variable. The labour-complementarity result implies that an increase in the quantity of capital is associated with an increase in the wage rates of labour, which in turn reflects an increase in the quantity of labour demanded. This result is contrary to the common belief that in Canada machines are displacing labour,[130] and highlights the importance of a more detailed investigation.

The third result, that physical capital was most complementary with workers who possess university education is consistent with the findings of Griliches' US study (1969), which indicated that physical capital was more complementary with skilled labour than with unskilled labour. However, the result differs somewhat from Grant's (1979) US study. While Grant 's study indicated that there was a consistent pattern of labour-capital complementarity, the present study found no consistent relationship

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[130] This view was noted in Chapter 1.

between the extent of capital-labour complementarity and the educational levels of labour.

The fourth result, that, in general, as educational attainments increased, wages became less sensitive to changes in the quantity of labour in the same labour group, differs from Grant's (1979) US study, which indicated that as workers' educational attainments increase, wages became more sensitive to changes in the quantity of workers in the same educational group. However, in another respect, the fourth result appears consistent with other studies, including another one done in Canada (Riddell, 1994) and one in the United States (Griliches, 1970): despite steady increases in the supply of better educated workers, earnings differentials between better educated workers and their less well educated counterparts remain relatively constant.

The fifth result shows that workers with higher levels of education contributed more to industrial output than their less-educated counterparts. Specifically, the marginal contribution of university-educated workers to industrial output was: (i) 1.23 times that of workers with post-secondary non-university education in 1980, and 1.24 times in 1990; (ii) 1.36 times that of workers possessing grade nine to thirteen education in 1980, and 1.49 times in 1990; and (iii) 1.44 times that of workers possessing grade 8 or less education in 1980, and 1.70 times in 1990.

The above results appear to support the central tenet of human capital theory, namely that education enhances productivity, and, therefore, benefits a country's industrial production and economic growth. However, as was noted earlier, these results were obtained using the indirect estimation method which assumed that workers were paid according to their marginal contributions to output. Hence the differences in workers' marginal contributions may only reflect wage differentials among workers with different levels of education. However, the finding that education and the marginal contribution of workers towards output are positively related is consistent with the findings of some US studies (e.g., Griliches, 1964; Welch, 1970), which indicated that education and productivity are positively related. The result is also consistent with a number of international comparative studies (e.g., Psacharopoulos, 1984, 1985), which suggested that, in Canada, as well as in many other countries, education contributes to economic growth. Nevertheless, the result is contrary to Liu and Armer (1993), who could not find a consistent relationship between the output contributions of workers and the levels of education received for Taiwan.

If the above results do reflect the output contributions of workers, then they suggest a reappraisal of the view which holds that large increases in educational attainments in recent decades have not had an effect on the productivity of Canadian workers. Related to this result is the finding that the estimated magnitudes of labour's marginal contributions declined during the period 1980-1990 (Table 18), while the educational attainment of the labour force increased during the same period (Table 35). This result highlights the importance of a careful investigation of the public's concern over educational quality decline in Canada reported by Livingstone and Hart (1991).A possible explanation for this result is that the quality of education at all levels declined over time. Furthermore, differences between the marginal contributions of workers possessing differing levels of education were greater in the goods sector. These results suggest that although education enhanced labour productivity in general, its impact was greater in the goods sector than in the service sector. It is possible that the skills and knowledge acquired through education were more productively utilized in the goods sector than in the service sector. Finally, it may be noted again that since marginal contribution results may reflect only wage differentials, a further analysis of output contributions of workers may be warranted.

The results obtained in the present study suggest that education plays an important role in the production of goods and services in Canada. It enhances labour productivity, thereby allowing production of goods and services to rise, which in turn benefits society in the form of higher incomes. The results also suggest that employers in Canada may have increasing preference for better educated workers for jobs at all levels. In addition, differences in the marginal contribution of workers with differing levels of education in the service and the goods sectors appear to suggest that the efficacy of education differs according to the nature of production. Furthermore, labour's marginal contribution to industrial output has declined over time.

The finding that education plays a positive and significant role in the production of goods and services in Canada suggests neither that one may be complacent about the Canadian educational system nor that improvements in the present educational system are not warranted. Rather these findings indicate that, given the important role of educated labour in the production of goods and services, greater emphasis should be placed on both the quantitative and qualitative provisions of education in this country.

