THE UNIVERSITY OF MANITOBA

TECHNOLOGICAL CHANGE IN THE CANADIAN IRON AND STEEL MILLS INDUSTRY, 1946-69

by

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ABSTRACT

The United States, which is usually referred to as the most technologically advanced and wealthy nation of the world, has often been the source of technological inspiration for Canada. Due to the close geographical relationship, Canada has depended on the United States economically to a large extent. In addition, the penetration and control by the Americans in the Canadian scence has created a general belief that it would be a surprise if the Canadians could outdo the Americans.

It is true that the United States is the leading nation in many fields, particularly in the field of technological innovation. Nevertheless, it does not follow that Canada should always be lagging behind its southern neighbour. If the resources are efficiently employed, there is no reason why Canada should remain a follower rather than a leader at a specific stage in a specific field. The development in the Canadian steel industry has provided us with an excellent illustration.

The gross and net outputs of the Canadian steel industry has increased by approximately 400-500 per cent while labour productivity, expressed as net output per man-hour, has increased by 250 per cent for the period 1946-1969. The net output growth of the American steel industry amounts to only 110 per cent and labour productivity grew by 145 per cent for the comparable period. The substantial growth of the Canadian steel industry has often been attributed to the prompt introduction of the new technologies in steel-making, namely, the basic oxygen furnace and the continuous casting

machine. The advantages of these new technologies have been the savings of raw materials, time, machine motions, capital costs and operating costs. A study of the process of the diffusion of technology reveals that the American steel industry had lagged behind its Canadian counterpart in adopting new technologies for a number of years. It is also found that small firms introduced new technologies earlier than big firms in both countries. The factors which contributed to the earlier adoption in Canada were the competitive structure of the industry, the rapid rise of the wage rate, the growth of the steel market and the healthy profit trend of the industry. Besides the young age of the newly installed open-hearth furnace in the United States at the time when the basic oxygen furnace was adopted by Canadian firms, the factors which delayed the adoption of the new technologies were the lack of competitive forces, the declining steel market and the falling profit rate of the steel industry.

The delay in the American steel industry has affected the growth in net output and labour productivity of the industry. A modified Solow model indicates that the technological index of the end year of the comparable periods has been higher in Canada than in the United States. Much of the net output growth in the Canadian industry is attributable to technological change since the analysis of a Denison approach shows that only five per cent of the net output growth is attributable to quality improvement of inputs. Production function estimations, which are based on a Cobb-Douglas function and a model derived from a CES function, again provide consistent results in general and, in addition, uncover that the elasticity of substitution and the degree of the returns to scale are both greater in the Canadian than in the American steel industry.

Thus, the diffusion of technology is positively related to productivity performance. Policy actions should then be directed to encourage the prompt introduction of new technology in order to increase the rate of productivity growth. The factors which can be manipulated in the present case are the growth rate of the wage rate and the market structure. Policies which are relevant in this connection are the wage-restraint policy and the enforcement of the competitive structure of the industry.

It is a well known fact that the productivity growth of the Canadian has been greater than that of the American steel industry in recent years. The present study provides evidence to substantiate the above assertion through a systematic analysis of technological change. It establishes the positive link between diffusion of new technology and productivity growth, and argues that the wage policy and the enforcement of a competitive market structure are relevant to the diffusion of new technology. The implication of this study is, therefore, that if policies are carefully designed such that the resources are used efficiently, Canada, though relatively small, can do better than the United States.

Chapter I

INTRODUCTION

A. General Scope

The purpose of this thesis is to attempt a systematic analysis of the rapid growth of the Canadian iron and steel mills industry since 1946. In terms of gross output, Canadian production of steel ingots and steel castings was 2,327,285 net tons in 1946 and it rose to 10,047,557 net tons in 1969. In terms of net output, the constant value added figures (in 1961 dollars) in 1946 and 1969 were 128,873,000 and 557,868,000, respectively.[1] This shows that both gross and net output have increased by approximately 400-500 per cent during the period under review. Labour productivity, expressed as net output per man-hour, has increased by 250 per cent for the same period.[2]

This unprecedented growth in steel-making in Canada is frequently attributed to the prompt introduction of new technologies. In other words, the adoption of new technology is considered as the crucial factor in the process of growth. However, it is not the accessibility of technical knowhow which is important since technical knowhow, apart from the protection

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[1]Gross output figures are obtained from Statistics Canada, Catalogue no. 41-203, *Primary Iron and Steel Industry*, 1947, p. 12, and 1969, p. 12. The derivation of constant value added is explained in Chapter V.

[2]Net output per man-hour increased from $2.1131 in 1946 to $5.3773 in 1969 (constant 1961 dollars). See Table V-3.

of patent rights, is generally easily accessible to all major steel producers. It is the decision to adopt new technologies which is crucial. This decision, however, depends on a number of factors such as expectations about further technological development and foreign competition; these factors can be labelled as determinants of diffusion of new technologies.

B. The Meaning of Technological Change

Before having gone too far, this may be the appropriate time to discuss the meaning of technological change. Generally speaking, the economics of technological change refers to the study of the production of new knowledge, general as well as technical. Schmookler defines technology as a set of applied science, engineering knowledge, invention and subinvention where subinvention refers to an "obvious" change in a product or process such as routine innovation.[1] Addition to knowledge in any of the above four categories is considered as technological progress.[2] Mansfield defines technological change in a more explicit way:

> "Technological change is the advance of technology, such advance often taking the form of new methods of producing existing products, new designs which enable the production of products with important new characteristics, and new techniques of organization, marketing, and management."[3]

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[1] J. Schmookler, *Invention and Economic Growth* (Cambridge: Harvard University Press, 1966), pp. 5-6.

[2] *Ibid.*, p. 7.

[3] E. Mansfield, *The Economics of Technological Change* (London: Longman's, Green Co., 1969), pp. 10-11.

Mansfield's definition makes no distinction between the terms technological change and technical change. In general, the latter refers to the addition of specific knowledge such as a new production technique which enables the making of more goods or better goods from a given set of inputs while the meaning of the former is broader, including the changes in organization, management and related knowledge as well as technical change. Thus, Mansfield's definition of technological change is a combination of the two terms -- technological change and technical change -- in the general sense.

The growth of the Canadian steel industry is attributable to the adoption of new technology and the improvement of the organizational and managerial systems in the industry. Thus, we have adopted Mansfield's definition of technological change and it is used interchangeably with technical change. However, the study of technological change in the present thesis is not a study of the creation of knowledge or the addition to the existing knowledge of steel-making. It is a study of the process and determinants of the adoption of new technology and their effects on the net output growth and the production relationship of the steel industry.

C. Objectives

In Canada, the steel industry ranked as the third largest industry by value added in 1967.[1] As the steel industry

[1] *Submission to the Standing Senate Committee on Banking, Trade and Commerce* by Algoma Steel Corporation Ltd., Dominion Foundries and Steel Ltd., and The Steel Company of Canada Ltd., May 1970, *Appendix C*, Table 20.

is generally regarded as the backbone of the economy, its excellent performance in recent years has no doubt had profound effects on the development of other industries. Thus, an analysis of its performance can be expected to yield useful conclusions. Particularly, an understanding of the process and determinants of diffusion in the steel industry can throw some light on the problem of technical change in other industries.

Bearing these in mind, the objectives of this thesis are set out as follows:

(1) To describe the development of the Canadian steel industry since 1946 with particular emphasis on its technical aspects of production.

(2) To examine the process of diffusion of new technologies in order to identify the determinants of rapid diffusion.

(3) To measure the rate of technical change and other parameters in steel production so that the relationship between rapid diffusion of technology and net output growth can be inferred.

Aiming at achieving the above objectives, the thesis is divided into eight chapters of which we will describe their contents briefly in the following section.

D. Outline of Contents

The present chapter is to provide an introduction of the thesis. Chapter II is devoted to a background study of the Canadian steel industry with an historical account of its development and the technological progress of steel-making techniques. After the foundation is laid, the third chapter reviews the basic theory and measurement method of technological diffusion and technical change. Salter's[1] and Mansfield's[2] works in diffusion of new technologies, the residual approach and the production function approach of measuring technological change are the topics of discussion. The following chapter (Chapter IV) is a study on the diffusion process of the basic oxygen furnace and the continuous casting machine in the Canadian steel industry. References will be made to the diffusion process of the same technologies in the American steel industry for the purpose of comparison. The remaining chapters, namely Chapter V, Chapter VI and Chapter VII, are all devoted to an analysis of the magnitude of technological change and net output growth in the Canadian steel industry. In Chapter V, a modified-Solow model[3] is used to evaluate the effect of technical change and its contribution to labour

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[1]W. Salter, *Productivity and Technical Change* (London: Cambridge University Press, 1960).

[2]E. Mansfield, *Industrial Research and Technological Change* (New York: W. W. Norton, 1968).

[3]R. M. Solow, "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, 1957, pp. 312-30.

productivity growth. The Solow measure of technical change is in fact a residual measure. As a step towards the breaking up of the residual black box, a modified-Denison framework is adopted in Chapter VI to quantify the sources of total factor productivity growth. The seventh chapter employs the production function estimation approach to investigate the nature of technical change, whether it is neutral or non-neutral, the degree of returns to scale and the elasticity of substitution between inputs by running regression. Again, the American steel industry is used as an instance in comparison. The final chapter, Chapter VIII, summarizes the findings of various chapters and offers some concluding observations.

The reason for using several alternative approaches, namely, Solow, Denison and production function estimation, to measure the rate of technical change and its contribution to net output growth can be explained as follows. Economists have been accused of using unrealistic assumptions in the formulation of economic theory, and the predicted result of the theory varies with the assumptions made. Thus, it is not desirable to make the conclusion from a theory or measurement which is based on some shaky assumptions. However, if the results obtained by employing different theories and approaches, which presumably are based on different assumptions, are consistent, then the results are invariant of the assumptions made and are therefore more reliable. Thus, the reason for using various approaches of measuring the rate of technical change in the Canadian steel industry is to see whether the results are consistent.

Chapter II

THE DEVELOPMENT OF THE IRON AND STEEL INDUSTRY

The purpose of this chapter is to outline the development of the Canadian iron and steel industry as a background to understanding the technological development of the industry. Special attention will be paid to the technological innovation in the industry since the ending of the Second World War. Economic effects of various technical changes will be evaluated.

A. History of Iron and Steel-Making in Canada

Iron was probably first melted in Western Asia during the period 1800 B.C. - 1400 B.C. The primitive blast furnace was developed in Europe around 1300 A.D. which evolved into charcoal blast furnace by the beginning of the 18th century. In 1736, the technique of iron-making was brought into Canada and a charcoal blast furnace was erected at Les Forges Saint-Maurice, Quebec, and the first usable iron was produced in 1738.[1] In Ontario, the first blast furnace was established at Lyndhurst in 1800. The Les Forges Saint-Maurice was closed down in 1883 due to exhaustion of local raw materials and the Lyndhurst work closed in 1802 due to unknown reasons. The failure of these furnaces was attributed to the small and separated markets, which was a

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[1]Harry Miller, *Canada's Historic First Iron Castings*, Department of Energy, Mines and Resources, Ottawa, 1968, p. 1.

consequence of slow industrial growth, technical difficulties and the inadequate protective tariff to meet import competition from England and the United States.[1]

In 1879, a national policy designed to stimulate the development of the iron and steel industry by custom tariff and bounty systems was adopted. Custom duties on iron and iron products were increased. For instance, pig iron was admitted at \$2 a ton. Beginning in 1883, the bounty on locally produced pig iron was fixed at \$1.50 per ton but reduced to \$1 per ton later. At the same time, the provinces and municipalities were granting aid to develop the industry. The Ontario government granted a bounty of \$1 for each short ton of iron ore produced. Consequently, iron-makers were benefitted from decreased ore prices resulting from keen competition among ore producers. Meanwhile, municipal governments offered free sites, tax exemptions and bonuses to induce the establishment of iron and steel works. As a result, two new plants -- the Pictou Charcoal Iron Company of Nova Scotia and the Hamilton Blast Furnace Company of Ontario -- came into being.

The bounty system survived until 1912 while the protective measures for the iron and steel industry were retained. While it is difficult to judge on the wisdom of the national policy of protection, the period between 1879 and 1914 witnessed the origin and growth of three of the present four

[1] W.J.A. Donald, *The Canadian Iron and Steel Industry*, Houghton Mifflin Co., Boston and New York, 1915, p. 78.

major integrated iron and steel firms, namely, the Sydney Steel Corporation of Nova Scotia (the former DOSCO), the Steel Company of Canada Limited (STELCO), and the Algoma Steel Corporation Limited (ALGOMA).

The years between 1914 and 1945 witnessed the outbreaks of the First World War and the Second World War. The two world wars provided great stimulation to the expansion of the iron and steel industry. The stimulation of the First World War was so great that the industry was overexpanded and capacity became excessive after the war. The outbreak of the Second World War provided another stimulation to the iron and steel industry and saved some of the firms from their financial difficulties. Steel capacity was greatly expanded and production increased from 1.5 million net tons in 1939 to 2.3 million net tons in 1946.[1]

The period since the ending of the Second World War has been a period of substantial growth in the Canadian steel industry. The fourth integrated steel company, the Dominion Foundries and Steel Limited (DOFASCO), was firmly established by the early 1950s. Pig iron and steel ingot production has been increasing at unprecedented rates. The following table clearly shows the increasing trend of total production since 1946.

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[1]G. E. Wittur, *Primary Iron and Steel in Canada*, Department of Energy, Mines and Resources, Ottawa, 1968, p. 24.

Table II-1

PRODUCTION OF PIG IRON, STEEL INGOTS AND STEEL CASTINGS

(Net tons)[1]

Year	Pig Iron	Steel Ingots and Steel Castings
1946	1,406,252	2,327,285
1947	1,962,848	2,945,952
1948	2,125,739	3,200,480
1949	2,154,485	3,190,377
1950	2,317,121	3,383,575
1951	2,552,893	3,568,720
1952	2,681,585	3,703,111
1953	3,012,268	4,116,068
1954	2,211,029	3,195,030
1955	3,215,367	4,534,672
1956	3,568,203	5,301,202
1957	3,718,350	5,068,149
1958	3,059,579	4,359,466
1959	4,182,775	5,901,487
1960	4,298,849	5,809,108
1961	4,946,021	6,488,307
1962	5,276,753	7,173,534
1963	5,933,270	8,197,070
1964	6,550,835	9,128,459
1965	7,079,439	10,068,342
1966	7,216,610	10,020,131
1967	6,950,803	9,700,832
1968	8,382,601	11,198,447
1969	7,461,219	10,047,557

[1]Net ton or short ton = 2000 pounds;
Gross ton or long ton = 2240 pounds.

Source: Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1949, 1958 and 1969.

A glance at Table II-1 convinces one that there has been a clear upward trend in industry output. Pig iron production increased six times from 1.4 million net tons in 1946 to 8.4 million net tons in 1968. The output of steel ingots and steel castings increased from 2.3 million net tons to 11.2 million net tons during the same period. The year-to-year rise in output is clear except during 1954, 1958, 1967 and 1969, when minor recessions and strikes led to reduction of output.

The postwar period has certainly been a period of unprecedented growth.[1] Technological change has no doubt played an important role in this growth process. Since the iron and steel industry is essentially resource-oriented, the availability of suitable raw materials is also a crucial factor in its growth. Thus, it is desirable to note the development in the use of raw materials in steel production before technical change is discussed.

B. Raw Materials of Steel Production

(a) Iron Ore

Besides technological change in the process of making iron and steel, the availability of better iron ore through new discoveries or through improvements in the techniques of ore extraction and ore preparation may be partly responsible

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[1]W. K. Buck and R. B. Elver have labelled this period as the period of growth. See W. K. Buck and R. B. Elver, *The Canadian Steel Industry - A Pattern of Growth*, Mineral Information Bulletin MR70, 1963, pp. 5-10.

for the observed growth in iron and steel output. Since iron ore is the most important raw material in the process of steel-making, a brief description of its development might throw some light on the development of the iron and steel industry.

Deposits of iron ore were known to exist in Canada at a very early date. Iron ore was first discovered in Nova Scotia as early as 1604.[1] Wabana Mines of Newfoundland has been exploited since 1895, and was the main source of supply for the iron and steel industry of Nova Scotia.[2] Saint-Maurice Mine of Quebec was discovered in 1667.[3] Other early mines such as Helen, Josephine and Magpie Mines were located in Northern Ontario. The discovery of iron ore in the West, such as deposits along the McKenzie River in Alberta and Vancouver Island in British Columbia came much later.

The quality of iron ore of early discoveries was low because of high sulphur and phosphorus content. These two elements were detrimental in producing good-quality pig iron by using the Bessemer process. Though a few mines with high grade iron ores were known, the costs of extracting the ores, which requires such things as the diversion of river and the

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[1]J. H. Bartlett, *The Manufacture, Consumption and Production of Iron, Steel and Coal in the Dominion of Canada* (Montreal: Dawson Brothers, 1885), p. 40.

[2]W.J.A. Donald, *ibid.*, p. 29.

[3]J. H. Bartlett, *op. cit.*, p. 6.

draining of lake, were prohibitive. The extraction of these ores was not carried out until a much later period. Canadian iron and steel works were forced to import iron ores from the Lake Superior district of the United States, while Canadian ores of high-phosphorus content were shipped to Europe where the ores were suitable for the technology there.[1]

However, the rapid growth of iron ore industry did not occur until the 1950s. The prime mover of increased iron ore search was the anticipated depletion of ores in the Mesabi ranges in Minnesota, which was then the most important source of iron ore supporting the gigantic American steel industry. The depletion of ore in the Mesabi ranges forced American companies to search for high-grade ore in Canada. By 1950, several high-grade ore mines had been exploited more intensively and production was increasing at a rapid rate. The most important of the new sources of ore were the Steep Rock Mine of Ontario and the New Quebec-Labrador ore belt of Quebec.

Steep Rock ore was discovered in 1937. Due to unsuccessful extraction under water, it was later abandoned. Diversion of the Seine River and the draining of Steep Rock Lake were made possible by American financial backing. In the fall of 1944, the first Steep Rock ore was mined. In 1949,

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[1]The Thomas converter is still used in Continental Europe, since it works well with iron ores of high-phosphorus content which are abundant in the Lorraine deposits. In Canada, the Thomas converter was not used for a long time.

Steep Rock Iron Mines Limited shipped 1.13 million tons of high-grade ore from its Errington Mine alone, and further expansion in production followed.[1]

The latest and the most important development is the exploration of iron ores in New Quebec and Labrador. The ore field is located in the Allard Lake district on Quebec's North Shore, and stretches some 300 miles north of Seven Island. The ore was mined in large scale in 1949 by the newly formed Iron Ore Company of Canada. The ores are of high grade which contain little phosphorus and most of the ores are classified into Bessemer ore which, by definition, contains less than .045 per cent phosphorus.[2] It was known later in 1961 that the ore was a percentage point or two higher in iron content than average Mesabi ores.[3] Higher production efficiency in steel-making is obtained by using the ores from New Quebec and Labrador than using the ores of Mesabi Mines. Besides, the preliminary estimate of ore deposits was 358 million long tons,[4] which was a huge deposit. The New Quebec-Labrador district is thus the largest ore deposit containing the highest grade of ores known in Canada.

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[1] V. C. Wansbrough, "Implications of Canadian Iron Ore Production", *Canadian Journal of Economics and Political Science*, 1950, p. 334.

[2] J. A. Retty, "The Discovery of Iron Galore in New Quebec-Labrador", *Canadian Geographical Journal*, January 1951, p. 8.

[3] "Big Steel Gets Jump in Canadian Ore Race", *Business Week*, January 28, 1961, pp. 62-78.

[4] *Op. cit.*, p. 8.

In addition to the newly discovered better grade of iron ore, technical advances in the beneficiation of ore have improved the quality of ore, both high-grade and low-grade, and make them more suitable for blast furnace use. Beneficiation involves not only an increase in the iron content of the ore and the rejection of undesirable chemical elements, but also a change in the size distribution and physical structure of the ore. The increase in iron content per ton of ore as a result of beneficiation is, in its economic implications, equivalent to a reduction in transportation cost per ton of ore. Also, blast furnace productivity is increased and unit coke consumption is reduced by using beneficiated ore. Consequently, beneficiation enables the extraction of low-grade ore which was previously unprofitable.

The process of beneficiation includes mainly three steps; namely, crushing-screening, concentration and agglomeration.[1] Crushing-screening is a process used to reduce the size of ore lumps and involves no raising of iron content. Concentration refers to the process of raising iron content by getting rid of undesirable elements. After concentration is carried out, if the ore turns out to be too fine for blast-furnace use, then agglomeration is necessary to put the fine ores "into a physical form that can withstand the weight of

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[1] R. B. Elver, *Survey of the Canadian Iron Ore Industry During 1959*, Department of Mines and Technical Survey, Ottawa, p. 56.

the charge in the blast furnace".[1] There are four methods to accomplish agglomeration; namely, sintering, pelletizing, nodulizing and briquetting. However, sintering and pelletizing are more commonly used in North America. In Canada, iron ore pellets were first produced by Marmoraton Mining Company Ltd. in 1955. Since then, pellet plants have been established and expanded in Ontario, Quebec and Labrador. In 1968, the total pellet plant capacity in Canada was estimated at 24.83 million long tons.[2]

As a result of the increased extraction of high-grade ore and the increased extraction of low-grade ore made profitable by the use of the pelletizing technique, Canadian iron ore production has increased substantially. Imports of ore from the United States, though still substantial, have been declining in the last few years. It is somewhat puzzling at first sight to note that, despite large domestic production, Canada still imports ores from the United States. There are, however, several reasons for this. One reason is that different types of ore have to be mixed in order to produce high-quality output and apparently some of the imports are types which are not found in Canada. Another reason is that there are contractual supply relationships between Canadian steel firms and American mining companies in the Lake Superior regions.[3] Also, the cost of

[1] *Ibid.*, p. 58.