An important limitation of this study is its use of cross-sectional data from only two years. A time-series analysis would be required to test the robustness of the results. However, as was noted in Chapter 3, care was taken to ensure that neither of the two years was anomalous by comparing the GDP. Another important limitation of the present study is its assumption that there are no qualitative differences among provinces. As mentioned in Chapter 3, there are conflicting views about provincial differences in educational quality. A third limitation is that estimates of cross- and own-price elasticity were calculated by considering two inputs at a time, while holding all other inputs constant. In the future better estimating techniques may allow the relaxation of this restriction.

The present study was conducted within the framework of human capital theory and used the production function approach to estimate education's contribution to the economy. Contrary to previous production function studies (e.g., Welch, 1970; Liu & Armer, 1993), this study does not simply provide an additional piece of evidence about education's economic benefits by estimating education's effect on economic output. Its inclusion of an analysis of education's impact on the labour and capital markets contributes to a better understanding of the role of education by showing its effect on labour-labour and labour-capital substitution in industrial production. A significant strength of the present study is its use of a more flexible form of the production function, i. e., the translog form. As discussed in Chapter 2, many previous production function studies used the Cobb-Douglas production function, which does not allow estimation of factor price elasticities to indicate the extent to which two inputs are substitutes or complements in production. By using the more flexible translog production function, this study contributes to public policy considerations. Specifically, the finding that labour cohorts disaggregated by education are substitutes for one another has important labour market implications. For example, since workers with higher levels of education are more productive and are substitutes for workers with lower levels of education, the demand for the provision of higher education will continue to grow. The employment of workers possessing lower levels of education will continue to fall if their wage rates are downwardly inflexible.

While the purposes of education are not restricted to those of an economic nature, and an individual's pursuit of education is not limited to facilitating fruitful participation in the workforce, some educational policies are necessarily concerned with education's impact on labour and capital markets, since the economic benefits of education are of public concern.

Johnson's (1964) broadly conceived concept of capital formulation discussed in Chapter 2, which emphasizes both human and physical capital, appears to provide a useful basis for public policy formulation. The finding of the present study that physical capital is complementary with all labour groups disaggregated by educational attainment appears to suggest that investment in physical capital benefits all labour groups. Therefore, it is advisable for public policies designed to enhance economic growth to take into account the complementary relationship between education and physical capital. A useful cautionary note, as Sweetland (1996) has pointed out, is that the consequences of focusing narrowly on the economic benefits are, among other things, the unfair scrutiny of educators, the education system, and education polices in terms of their economic importance, especially during sustained periods of economic downturn.

Appendices

Appendix A

LIST OF 15 MAJOR INDUSTRIES USED IN THE PRESENT STUDY, 1980

1. Agricultural and related services industries (Division A)

2. Other primary industries (Divisions B, C, D)

3. Total manufacturing industries (Division E)

4. Construction industries (Division F)

5. Transportation and storage industries (Division G)

6. Communication and other utility industries (Division H)

7. Wholesale trade industries (Division I)

8. Retail trade industries (Division J)

9. Finance, insurance, and real estate industries (Divisions K, L)

10. Business service industries (Division M)

11. Government service industries (Division N)

12. Education service industries (Division O)

13. Health and social service industries (Division P)

14. Accommodation, food and beverage services industries (Division Q)

15. Other service industries (Division R)

Source

The industrial divisions and group numbers are based upon the 1980 Standard Industrial Classification. Statistics Canada.

Appendix B

LIST OF 16 MAJOR INDUSTRIES USED IN THE PRESENT STUDY, 1990

1. Agricultural and related services industries (Division A)

2. Other primary industries (Divisions B, C, D)

3. Total manufacturing industries (Division E)

4. Construction industries (Division F)

5. Transportation and storage industries (Division G)

6. Communication and other utility industries (Division H)

7. Wholesale trade industries (Division I)

8. Retail trade industries (Division J)

9. Finance, insurance, and real estate industries (Divisions K, L)

10. Business service industries (Division M)

11. Federal government service industries (Division N, major group 81)

12. Other government service industries (Division N, major groups 82, 83, 84)

13. Education service industries (Division O)

14. Health and social service industries (Division P)

15. Accommodation, food and beverage services industries (Division Q)

16. Other service industries (Division R)

Source

The industrial divisions and group numbers are based upon the 1980 Standard Industrial Classification. Statistics Canada.