[2] P. Lafleur, *Canadian Iron Ore Industry*, 1968, p. 47.

[3] These supply contracts could arise from certain financial arrangements between mining firms and steel firms.

transportation might be higher from some distant Canadian iron mines than from American mines to Canadian steel companies. Production, import, export and domestic consumption of iron ore are shown in Tables II-2 and II-3.

Table II-2 shows that the output of iron ore in 1968 was nearly 40 times that of 1948. Imports of ore, after some fluctuation, shows signs of declining. Consumption of ore has increased consistently and reached between 10 and 11 million tons in 1968. It is surprising to see, from Table II-3, that pelletized and sintered ore consumed accounts for 92.4 per cent of total iron ore charged to iron blast furnaces in 1969. The trend in the use of pelletized-sintered ore, rather than crude ore, is quite clear. The percentage point continuously increases from 21.3 in 1955 to 92.4 in 1969.

Although the price of pelletized ore is somewhat higher than that of crude ore, the advantage obtained and the resultant productivity increase have far outweighed the additional cost. Thus, despite the declines in crude ore price in April 1962, and August 1963, the price of pelletized ore remained stable throughout the whole period 1955-69. The decrease in transportation cost per ton of ore and in unit coke consumption resulting from the use of pelletized iron ore, undoubtedly decreases input costs at the blast furnace stage. The considerable increase in the use of pelletized-sintered ore, which is clearly seen from Table II-3, must have contributed to some extent to the rapid growth of the iron and steel industry.

Table II-2

IRON ORE PRODUCTION, TRADE AND CONSUMPTION, 1948-69

Year	Production	Imports	Exports	Indicated* Consumption	Unit:** Million Long Tons
1948	1.19	3.84	0.96	4.07	
1949	3.28	2.25	2.28	3.15	
1950	3.22	2.74	1.99	3.97	
1951	4.18	3.42	2.88	4.72	
1952	4.71	3.81	3.43	5.09	
1953	5.81	3.72	4.30	5.23	
1954	6.57	2.71	5.47	3.81	
1955	14.54	4.05	13.01	5.58	
1956	19.95	4.53	18.09	6.39	
1957	19.87	4.05	17.97	5.95	
1958	14.04	3.05	12.39	4.70	
1959	21.87	2.50	18.55	5.82	
1960	19.24	4.51	16.94	6.81	
1961	18.18	4.13	18.87	7.44	
1962	24.43	4.60	21.65	7.38	
1963	26.91	5.33	23.85	8.39	
1964	34.22	5.23	30.47	8.98	
1965	35.68	4.76	30.80	9.64	
1966	36.33	4.32	30.69	9.96	
1967	37.78	2.40	31.41	8.77	
1968	44.08	2.75	36.01	10.82	
1969	35.71	2.26	27.91	10.06	

*Indicated Consumption = Production + Imports - Exports. It does not take stock changes into account.

**Long ton = 2240 pounds, net ton = 200 pounds.

Source: T. H. Janes and R. B. Elver, *Survey of the Canadian Iron Ore Industry During 1958*, p. 18; P. Lafleur, *Canadian Iron Ore Industry*, 1968, p. 14; and *Canada Mineral Yearbook*, 1969, Reprint No. 24, p. 2.

Table II-3

IRON-ORE CHARGED TO IRON BLAST FURNACES, 1955-69

(Unit: net tons)

Year	Crude Ore	Pelletized and Sintered Ore	Total	% = (2)/(3)
	(1)	(2)	(3)	(4)
1955	4,738,176	1,279,259	6,017,435	21.3
1956	4,667,506	1,855,052	6,522,558	28.3
1957	4,646,179	2,082,952	6,729,131	31.0
1958	3,384,351	2,071,147	5,455,498	38.0
1959	3,914,111	3,248,605	7,162,716	45.4
1960	3,590,484	3,434,298	7,024,782	48.9
1961	3,021,487	4,866,899	7,888,386	61.7
1962	2,730,337	5,781,019	8,511,356	67.9
1963	2,486,976	6,870,844	9,357,820	73.4
1964	1,839,910	8,025,313	9,865,223	81.4
1965	1,818,193	8,573,066	10,391,259	82.5
1966	1,696,868	8,183,926	9,880,794	82.8
1967	950,619	8,255,980	9,206,599	89.7
1968	885,171	10,571,003	11,456,174	92.3
1969	805,262	9,721,002	10,526,264	92.4

Source: Statistics Canada, *Iron and Steel Mills* (various issues), and *Primary Iron and Steel*, 1968 and 1969.

(b) Other Materials

Besides iron ore, other major items of materials needed in making iron and steel are coke, limestone, scrap iron and steel, air, water, and oxygen. Coke is used as fuel in blast furnace. In the early days, charcoal was used as fuel, but was later substituted by coal. However, coal contains sulphur which makes wrought iron "hot short", meaning that it cannot be worked when heated.[1] It was later discovered that the sulphur element in coal could be removed by coking the coal. This is probably the origin of the use of coke as fuel in blast furnaces. In Canada, major coal deposits are located in Nova Scotia and some deposits in Alberta and British Columbia. The coal in Nova Scotia, however, contains too much sulphur for making coke. Thus, most of the required coal is imported from the United States.

Oxygen is a new and important input in modern steel-making process. As early as 1856, Bessemer recognized that it was the decarbonization of the molten iron by oxygen, obtained from currents of air, which turned iron into steel. If pure oxygen could be supplied, then the speed and efficiency of steel-making would certainly increase. But large quantities of commercial oxygen were not available at that time. It was not until the end of the Second World War that commercial oxygen was produced in large quantities by a liquid-air process. The success of tonnage oxygen production enables the commercial use of oxygen in steel plants and contributed substantially to the rapid growth of the steel industry in the last two decades.

Other inputs like limestone, scrap, and water are also important. Limestone is used as flux to absorb undesirable chemical elements such as sulphur and phosphorus. Scrap is

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[1]W.K.V. Gale, *The British Iron and Steel Industry - A Technical History*, Augustus M. Kelley. New York, 1967, p. 30.

used in a certain ratio with pig iron in making steel. It can also be used solely in an electric arc furnace. The last item, water, is used for cooling.

C. Technological Change

Major technical innovations in the art of steel-making have taken place in the past two or three decades. For a thorough understanding of the significance of these changes, a brief technical history of the industry is in order.

(a) The History of Steel-Making

At the present time, the two most important steps in making steel are the making of pig iron in the blast furnace and the making of steel in an open-hearth furnace or an oxygen furnace.[1] The blast furnace is said to have had its origin in Belgium sometime before 1400 A.D.[2] but it was not introduced into Britain until 1500 A.D. It was usually built with brick with filling holes in the top for charging iron ore, limestone and charcoal. Iron ore was melted into molten iron and tapped from the tap hole at the bottom of the structure. Molten iron was then solidified into pig iron. As fuel, charcoal was replaced by coal in 1621 which was again replaced by coke in the early 18th century. In 1828, J. B. Neilson discovered the use of the hot blast for blast furnaces, that is, the

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[1]L. Morgan, *The Canadian Primary Iron and Steel Industry*, Royal Commission Report, October 1956, p. 51.

[2]W.K.V. Gale, *op. cit.*, p. 20.

passing through of hot air lessens the moisture in the air, which results in an increase of furnace yield.

The invention of the Bessemer converter in 1856 marked the beginning of the steel age. The converter was so constructed that hot air could blast into it through a group of small holes at its bottom. Then molten pig iron was poured into the converter. After a series of chemical reactions, the wholly decarbonized iron, that is, steel, was found. The art of steel-making was further improved by the invention of the open-hearth process by C. W. Siemens around 1857. The principle was more or less the same as the Bessemer process but the design of generating hot air was different. Siemens used two regenerator chambers, one on each side of the vessel holding molten iron. One of the chambers generated hot air while the other chamber was saving the waste hot air which had just passed through the molten iron in the vessel. The process was alternatively repeated such that a very high-temperature hot air could be generated and fuel could be saved by a large percentage because of the conservation of waste air. The temperature generated was much higher than in the Bessemer process, and, therefore, 100 per cent of solidified pig iron or scrap metal could be melted in the open-hearth converter. While the open-hearth process could use molten or solidified iron to make steel, the Bessemer process could only use molten iron. Thus, the advantage of the open-hearth process was that it could work with either pig iron or with scrap.

Besides the open-hearth process, Siemens also had the idea that intense heat could be generated by striking an arc between two electrodes, which could be used to smelt steel. This served as the basis of the subsequently developed electric arc furnace. The electric arc furnace does not require fuel and so no contamination of the steel from the fuel is possible. This enables it to make high-quality steel by using scrap.

Technical inventions and innovations in the art of making iron and steel seems to have some pattern of geographical distribution. Almost all the basic techniques of iron and steel-making were developed in Britain within the 18th and 19th century. Subsequent technological developments in the 20th century were scattered mainly in continental Europe and North America. Major technical improvements in the last two decades are (i) basic oxygen process in steel-making, (ii) continuous casting in steel processing, (iii) fuel injection into the blast furnace, (iv) vacuum process in alloy-making, and (v) automatic control by computer. Of these innovations, the first two have produced the most profound effects on steel production and therefore deserve our special attention in the following discussion.

(b) <u>Modern Technological Improvements</u>

(i) Basic oxygen process

As mentioned above, the idea of making steel by using pure oxygen originated from Bessemer in 1856. He recognized that atmospheric air consisted of only 20 per cent oxygen and the rest nitrogen which made steel brittle and not sufficiently malleable. The quality of steel could be much improved if pure oxygen was used instead of atmospheric air. However, attempts to produce oxygen in large quantities did not succeed until 1929. Experiments for using pure oxygen in steel production had been carried out since 1929 and eventually, the first successful test of the basic oxygen technique was conducted at Linz, Austria, in June 1949. In 1952, the same Austrian firm (VOEST) which conducted the test in 1949 began large-scale commercial production of steel by using the basic oxygen technique *(L - D)*. The first firm outside Austria to produce steel by using the new technique was the Dominion Foundries and Steel Ltd., at Hamilton, Ontario, in 1954.

The oxygen vessel which contains molten iron, scrap and flux is usually pear-shaped.[1] The top of the vessel is open where the charging of raw materials and removing of slag are done. An oxygen lance is vertically drawn into the vessel from its open top. After the charging is done, pure oxygen is blown into the charge through the oxygen lance which generates heat and carries out chemical reaction with the impurities of the charge. The major advantage of the basic oxygen process is that, unlike open-hearth furnace, no fuel is needed to generate heat. The saving is enormous. The reaction in the vessel is so strong that the bottom of the vessel would be damaged if the

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[1]B. A. Strathdee and F. J. McMulkin, "Steel Making", *Aspects of Modern Ferrous Metallurgy*, J. S. Kirkaldy (ed.) (Toronto: University of Toronto Press, 1964), p. 153.

lance was lowered too close to it. The speed of the process is so high that after about 30 to 40 minutes, the molten steel is ready to be tapped.[1] The advantages of the basic oxygen process over other processes are the low-capital cost of equipment, the low-operating cost, its suitability for low-carbon steel and the high-production rates.[2] Some concrete facts can be cited to substantiate these claims. The January 1955 issue of the *Iron and Steel Engineer* reports that production rates for the basic oxygen converters are "three times higher than for the conventional open-hearth furnaces", and operating costs are $3 per ton of steel less than similar costs for open-hearth steel. "Capital costs are estimated at 50 per cent less than a comparably sized open-hearth shop."[3] In 1959, the same journal reported that the capital cost of the oxygen converter was estimated at $15 a ton while that of the open-hearth furnace was $40 a ton.[4] The trend indicates that the basic oxygen converter will replace the open-hearth furnace in the foreseeable future. Thus, the same journal declared in 1960 that "the United States has probably seen the last large new open-hearth shop to be built".[5]

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[1]W.K.V. Gale, *op. cit.*, p. 157.

[2]B. A. Strathdee, *op. cit.*, p. 152.

[3]W. Adams and J. B. Dirlam, "Big Steel, Invention and Innovation", *Quarterly Journal of Economics*, May 1966, p. 178.

[4]*Ibid.*, p. 179.

[5]*Ibid.*, p. 180.

(ii) Continuous casting machines

After molten steel is produced either in the open-hearth furnace or the basic oxygen converter, the next step in the traditional treatment is to mould the molten metal into steel ingot by pouring it into a copper mould. The function of the ingot moulds is to cool and solidify molten metal by circulating water inside the hollow walls of the moulds. Then steel ingot is stripped off the mould and reheated in the soaking pit. Finally, steel ingots are sent to the primary mill for cutting and processing into either billets or slabs.

The invention of the continuous casting process in the 1939-45 period enabled the moulding of steel ingots and the cutting of billets or slabs to be done in a single machine, thus eliminating the need for using the soaking process and the primary mill. The essential structure of the machine is that there is a refractory-lined tundrish at the top through which molten metal is poured into copper ingot moulds to be solidified. Each mould is specially built to solidify ingot of specified shape and size. Then solid steel ingot is pulled out by a dummy bar through the open bottom of each mould and is cut immediately by an automatic frame-cutting machine into lengths as required. The apparent advantage of the continuous casting process is cost-reduction and speed. The disadvantage, however, is the low tonnage which a machine can handle each time. Nevertheless, the machine has been improved to handle much larger tonnage of ingots in recent years. In 1954, Atlas Steels of Canada was the first company which adopted the continuous casting method in North America.

In addition to the above two major changes, a direct reduction method which bypasses the blast furnace is being researched.[1] Other inventions and innovations, such as the induction furnace used for melting titanium, the vacuum furnace used to make special alloy steels, the fuel injection technique, the use of computer for automatic gauge control as well as spectrographic analysis of steel sample, have been gradually adopted in the past 30 years. All these innovations, especially the oxygen converter and the continuous casting process, have revolutionized the art of steel-making. And it is most surprising to find that both these innovations were first adopted by Canadian firms in North America. It was DOFASCO which took the lead in installing the oxygen converter and Atlas which took the lead in using the continuous casting process. The merits demonstrated by the new techniques have persuaded other Canadian as well as American firms to follow suit.

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[1]See J. G. Sibakin and M. J. Fraser, "Direct Reduction", in *Aspects of Modern Ferrous Metallurgy*, p. 13.

D. The Effect of Technological Innovations on Steel Production

The main effects of technological change are material input saving and processing time saving. Since steel production is essentially an integration of several production stages, the following discussion of the effects will therefore be conducted on a stage basis.

The manufacturing activity of steel can be roughly divided into four stages; namely, coke oven stage, blast furnace stage, steel furnace stage and rolling mill stage. Let us first look at the coke oven stage. From 1960 to 1968, the coal requirement of making a net ton of coke had fallen from 1.3509 ton to 1.1775 ton, approximately 13 per cent.[1] The requirements of other items, such as absorbing-wash oil, caustic soda and sulphuric acid, had gone down much more.[2] Note that these changes took place between 1960 and 1968. If the same trend persisted before 1960, then the savings of raw materials between 1946 to 1968 were quite substantial.

Originally, metallurgical coke was produced by the beehive process. It was later replaced by the by-product process. The difference between the two processes is that the latter also produces coal chemicals and gas as by-products, and 40 per cent of the gas produced is returned to the ovens

[1]See Appendix Table A-1.

[2]Wash oil is used in the recovery of light oil, and sulphuric acid is used to wash light oil fractions and remove impurities by chemical reaction.

for heating purposes.[1] The by-product oven has been used long before 1960. Thus, the savings in raw materials do not come from replacing of the beehive ovens by the by-product ovens, but from the improvement of the by-product ovens.

Coke is mainly used as fuel in the second production stage -- the making of pig iron in blast furnace. The most important raw materials in this stage are iron ore and steel scrap. In addition, limestone, dolomite mill cinder and scale are also essential. The changes in the raw materials requirements of producing a net ton of pig iron between 1946 and 1968 are shown as follows:[2]

Mill cinder, scale, etc.	-66.2%
Iron and steel scrap	+51.2%
Coke	-51.1%
Limestone	-82.2%
Dolomite	+118.1%
Iron Ore	-38.4%

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[1]U.S. Steel, *The Making, Shaping and Treating of Steel*, 8th edition, p. 99.

[2]See Appendix Table A-2. The changes in the use of flux in blast furnaces were not due to the changes in their relative prices. For instance, the prices of limestone and dolomite were:

	1950	1961	1968	($ per ton)
Limestone	1.73	1.70	1.62	
Dolomite	1.51	1.74	2.01	

But the use of limestone per ton of pig iron declined. See Statistics Canada, *Iron and Steel Mills*, 1950, 1961 and 1968 issues. See also Appendix A-6 for a discussion on the sources of productivity growth.

Special attention should be paid to iron ore and mill cinder, scale. The latter originally included iron ore in processed form such as sinters, but since 1956, all processed ores are excluded and added to the column "iron ore". Thus, the actual percentage decline of pure iron ore, i.e., excluding processed ore, between 1946 and 1968, is more than 38.4 per cent and that of mill cinder, scale is less than 66.2 per cent.

Most iron and steel scrap used in blast furnace comes from the scrap generated in pig iron casting and few from external sources.[1] The proportions of scrap used in producing a net ton of pig iron fluctuate throughout the period. This indicates that the proportions of scrap to pig iron is flexible, and the increase in the proportion is simply because more scraps are available. Note that iron ore, cinder, scale and scrap are all iron-bearing materials and they are substitutable to a certain extent.

The falling of coke requirements has been quite steady. The coke requirement in 1968 was only half of that in 1946. Limestone and dolomite are used as fluxes. They are substitutable for each other. Limestone is preferred to dolomite, if large amounts of sulphur are to be removed from iron-bearing materials. With the increase in the use of sinter, limestone and dolomite are usually crushed and mixed with sinter. These fluxing fines combine and absorb impurities of iron-bearing materials before charging and so lessen the quantities of raw stone required in the blast furnace.

[1]U.S. Steel, *op. cit.*, p. 387.

The proportions of limestone used have fallen, but those of dolomite have increased. It is clear that some substitution between them has taken place. If the six items are regrouped into three categories, namely, iron-bearing materials, coke, and fluxes, the material requirements in producing a net ton of pig iron between 1946 and 1968 can be shown as:

	Iron-Bearing Materials	Coke (Unit: net tons)	Fluxes
1946	1.9277	.9391	.4579
1968	1.1701	.4595	.1115
U.S. standard reported in 1964	1.7	.50 ∿ .65	.25

Source: Appendix Table A-2; and U.S. Steel, *op. cit.*, p. 387.

The decline in material requirements which is equivalent to productivity growth of the materials concerned is substantial. The sources of productivity growth in blast furnace stage are essentially five; namely, blast-humidity control, fuel injection, oxygen enrichment, high-pressure operation, and beneficiated burden materials.[1] All these improvements are responsible for the productivity growth in blast furnace stage, although their relative weights of contribution are not known.

[1]U.S. Steel, *op. cit.*, pp. 432-34.

The next stage of steel production is the making of steel ingot and casting in steel furnace. Major materials are, of course, pig iron and steel scrap. The use of pig iron in producing a net ton of steel increased by 39.5 per cent between 1946 and 1968, while those of steel scrap and iron ore declined by 33.1 per cent and 47.4 per cent, respectively.[1] The use of fluxes, namely, limestone, dolomite and fluorspar, also declined. The first two, namely, limestone and dolomite, are substitutable for each other, while fluorspar is used as a neutral flux to make slags more fusible.

The development of the basic oxygen furnace permits a more flexible use of steel scrap. The open-hearth furnace generally uses 50 to 60 per cent scrap, while the basic oxygen furnace uses 12 to 30 per cent scrap and more molten iron.[2] The replacement of basic oxygen process for open-hearth process beginning in the mid-1950s is responsible for the decline in scrap use and the rise in pig iron use. The replacement also produces a depressing effect on scrap price which might encourage the expansion of alloy-steel-making and hence the use of scrap. However, the depressing effect is offset by the short supply of home scrap as a result of using continuous casting process. Thus, the decline in the use of scrap is simply the effect of substituting pig iron for scrap but not saving in material use.

[1] *Ibid.*, pp. 432-34.

[2] See G. E. Wittur, *op. cit.*, pp. 87-88, and U.S. Steel, *op. cit.*, p. 455.

For other material inputs such as iron ore, limestone, dolomite and fluorspar, savings do exist.

Therefore, it is safe to conclude that although there are some savings of minor material inputs, no saving of major material inputs such as pig iron and scrap exists in the steel furnace stage. However, this does not mean that technological innovations produce no positive effect on productivity in this stage. On the contrary, ample savings of labour and capital input per unit of output have been made possible as a result of cutting blowing time by introducing basic oxygen process.