Appendix C

Provincial Industry Weights

Newfoundland	1984	1985	1986
Transportation and storage industries	0.049	0.049	0.045
Communication and other utility industries	0.094	0.094	0.094
Wholesale trade industries	0.031	0.033	0.032
Retail trade industries	0.069	0.070	0.073
Finance, insurance, and real estate industries	0.136	0.141	0.142
Business service industries	0.019	0.019	0.018
Other service industries	0.008	0.008	0.007
Government service industries	0.113	0.113	0.111

Nova Scotia	1984	1985	1986
Transportation and storage industries	0.034	0.035	0.035
Communication and other utility industries	0.071	0.058	0.055
Wholesale trade industries	0.037	0.039	0.039
Retail trade industries	0.075	0.076	0.076
Finance, insurance, and real estate industries	0.150	0.159	0.157
Business service industries	0.022	0.023	0.022
Other service industries	0.010	0.010	0.012
Government service industries	0.132	0.127	0.122

New Brunswick	1984	1985	1986
Transportation and storage industries	0.044	0.044	0.042
Communication and other utility industries	0.089	0.089	0.090
Wholesale trade industries	0.049	0.050	0.051
Retail trade industries	0.073	0.075	0.073
Finance, insurance. and real estate industries	0.138	0.145	0.148
Business service industries	0.024	0.024	0.024
Other service industries	0.010	0.010	0.009
Government service industry	0.105	0.104	0.100

(continued)

Appendix C (continued)

Quebec	1984	1985	1986
Transportation and storage industries	0.040	0.040	0.039
Communication and other utility industries	0.078	0.079	0.076
Wholesale trade industries	0.054	0.054	0.055
Retail trade industries	0.065	0.068	0.068
Finance, insurance, and real estate industries	0.121	0.123	0.130
Business service industries	0.035	0.038	0.040
Other service industries	0.011	0.011	0.012
Government service industries	0.077	0.074	0.073

Ontario	1984	1985	1986
Transportation and storage industries	0.037	0.037	0.036
Communication and other utility industries	0.058	0.058	0.057
Wholesale trade industries	0.050	0.053	0.055
Retail trade industries	0.061	0.060	0.060
Finance, insurance, and real estate industries	0.143	0.143	0.152
Business service industries	0.037	0.038	0.041
Other service industries	0.013	0.013	0.013
Government service industries	0.066	0.064	0.062

Manitoba	1984	1985	1986
Transportation and storage industries	0.077	0.070	0.072
Communication and other utility industries	0.064	0.063	0.065
Wholesale trade industries	0.065	0.062	0.063
Retail trade industries	0.059	0.059	0.059
Finance, insurance, and real estate industries	0.142	0.143	0.153
Business service industries	0.021	0.021	0.022
Other service industries	0.009	0.009	0.009
Government service industries	0.088	0.087	0.088

(continued)

Appendix C (continued))

Saskatchewan	1984	1985	1986
Transportation and storage industries	0.054	0.048	0.053
Communication and other utility industries	0.052	0.053	0.056
Wholesale trade industries	0.042	0.043	0.048
Retail trade industries	0.055	0.056	0.059
Finance, insurance, and real estate industries	0.166	0.155	0.164
Business service industries	0.017	0.017	0.019
Other service industries	0.006	0.006	0.006
Government service industries	0.070	0.067	0.071

Alberta	1984	1985	1986
Transportation and storage industries	0.042	0.042	0.049
Communication and other utility industries	0.053	0.051	0.062
Wholesale trade industries	0.033	0.035	0.042
Retail trade industries	0.042	0.044	0.053
Finance, insurance, and real estate industries	0.188	0.175	0.175
Business service industries	0.032	0.032	0.037
Other service industries	0.010	0.011	0.012
Government service industries	0.048	0.047	0.056

British Columbia	1984	1985	1986
Transportation and storage industries	0.074	0.072	0.074
Communication and other utility industries	0.059	0.062	0.056
Wholesale trade industries	0.049	0.049	0.049
Retail trade industries	0.066	0.067	0.068
Finance, insurance, and real estate industries	0.174	0.179	0.179
Business service industries	0.034	0.034	0.035
Other service industries	0.010	0.010	0.010
Government service industries	0.064	0.061	0.060

(continued)

Appendix C (continued)

Prince Edward Island, Yukon, and Northwest Territory	1984	1985	1986
Transportation and storage industries	0.046	0.052	0.050
Communication and other utility industries	0.062	0.063	0.063
Wholesale trade industries	0.022	0.022	0.022
Retail trade industries	0.057	0.052	0.053
Finance, insurance, and real estate industries	0.107	0.113	0.116
Business service industries	0.016	0.017	0.017
Other service industries	0.011	0.011	0.010
Government service industries	0.166	0.162	0.164

Source

These provincial industry weights are computed based upon data obtained from Statistics Canada (1994a).