The final stage of steel production is the rolling mill which manufactures semifinished products such as bars, structural shapes and plates from billets, blooms and slabs. The material inputs here are billets, blooms, slabs and even steel ingots, and the outputs are bars, rails, shapes, plates and so on. Although the quantities of individual material inputs and of products are reported in Statistics Canada publication (Catalogue no. 41-203), no detailed breakdown is made. For instance, the quantities of blooms used and its subsequent products, namely, structural shapes and rails, are both reported but the exact amounts of blooms used to make either shapes or rails are not listed. Thus, there is no way to calculate the proportion of bloom used in producing a net ton of shapes or rails.[1]

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[1]Although the requirement of blooms used for per net ton of "shapes and rails" can be calculated, it is not very meaningful because the shift in the composition of shapes and rails can also change the bloom requirement.

The possible sources of productivity growth in this stage are the shortening of processing time required and the decrease in waste motion as well as material requirements during processing. The shortening of processing time and the decrease in waste motion reduce the length of time during which "goods in process" stick in the process of production. In other words, it cuts down the requirement of working capital. These two sources are combined in most cases. For instance, the continuous casting machine has substituted the whole series of ingot preparation work, including soaking pit, forging press and roughing mill. This enables a great saving in time. In addition, continuous casting avoids the necessary waste of cutting off the hollow top of ingots prepared by the traditional method. Another example is the continuous billet mill. Its feature is that there are more than one stand in the same process so a billet can go through several stands of different rolls at a time. This avoids the changing of stands and its consequent waste in time and motion. In general, it can be said that the combination of or the reorganization of several processes into a continuous process is the main source of productivity growth through the savings of time, motion and material inputs. The reorganization of production process is part of technological change. Thus, it can be concluded that technological change has been taking place in the rolling mill stage.

E. Conclusion

The previous discussion indicates that the growth of the Canadian iron and steel industry has been associated with technological change. By the end of 1970, there were more than 40 iron and steel firms across Canada. Out of this number, only 5 are integrated iron and steel producers.[1] Four of these integrated firms, namely, Sydney Steel Corporation at Sydney, Nova Scotia, Dominion Foundries and Steel Limited at Hamilton, Ontario, The Steel Company of Canada Limited at Hamilton, Ontario, and the Algoma Steel Corporation Limited at Sault Ste Marie, Ontario, are the leading steel-producing firms in Canada. All these four major firms were established before the First World War while the Sydney Steel Corporation is the former DOSCO, which was taken over by the Nova Scotia government in 1968. Other non-integrated firms are either iron and raw steel producers or rolling mills.

A distinctive feature of the Canadian steel industry is its high Canadian ownership. In 1963, about 80 per cent of capital employed by the industry was owned by Canadians, and 86 per cent of capital employed was controlled in Canada.[2]

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[1]An integrated producer is a firm which has a coke oven to make coke from coal, a blast furnace to smelt iron ore, a steel furnace to make steel ingot and a primary mill or a continuous casting machine to cut and process ingots and castings into billets, blooms and slabs.

[2]In terms of value added, the pulp and paper industry was the first and automobile industry was the second. The largest employer of labour was the pulp and paper industry. See V. B. Schneider, *op. cit.*, p. 1.

This indicates that the steel industry is probably the industry with the highest Canadian ownership and control in Canada.

As steel is an important industrial material, the importance of the steel industry in an advanced economy is conceivable. In terms of value added, the Canadian steel industry was ranked as the third largest industry in 1967. At the same time, it was the second largest employer of labour.[1] On the product demand side, the construction industry has traditionally been the most important buyer of steel products. The automobile and aircraft industries have rapidly emerged as important buyers of steel products.[2] With the growth of the economy, steel production increased substantially. In 1968, the total raw steel production had reached 11 million net tons. Taking 1946 as the base year, steel production in 1968 had increased by 483.5 per cent while real GNP had increased only by 283.2 per cent.[3]

Since the rapid development of the steel industry has been associated with technological change, it will be useful for policy purpose to identify the determinants of this change. After this is done, the nature of production relationship under technological change will be studied. As a step towards this direction, a review of theoretical discussions and measurement methods is in order.

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[1] *Submission to the Standing Senate Committee on Banking, Trade and Commerce*, Appendix C, Table 24.

[2] Schneider, *op. cit.*, p. 1.

[3] *Submission* ..., *op. cit.*, Tables 4 and 5.

Chapter III

ECONOMICS OF TECHNOLOGICAL DIFFUSION AND CHANGE: THEORIES, MEASUREMENTS AND EMPIRICAL STUDIES

We have seen in the previous chapter that technological change has taken place in the Canadian iron and steel industry since 1946. The change has resulted in a substantial increase in productivity, making Canada a competitive producer of steel in the world. To be sure, Canada is not the most efficient steel producer in price terms. Nonetheless, the fact that the Canadian steel industry has grown from a small, import-dependent industry to an efficient producer supplying most of the expanding domestic needs, is not insignificant. Moreover, the rapid catching-up of the American productivity by Canadians is striking. For a proper evaluation of the nature and process of technological change, a brief survey of the theories is needed.

A. Theories of Diffusion of New Technologies

(a) Salter's Theory of Technological Diffusion

After a new production process or equipment has been proved to be technically successful, it usually takes some time for it to substitute the old process or equipment, even though the former is clearly more efficient than the latter. A firm using an existing technique of production will have to rely on some sort of principle which governs the abandonment of the existing technology, and the adoption of the new when the new technology comes into being. In Salter's view, the principle is simply that "capital equipment in existence earns rents in a manner analogous to land" and as long as a positive rent is earned, it will remain in operation although its operating cost is higher and productivity is lower than new equipment. For the existing equipment, its investment was made in the past and once it is made, "bygones are bygones".[1] It is equivalent to the case where no capital cost exists. Thus, the only two things which concern the producer are the price of product and the operating cost of the equipment. If a surplus exists, then the equipment will be kept in operation no matter if it is big or small.[2] Thus, machines with different ages, implying different technological embodiments, earn different rents in co-existence.

By assuming competition and indivisible[3] complex of plants, Salter describes the diffusion process of new techniques as follows. Every piece of capital equipment is embodied with the latest technology when it is made. Thus, a plant built in

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[1]W.E.G. Salter, *op. cit.*, p. 62. This is true only if there exists no used equipment market.

[2]Qualification is needed for this statement. Assume that a new machine can produce 1000 units of products in a year while the old produces 500 units and the price of product is $1. The following examples show that it might be better off to install the new machine and discard the old.

	New Machine	Old Machine
machine cost	$500	-
operating cost	$125	$225
interest cost	$ 50	-
Total cost	$675	$225
Profit	$325	$275
Total revenue	$1000	$500

However, the assumed differences in the operating costs and productivities of the two machines do not seem to be realistic.

[3]"Indivisible" is in the sense that production equipment in a plant is made with the same technology. That is, no machine embodied with more advanced technology can work together with the old machines.

period $n - t$ is embodied with the best practice technique of $n - t$. With the continuous flow of technological progress, the best practice technique of $n - t$ is soon outmoded and degraded into the average practice technique of subsequent periods and eventually into the marginal practice technique. The technological structure of an industry at any point of time is comprised of various types of techniques, efficient as well as inefficient, since the best average and marginal practice techniques are all being used.

The plant which is using the marginal practice technique will be kept in production as long as it is still producing some surplus over operating costs. It will be abandoned only when the plant is no longer capable of producing any surplus over operating costs.[1] It occurs in this way: the plant with the best practice technique apparently reaps super-normal profits and so it will continue to expand its output until the super-normal profits are eliminated. Meanwhile, further technical progress takes place and the subsequent expansion in production forces prices to fall. The fall in price eliminates the little surplus which the marginal plant enjoys and forces it to be abandoned.

The important assumption that competition exists provides external compulsion to force competitors to adopt a rational replacement policy. For a monopoly, this external compulsion does not exist. In imperfect competition, a firm

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[1] See the qualification noted in the previous page.

with obsolete equipment can more easily preserve some surplus than under competition, by using product differentiation and advertising. Thus, the rate of abandoning obsolete equipment and carrying out replacement investment will be slower in the case of imperfect competition than in the case of perfect competition.

(b) Mansfield's Study of Intrafirm, Interfirm and Interindustry Diffusion

After an innovation has been adopted by the first firm, some other firms will follow suit sooner or later. The rate of imitation, in Mansfield's view, is a function of the profitability of the innovation in question and the size of investment required to carry out the innovation.[1] According to his theory, the rate of imitation of a certain innovation should be higher if the profitability is greater and the amount required to invest is smaller than another innovation.

As far as interfirm diffusion is concerned, Mansfield argues that both the size of firms and the profitability of the innovation in question are related to the delay in introducing the innovations by individual firms.[2] His contention is that the greater the profitability and the larger the firm, the shorter will be the period of waiting. In other words, the speed of response of individual firms to innovation will be greater if the size of firm is larger and the profitability is greater.

[1]E. Mansfield, *op. cit.*, p. 140.

[2]*Ibid.*, p. 157.

The intrafirm diffusion study asks the question: how fast will a firm substitute the new process or equipment for the outdated process or equipment within itself after it has adopted an innovation for the first time. Why is the diffusion of an innovation faster in some firms than in others? Mansfield uses the diffusion of the diesel locomotive as an example and explains the interfirm variations in the intrafirm diffusion rate among railroad companies, by the rate of return of using a diesel locomotive, lag between the time the first firm began using diesel locomotive and the time other firms began using it, and the firm's liquidity at the time when it began to dieselize.

B. Theories of Technological Change

(a) Neutral and Non-Neutral Technical Progress

Technological change refers to the advance of technology, including improvements in techniques of production, organization and management. It results in a shifting of the production function. According to Brown, the characteristics of a production function, namely, the efficiency of the technology, the degree of technologically determined economies of scale, the degree of capital intensity of the technology, and the ease with which capital is substituted for labour, are lumped together to form an "abstract technology". Any change of these four characteristics constitutes a technological change.[1]

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[1]See M. Brown, *On the Theory and Measurement of Technological Change* (Cambridge, Mass.: Cambridge University Press, 1966), pp. 12-21.

Technological change can be neutral or biased. Hicksian neutrality refers to the case where, after the change in technology, the ratio of the marginal product of labour to the marginal product of capital, as well as capital-labour ratio, remain unchanged.[1] In other words, technological progress changes both marginal products of capital and labour through changes in the quantities of labour and capital employed but the changes in marginal products of the two factors are proportional such that the ratio of the marginal products is the same as before. If the change in the marginal product of labour is proportionally greater than that in the marginal product of capital, at given capital-labour ratio, then technological change is not neutral but labour-using or capital-saving. In the opposite case, if the change in marginal product of capital is greater than that in the marginal product of labour, then it is capital-using or labour-saving.

Harrod's neutral technical progress is said to have occurred "if the level of $\frac{K}{L}$ which causes ρ to remain constant after a technical improvement is such as to cause the capital-output ratio to remain constant" where ρ stands for the interest rate.[2] The quote can be interpreted in this way. If the interest rate is or has to be constant, then a technical

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[1] J. R. Hicks, *The Theory of Wages* (London: MacMillan & Co. Ltd., 1963), p. 122.

[2] F. H. Hahn and R.C.O. Matthews, "The Theory of Economic Growth: A Survey", *Survey of Economic Theory* (Britain: Royal Economic Society and American Economic Association, 1965), p. 49.

progress will increase the use of capital and hence capital per unit-labour, since, otherwise, the marginal product of capital will rise and hence the interest rate cannot remain constant. Suppose the use of capital is increased by a proportion g with no change in the labour employed, then the capital per unit-labour, $\frac{K}{L}$, is also increased by g. The result is that the output is also increased by the proportion g so that the capital-output ratio after technical progress is unchanged. This is neutral technical progress in Harrod's sense. If the capital-output ratio is changed, then it is either capital-using or capital-saving. Hence, the effect of technical progress which calls forth the increased use of capital by g and the resultant increase in output by g is equivalent to an increase of labour by g with the old technique of production. Thus, Harrod's neutral technical progress is equivalent to "an all-round increase in the efficiency of labour".[1]

Solow's capital-augmenting neutral technical progress is exactly the opposite of the Harrod neutral case. If the wage rate remains unchanged after technical progress, then the use of labour would be increased by a proportion m. With constant capital, this means that $\frac{L}{K}$ is increased by m. If the resultant output is also increased by m so that the labour-output ratio is unchanged, then it is Solow's neutral technical progress.

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[1]J. Robinson, "The Classification of Inventions", *Review of Economic Studies*, 1938, p. 140.

It is labour-using, if the resultant labour-output ratio is increased, and labour-saving if it is decreased. In the neutral case, the effect of the technical progress is equivalent to an increase of capital employed. Hence, it is called "capital-augmenting", in contrast with Harrod's "labour-augmenting". In sum, neutrality means unchanged factor shares after technical change. But which two points on the new and old production function should be taken to compare the factor shares? According to Hicks, they should be the points with the same capital-labour ratio. For Harrodian neutrality, they should be the points with the same capital-output ratio. On the other hand, in the case of Solow neutral, the points should be those with the same labour-output ratio.

By using Hicks' definition of neutral technical progress, Brown has differentiated neutral and non-neutral technological change by observing the change or changes in the four characteristics. A technological change might increase the efficiency of the old technology by using the same amount of inputs and producing a greater amount of output than before. It might also change the returns to scale. For instance, a new technology might provide constant or increasing returns to scale compared with decreasing returns provided by the old technology. Note that this is different from changes in economies of scale derived from the expansion of scale of production since in the latter case, there is no technological change involved. Changes in any of these characteristics, namely, efficiency and technologically determined returns to scale, caused by technological progress, are labelled as neutral technical change since their changes do not involve any change in the ratio of labour and capital employed. The capital intensity of a technology, which is the third characteristic, is represented by capital-labour ratio, $\frac{K}{L}$. A firm could have a higher $\frac{K}{L}$ at one time than another, as a result of a cheapening of capital or using a new technology which requires more capital relative to labour than before. The change in capital intensity here refers only to the latter. Thus, "Degrees of capital intensity are reflected in the size of the labour-capital ratios for given relative factor prices."[1] The last characteristic is the ease of substitution of labour for capital, that is, the elasticity of substitution. It expresses the degree of change in capital-labour ratio which is caused by a change in the ratio between the marginal products of labour and that of capital. According to the Hicksian definition, the changes in the capital intensity and the elasticity of substitution are non-neutral technical changes, since in both cases the ratio between the marginal product of capital and that of labour must change for a given $\frac{K}{L}$. If technical progress raises the marginal product of labour for a given $\frac{K}{L}$ such that the marginal rate of substitution of labour for capital, $\frac{MP_K}{MP_L}$, is lowered, then it is a labour-using (capital-saving) technological change. Similarly, it is a capital-using (labour-saving) technological change if the marginal product of capital for a given $\frac{K}{L}$ and hence the $\frac{MP_K}{MP_L}$

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[1] M. Brown, *op. cit.*, p. 17.

rises as a result of technical progress. By the same token, a rise in the capital intensity of a technology raises the marginal product of capital relative to that of labour, and so it is a capital-using technological change.[1] A rise in the elasticity of substitution between labour and capital would be a capital-using technical change if capital grows faster than labour, and a labour-using change in the opposite case. The explanation lies in the fact that if capital grows faster than labour, then capital would be relatively cheap. A technological change which eases the substitution between capital and labour must thus be capital-using as more and more capital is used to substitute for labour.

Thus, we have seen that a technological change can be decomposed into changes in the four characteristics and the total effect of a technological change is the sum of the effects of these four changes. Though there could be some negative effect -- e.g., a rise in capital intensity might reduce the rate of output if capital grows slower than labour, since capital becomes expensive relative to labour while the new technology requires more capital in the production process than before -- the final effect of a technological change in the long run must increase the rate of output.

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[1]It is important to note that as capital supply increases, the marginal product and hence the price of capital falls. However, the marginal product of capital "for a given $\frac{K}{L}$" rises.

(b) Induced Innovation

After we have some basic concepts of technological change, we might ask where do these changes come from. In his celebrated *The Theory of Wages*, Hicks divides inventions into two groups: autonomous and induced. Induced inventions are "those inventions which are the result of a change in the relative prices of the factors" and the rest are called autonomous inventions.[1] The direction of invention, whether it is capital-saving or labour-saving, depends on which factor is more expensive than the other. Hicks observes that labour has become scarce relative to the rapid growth of capital and this has stimulated labour-saving invention. Fellner suggests that it is the "anticipated" rise in real wage rates relative to interest rates rather than the present wage-interest relationship which makes the firm seek labour-saving devices in preference to neutral technical innovation, since labour-saving technology will be superior to a new technique which has the same factor proportion in the future.[2] Salter however argues that what entrepreneurs are interested in is not the reduction of capital cost or labour cost but the total unit cost of products. Thus, there is no reason to say that

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[1]See J. R. Hicks, *The Theory of Wages*, *op. cit.*, p. 125. He also states that "A change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind -- directed to economising the use of a factor which has become relatively expensive", p. 124.

[2]W. Fellner, "Two Propositions in the Theory of Induced Innovations", *Economic Journal*, June 1961.

inventions are induced by the rising cost of labour and that, therefore, they are labour-saving.

> "The entrepreneur is interested in reducing costs in total, not particular costs such as labour costs or capital costs. When labour costs rise any advance that reduces total cost is welcome, and whether this is achieved by saving labour or capital is irrelevant."[1]

But Kennedy, while he does not endorse Hicks' theory, argues that Salter "was misled by his own algebraic treatment".[2] According to Kennedy, what is important in this connection is the proportionate reduction in unit costs, r, which is a function of the proportionate reduction in labour requirement, p, and the proportionate reduction in capital requirement, q. That is:

$$r = \lambda p + \gamma q \qquad \text{(Equation 3.1)}$$

where λ and γ are the distributive shares of labour and capital. There is a tradeoff between p and q, for example, if a given innovation is more labour-saving, then it is at the same time less capital-saving. Written in the functional form, it is:

$$p = f(q) \qquad \text{(Equation 3.2)}$$

which is called the innovation possibility function. The entrepreneur, according to Kennedy, is interested in maximizing the proportionate reduction in unit cost, r, in Equation 3.1, subject to the constraint in Equation 3.2. It is clear from

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[1]W.E.G. Salter, *op. cit.*, p. 43.

[2]Charles Kennedy, "Induced Bias in Innovation and the Theory of Distribution", *Economic Journal*, September 1964, p. 543.

Equation 3.1 that in order to maximize r, a high p should be adopted if λ is greater than γ, and a high q if γ is greater than λ. Since λ and γ are the shares of labour and capital costs, respectively, and a high p means labour-saving (similarly, a high q means capital-saving), this leads to Kennedy's conclusion that "the greater the share of labour costs in total costs, the more labour-saving will be the innovation chosen, or searched for, by the entrepreneur".[1] In other words, the direction of innovation is not dictated by the rising price of one of the factors but by the magnitude of the distributive shares.

(c) Endogenous Theories of Innovation

Exogenous theories of innovation assume that inventions are exogenously given while endogenous theories operate under the assumption that they are endogenously determined within the economic system. Kaldor regards labour-productivity as a function of gross investment,[2] and Arrow argues that it is a function of "accumulated" gross investment.[3] More recently, a theory which emphasizes education and research and development activities as the determinants of technological change has been developed and tested against empirical evidence. The exogenous theory, which in Schmookler's words "was exogenous in the sense that it was

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[1]*Ibid.*, p. 544.

[2]N. Kaldor, and J. Mirrlees, "A New Model of Economic Growth", *Review of Economic Studies*, 1962, pp. 174-92.

[3]K. J. Arrow, "The Economic Implications of Learning by Doing", *Review of Economic Studies*, June 1962, pp. 155-73.

not controlled by economic variables" is challenged by the theory that "invention is largely an economic activity which, like other economic activities, is pursued for gain".[1]

> "But the belief that invention, or the production of technology generally, is in most instances essentially a non-economic activity is false. Invention was once, when strictly a part-time, *ad hoc* undertaking, simply a *nonroutine* economic activity, though an economic activity nonetheless. Increasingly, it has become a full-time, continuing activity of business enterprise, with a routine of its own. ... But the production of inventions and much other technological knowledge, whether routinized or not, when considered from the standpoint of both the objectives and the motives which impel men to produce them, is in most instances as much an economic activity as is the production of bread."[2]

In their book *Technology, Economic Growth and Public Policy*, Nelson, Peck and Kalachek also have this to say:

> "The output of technological advances is sensitive to the same economic factors that influence the output of more pedestrian products and services. It is true that many of the advances that have been achieved stemmed, at least in part, from the work of a single man or a small group of men with zeal for an idea and only limited concern for profit, social value, or cost. Even for these, the need for outside financing brings the effort increasingly within the orbit of economic calculation as work proceeds and costs rise."[3]

The authors of the above book believe that factors from the demand side such as the profit prospect of an innovation and the relative scarcity of inputs and from the supply side

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[1] J. Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University Press, 1966), pp. 206-207.

[2] *Ibid.*, p. 208.

[3] R. R. Nelson, M. J. Peck, and E. D. Kalachek, *Technology, Economic Growth and Public Policy* (Washington, D.C.: The Brookings Institution, 1967), p. 28.

factors such as the capacity of the industry, the advance of science and education and the development of a scientific base are all determinants of technological change. This seems to be too broad. Nordhaus has explicitly narrowed the factors down to industrial research and development:

> "At any point of time the firm acts within the boundaries of its own technological and scientific knowledge. The boundaries may -- and in fact actually do -- differ among competing firms. Boundaries change over time because the firm devotes a certain amount of resources to expand its knowledge."[1]

Mansfield, in his recent works, has emphasized the role of research and development effort in production.[2] Besides, education is another important factor which contributes to the rise of productivity. Griliches has found that this conclusion holds for both agricultural and manufacturing production.[3] Other factors such as investment and market structure are also considered as related to technological change.