Appendix D

GLOSSARY OF SELECTED TERMS

Constant Returns to Scale A situation in which output increases proportionately with the quantity of inputs as the scale of production is increased.

GDP Gross Domestic Product is a measure of the total value of the goods and services produced within the geographic boundaries of a nation. In deriving total GDP, Statistics Canada uses the "value added" approach. This approach entails subtracting the value of intermediate inputs used in each industry from the corresponding value of industrial output.

GNP Gross National Product is a measure of the market value of all final goods and services produced in the country plus net foreign investment income.

Heteroscedastic Error Term A violation of the assumption of constant error terms in a regression model.

Marginal Product The additional output produced by one more unit of a particular input while holding all other inputs constant.

Monopsony A market situation in which there is a single buyer or a group of buyers making joint decisions.

Production Function A conceptual mathematical function that describes the relationship between inputs and outputs.

Stochastic Random fluctuations.

Appendix E

ABBREVIATIONS

BLUE	Best Linear Unbiased Estimators
CPI	Consumer Price Indices
OECD	The Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
SURE	Seemingly Unrelated Regression Estimation

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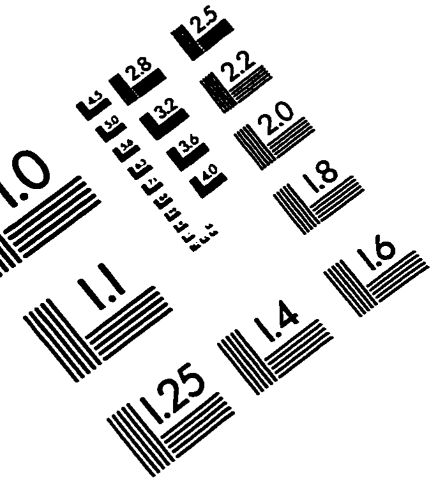
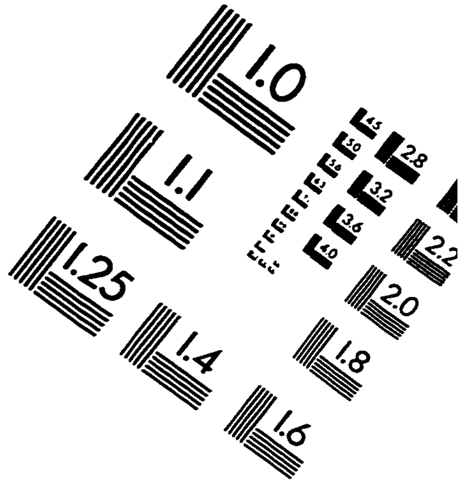
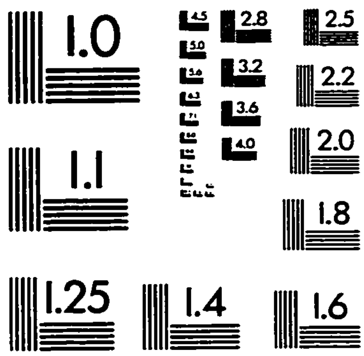
IMAGE EVALUATION TEST TARGET (QA-3)







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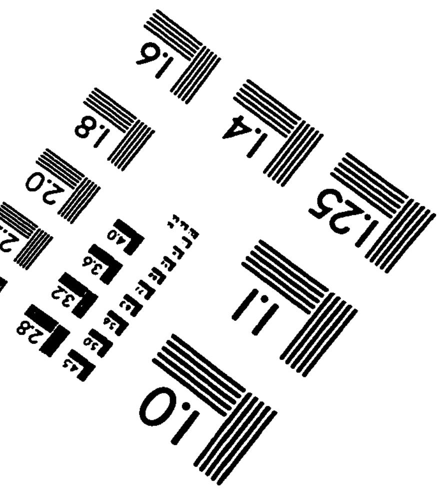

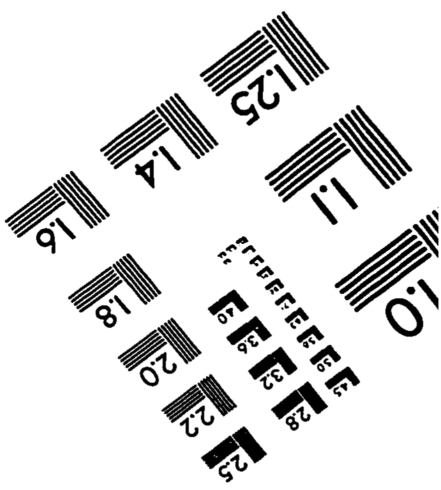

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