In fact, the two theories of innovation, exogenous as well as endogenous, are complementary rather than competitive. The exogenous theory takes innovation as given but concentrates in discussing the direction of innovation, while the endogenous

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[1]W. D. Nordhaus, *op. cit.*, p. 8.

[2]E. Mansfield, *The Economics of Technological Change*, and *Industrial Research and Technological Innovation* (New York: W. W. Norton & Co. Inc., 1968).

[3]Z. Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function", *American Economic Review*, December 1964.

theory goes further to investigate the determinants of innovation. The scarcity and rising price of an input as a stimulus to innovation and an explanation of its direction have been incorporated into the endogenous theory.[1]

(d) The Case of the Canadian Steel Industry

As to the nature of technological innovations in the steel industry, are they exogenous or endogenous? As far as the Canadian steel industry is concerned, the innovation can be regarded as exogenously given since both basic oxygen furnace and continuous casting machine were developed in other countries. But the introduction of these innovations into the Canadian scene involves economic consideration. Thus, the problem which we face is not to explain the determinants of BOF innovation in Austria but the decisive elements in adopting the innovation in the

[1]See Nelson, Peck and Kalachek, "An increase in the price of a factor increases the profitability of technological advances which reduce the requirements for that factor relative to others.", *op. cit.*, p. 31.

Canadian industry. In other words, we are concerned with the factors which determine the diffusion of new technologies in Canada. After a detailed enquiry into the determinants of diffusion in the next chapter, the magnitude of technological change in the steel industry will be appropriately quantified. Towards this end, a review of methods of measuring technological change is undertaken next.

C. Measurement of Productivity Growth

(a) Productivity Indexes

(1) Partial factor productivity index

Productivity index refers to an index showing changes in output-input ratio through time relative to a certain base period. The most frequently used productivity index is the partial factor productivity index, especially the labour-productivity index. The inadequacies of this index as a measure of technological change is intuitively clear: it does not take the changes in other inputs such as capital into account -- a change in labour-productivity could be due to a change in capital input. Thus, it cannot adequately represent technological improvement.

(2) Total factor productivity index

To obtain a more meaningful measure of efficiency increase, the changes of all inputs have to be taken into account. Kendrick has developed a total productivity index which is the quotient of output and the sum of weighted inputs. It can be written as:

$$\text{Total productivity index} = \frac{X}{aL + bK}$$

where X is the output weighted by product prices at factor cost and L and K are inputs weighted by their respective factor prices a and b.[1]

(3) Abramovitz residual

If we can label the growth of the contribution of all factors other than those of capital and labour as technological change, then under the assumption that constant returns to scale prevail, the following formula can be used:

$$\frac{dX}{X} - a' \frac{dL}{L} - b' \frac{dK}{K} = \text{residual}$$

where a' and b' are the respective shares of labour and capital in the base period. Abramovitz used the above formula to indicate the productivity increase in the United States since 1870.[2]

(4) Solow's measure of technological change

Starting with a production function which assumes constant returns and neutral technical change, $Q = A(t)f(K,L)$, Solow has obtained the following measure of technological change:

$$\frac{\dot{A}}{A} = \frac{\dot{q}}{q} - W_k \frac{\dot{k}}{k}, \quad \text{where } q = \frac{Q}{L}, \quad k = \frac{K}{L}.$$

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[1]"By this method the values of output and of input are equal in the base period; the unit values of the outputs are proportional to the values of the factor services required for their production; and the unit values of the inputs are proportional to the shares of the value of outputs which they obtain for their services." See J. W. Kendrick, *Productivity Trends in the United States* (Princeton: Princeton University Press, 1961), p. 9.

[2]M. Abramovitz, "Resources and Output Trends in the United States since 1870", *American Economic Review, Papers & Proceedings*, vol. 46, 1956.

In the above formula, $\frac{\dot{A}}{A}$ represents the rate of technical change, and W_k is the share of capital in total output. The first term on the right hand side stands for the rate of increase of output-labour ratio, and the second term, the weighted rate of increase of capital-labour ratio between two consecutive periods. The basic idea is that two points on the production surface might not lie on the same production function curve. A movement along the curve and a shifting of the curve are combined. Thus, the effect of the movement along the curve has to be eliminated in order to see the effect of the shifting of the curve, which is $\frac{\dot{A}}{A}$, the rates of technical change.[1] Further discussion on Solow's model is left to the latter part of this study.

(5) Salter's measure of technological change

Both Abramovitz and Solow measures are essentially measures of the residual. Salter has attempted to decompose the residual in the following fashion. He defined and measured technical change by the relative change in total unit costs, that is, by asking "how much would unit costs of production fall if nothing changed except technical knowledge".[2] This is neutral technical change and is expressed as:

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[1]See R. M. Solow, "Technical Change and the Aggregate Production Function", *Review of Economic and Statistics*, vol. 39, August 1957, pp. 312-20.

[2]W.E.G. Salter, *op. cit.*, p. 31.

$$T_r = \frac{\frac{dL}{dt}w + \frac{dK}{dt}i}{Lw + Ki}$$

where w and i are the respective prices of labour and capital, and t denotes time variable. Non-neutral technical progress is measured by "the relative change in capital per labour unit when relative factor prices are constant", denoted by D_r.

$$D_r = \frac{d\left(\frac{K}{L}\right)}{dt} \circ \left(\frac{L}{K}\right) .$$

It is labour-saving if $D_r > 0$ and capital-saving if $D_r < 0$.

(b) Production Function Estimation Approach

Another approach to measure technological change is the production function approach. First, let us look at the Cobb-Douglas production function.

(1) Cobb-Douglas function

The Cobb-Douglas production function is written as:[1]

$$Q = AL^{\alpha}K^{\beta}$$

where Q is output, A is the efficiency parameter, α and β are the production elasticities of labour and capital services. What the function means is that if labour service and capital service were both increased by 1 per cent, then total output would increase by $(\alpha + \beta)$ per cent. Thus, if $\alpha + \beta = 1$, then

[1]The original Cobb-Douglas function, developed in 1927, was written as $X = AL^{\alpha}K^{1-\alpha}$. See C. W. Cobb and P. H. Douglas, "A Theory of Production", *American Economic Review*, Supplement (March 1928), pp. 139-65.

a 1 per cent increase in both *L* and *K* would cause a 1 per cent increase in *Q*, which is the case of constant returns to scale. There are increasing returns if $\alpha + \beta > 1$ and decreasing returns if $\alpha + \beta < 1$.

A feature of the Cobb-Douglas function is that the elasticity of substitution between capital and labour is always one.[1] Thus, the function ensures that "a proportionate change in relative factor prices produces a compensating proportionate change in relative factor inputs and relative shares remain constant",[2] assuming no technological change has taken place.

Technological change can partly be represented by an increase in the value of the efficiency parameter, *A*. Since the increase in *A* does not affect the marginal products of inputs and hence the marginal rate of substitution, the increase in *A* is an element of neutral technical progress. An increase in the sum of the production elasticities, $\alpha + \beta$, represents an increase in the returns to scale. Economies of scale could be obtained from two sources: the expansion of scale of production and technological change. For the latter, if changes in α and β are proportional such that the ratio $\frac{\beta}{\alpha}$ remains unchanged, then the increase in $(\alpha + \beta)$ represents Hicks' neutral technical change. This is so because if α and β change proportionally, the ratio of the marginal products of labour and capital does

[1]The proof that $\sigma = 1$ can be found in M. Brown, *On the Theory and Measurement of Technological Change*, *op. cit.*, p. 35.

[2]*Ibid.*, p. 36.

not change for each combination of K and L.[1] If, however, the ratio $\frac{\beta}{\alpha}$ changes, then it is biased technical change. The change is said to be capital-using if β increases relative to α and labour-using if α increases relative to β. This is easy to conceive since the ratio $\frac{\beta}{\alpha}$ represents the ratio between capital share and labour share in competitive equilibrium.[2] For each given factor-price ratio, if the capital share increases relative to the labour share, then the technical change is capital-using and vice versa. In summary, a change in A or the sum α and β are neutral technical change. A change in the ratio $\frac{\alpha}{\beta}$ is biased technical progress.

(2) The Constant Elasticity of Substitution (CES) production function

We saw that in the Cobb-Douglas production function, the elasticity of substitution is always one. However, it is only one of the special cases of the CES production function. The other special case is Leontief's fixed input coefficient production function of which elasticity of substitution is zero. In a path-breaking article, Arrow, Chenery, Minhas and Solow found that "the elasticity of substitution between capital and

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[1]Since the marginal product of labour is $\frac{\partial X}{\partial L} = \alpha\frac{X}{L}$ and that of capital is $\frac{\partial X}{\partial K} = \beta\frac{X}{K}$, the ratio of their marginal products, $\frac{\partial X}{\partial K}\Big/\frac{\partial X}{\partial L} = \frac{\beta}{\alpha} \circ \frac{L}{K}$ does not change if $\frac{\beta}{\alpha}$ remains unchanged.

[2]Since $\frac{\partial X}{\partial K}\Big/\frac{\partial X}{\partial L} = \frac{i}{w}$, $\therefore \frac{i}{w} = \frac{\beta}{\alpha} \cdot \frac{L}{K}$ $\therefore \frac{\beta}{\alpha} = \frac{iK}{wL}$ = capital share/ labour share.

labour in manufacturing may typically be less than unity".[1] The general form of a new function with constant (but not necessarily unitary) elasticity of substitution is developed as:[2]

$$Q = \gamma[\delta K^{-\rho}+(1-\delta)L^{-\rho}]^{-\frac{\nu}{\rho}} \quad \text{where} \quad \begin{array}{l} 0\leq\delta\leq 1 \\ \infty\geq\rho\geq -1 \end{array}$$

where Q is the value added, γ is the efficiency parameter, δ expresses capital intensity which is called the distribution parameter, ρ is the substitution parameter, and ν denotes the degree of returns to scale. ρ is the substitution parameter since its value is determined by the elasticity of substitution between capital and labour, written as:

$$\sigma = \frac{1}{1+\rho} \quad \text{or} \quad \rho = \frac{1-\sigma}{\sigma} .$$

Like the efficiency parameter A in the Cobb-Douglas production function, an increase in γ in the CES function represents a neutral technical change for "A uniform technical change is a shift in the production function leaving invariant the marginal rate of substitution at each $\frac{K}{L}$ ratio".[3] Another source of neutral technical change is a change in the value of the technologically determined return to scale parameter ν since a change in ν does not affect the marginal rate of substitution.

[1] K. J. Arrow, H. B. Chenery, B. S. Minhas, and R. M. Solow, "Capital-Labour Substitution and Economic Efficiency", *Review of Economics and Statistics*, August 1961, p. 246.

[2] M. Brown claims that he and J. S. de Cani developed the CES function independently of Arrow-Chenery-Minhas-Solow in an article appearing in *International Economic Review*, vol. 4, 1963.

[3] Arrow-Chenery-Minhas-Solow, *op. cit.*, p. 233.

Non-neutral technical change in the CES function is caused either by a change in the capital intensity parameter δ or the substitution parameter ρ. This is so because a change in either δ or ρ will change the marginal rate of substitution.[1]

$$MRS = \frac{\partial Q/\partial K}{\partial Q/\partial L} = \frac{\delta}{1-\delta}\left(\frac{L}{K}\right)^{(1+\rho)} .$$

If technical change causes the capital intensity parameter δ to increase, then it is capital-using (labour-saving) technological change, since if the value of *MRS* increases when δ increases, it indicates an increase in the marginal product of capital relative to that of labour at given capital-labour ratio. Similarly, a technical change which causes a decrease in δ is labour-using.

A change in ρ means a change in the elasticity of substitution between capital and labour for $\sigma = \frac{1}{1+\rho}$. From the above expression, we see that a change in the value of ρ changes the ratio between the marginal product of capital and that of labour, meaning that the technical change is non-neutral. Will an increase in the elasticity of substitution be capital-using or labour-using? The bias of technical change resulting from an increase in the elasticity of substitution depends upon the

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[1]The marginal product of capital

$$\frac{\partial Q}{\partial K} = -\frac{v}{\rho} .\gamma[\delta K^{-\rho}+(1-\delta)L^{-\rho}]^{-\frac{v}{\rho}-1}\ \delta(-\rho)K^{-\rho-1}$$

similarly $\frac{\partial Q}{\partial L} = -\frac{v}{\rho} .\gamma[\delta K^{-\rho}+(1-\delta)L^{-\rho}]^{-\frac{v}{\rho}-1}\ (1-\delta)(-\rho)L^{-\rho-1}$.

Thus, $MRS = \frac{\partial Q/\partial K}{\partial Q/\partial L} = \frac{\delta}{1-\delta}\left(\frac{K}{L}\right)^{-1(1+\rho)} = \frac{\delta}{1-\delta}\left(\frac{K}{L}\right)^{(1+\rho)}$.

relative growth rates of capital and labour. The elasticity of substitution measures the ease of substitution between capital and labour and so its increase means that capital can now be more easily substituted for labour and vice versa. If capital were growing faster than labour, then more capital would be used because capital is now becoming relatively cheaper and also it can be used to substitute for labour to a greater extent than before new technology is introduced. Thus, the technical change is capital using. Similarly, if labour grows faster than capital then it is labour-using.[1]

(3) Vintage production function

In the above models, it has been assumed that technical change raises productivity of capital equipment generally, new as well as old. In familiar jargon, this is to treat technical knowledge as falling like manna from heaven. However, technical knowledge, and hence productivity, has been increasingly recognized as a function of gross investment. Salter regards gross investment as the vehicle of technical change.[2] Kaldor has said that "most, though not all, technical innovations which are capable of raising the productivity of labour require the use of more capital per man".[3] If technological improvements can only be effected by the installing of new machines, then productivity increase

[1]M. Brown, *op. cit.*, p. 56.

[2]Salter, *op. cit.*, p. 63.

[3]N. Kaldor, "A Model of Economic Growth", *Economic Journal*, December 1957, p. 595.

resulting from such improvement must have come from the newly installed machines only. This is not to deny the existence of "disembodied" technical change but to deny the assumption that all technical changes are disembodied. Solow has this to say:

> "Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models, with a consequent shift in the distribution of equipment by date of birth."[1]

Thus, Solow first constructs a new function with a Cobb-Douglas form and later another function in CES form which depict the embodied technical change.[2] The first feature of these two models is the substitution of $J(t)$, the "productivity-corrected stock of capital at time t", for the conventional capital stock $K(t)$. $J(t)$ is the sum of equivalent capital stocks of all vintages. The productivity of a machine of vintage t is $(1+\mu)$ times that of a same machine of vintage $t-1$ if the rate of technical change is μ between the two periods. Thus, a machine of vintage t is equivalent to $(1+\mu)$ machines of vintage $t-1$, and so technical progress is "capital-augmenting" in the vintage sense.[3]

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[1]R. M. Solow, "Investment and Technical Progress", *Mathematical Methods in the Social Sciences* (Stanford University, 1960), p. 93.

[2]For the models and their derivations, see Solow, *ibid.*, pp. 91-93; and "Capital, Labour, and Income in Manufacturing", in *The Behaviour of Income Shares* (Princeton: Princeton University Press, National Bureau of Economic Research, 1964), pp. 106-109.

[3]Hahn and Matthews, *op. cit.*, p. 65.

This leads to the second feature that the bias of the embodied technological change depends upon the magnitude of the elasticity of substitution. If the elasticity of substitution is less than unity, meaning that capital and labour are not easily substitutable, an embodied technical change which raises the productivity of capital by μ will increase the use of labour but not that of capital proportionately. This is because the embodied change of raising productivity by μ is equivalent to an actual increase of capital and since capital is not so easy to substitute for labour, a greater proportion of additional labour than capital has to be employed. (Though there is no fixed proportion between capital and labour, the range of substitution is quite narrow.) Thus, the embodied technical change is capital-saving. If the elasticity is greater than unity, capital can be used to substitute for labour easily. Thus, the embodied change which raises capital productivity by μ requires a smaller increase of labour in proportion than that of capital. Hence, the embodied change is labour-saving. Following the same logic, it is neutral if the elasticity of substitution is unity.

(4) Recent developments in production function: VES and GPF

One of the recent developments in production function approach is the formulation of the variable elasticity of substitution function. The basic difference between the CES and the newly developed VES lies in an assumption concerning the relationship between value added per unit of labour, $\frac{Q}{L}$, and the wage rates, w. The original ACMS article which develops the CES function states that there exists "a relationship between $\frac{Q}{L}$ and w, independent of the stock of capital".[1] However, Lu and Fletcher argue that "when the capital/labour ratio varies, due to changes in the factor price ratio, it is possible that the elasticity of substitution will vary as the capital/labour ratio varies".[2] Thus, a new production function is formulated by incorporating the capital-labour ratio into the ACMS' labour productivity and wage relationship. This new function is known as the VES function. Another recent development is the relaxation of the assumption of constant returns to scale to allow the returns to scale to vary with the output level.[3] This new function may have either a constant elasticity or variable elasticity of substitution. Thus, Zellner and Revankar call it the generalized production function (GPF).[4]

This completes our survey of developments in the formulation of production functions. We have seen that the Cobb-Douglas function with elasticity of substitution equal to unity is a special case of the CES function and that the

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[1]Arrow-Chenery-Minhas-Solow, *op. cit.*, p. 231.

[2]Yao-chi Lu and L. B. Fletcher, "A Generalization of the CES Production Function", *Review of Economics and Statistics*, November 1968, p. 449.

[3]See David Soskice, "A Modification of the CES Production Function to Allow for Changing Returns to Scale over the Function", *Review of Economics and Statistics*, 1969.

[4]A. Zellner and N. S. Revankar, "Generalized Production Function", *Review of Economic Studies*, April 1969.

CES function itself is a limiting case of the VES function. Further, all these functions are special cases of the still more general GPF with returns to scale varying with the real output level.

D. Empirical Studies of Productivity Increase and Technological Change

Empirical studies of technological change have been conducted both at the aggregate economy level, at the sector level, such as the manufacturing sector, and at the industry level. The earliest approach used in analysing productivity growth is the residual approach, which we shall now briefly describe.

(a) The Residual Approach

If the relationship between input and output is known or assumed, the percentage of output growth attributable to input growth can be quantified and hence, given the returns to scale, the percentage of output growth attributable to the residual factor can also be calculated. M. Abramovitz's *Resource and Output Trends in the U.S. Since 1870*, is the pioneer study utilizing this approach. The first question which he asks in the study is: "How large has been the net increase of aggregate output per capita, and to what extent has this increase been obtained as a result of greater labour or capital input on the one hand, and of a rise in productivity on the other?"[1]

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[1]Abramovitz, *op. cit.*, p. 5.

Solow states the same question as the problem of segregating out the effect of moving along the production function curve and the shifting of the curve in output per man-hour and capital per man-hour space.[1] The findings of his study which covers the period 1909-49, is that for the American nonfarm sector, 90 per cent of the rise in the real GNP per man-hour is attributable to unknown factors, which are labelled as technical change.[2] Applying Solow's analytical model to the manufacturing sector of the American economy between 1919 and 1955, Massell also finds that the contribution of technical change to the growth in output per man-hour is about 90 per cent.[3]

The productivity indicator employed so far has been labour productivity such as output per man-hour used in Solow's study. Kendrick, however, argues that "a given quantity of output, with given technical knowledge, can usually be produced with differing combinations of inputs" and so "changes in factor combinations mean that ratios of output to particular inputs, even to a major class of inputs such as labour, cannot be used as measures of changing productive efficiency".[4] Instead, he proposes to measure

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[1]R. M. Solow, "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, August 1957.

[2]See W. P. Hogan, "Technical Progress and Production Function", *Review of Economics and Statistics*, 1958, p. 408.

[3]B. F. Massell, "Capital Formation and Technological Change in U.S. Manufacturing", *Review of Economics and Statistics*, 1960, p. 186.

[4]J. W. Kendrick, *op. cit.*, p. 7.

productivity changes by total factor productivity, which he uses in his book in measuring productivity in the total economy and at the industry level.

(b) The Refined Residual Approach

"Technical change" is a catch-all term in the residual approach, which is also a measure of our ignorance. The general finding that about 90 per cent of output per man-hour growth in the total economy is attributable to technical change is believed to be overstated. The error comes, according to Griliches, Jorgenson and Christensen, from the incorrect measurement of inputs, namely capital and labour service. One aspect of the incorrect measurement, as Griliches points out, is the neglect of quality changes in inputs.[1] Griliches and Jorgenson even argue that "if quantities of output and input are measured accurately, growth in total output is largely explained by growth in total inputs".[2] The conclusion which they derive after using correct measurement of both output and inputs for the U.S. economy for the period 1945-65 is that the rate of growth of input explains 96.7 per cent of the rate of growth of output.[3] Although this conclusion is slightly changed in a

[1]See, for example, Z. Griliches, "The Sources of Measured Productivity Growth: United States Agriculture, 1940-60", *Journal of Political Economy*, 1963, pp. 331-46.

[2]D. W. Jorgenson and Z. Griliches, "The Explanation of Productivity Change", *Review of Economic Studies*, 1967, p. 249.

[3]*Ibid.*, p. 272.

later study which covers the period 1929-67, the departure from the crude residual approach is evident.[1]

Another development of the refined residual approach is the inclusion of factors other than capital and labour in evaluating total factor productivity. Factors such as economies of scale, education and research and development expenditures have been taken into account, as a step towards the breaking of the residual black box. Massell, using a modified-Solow model, divides technical change in the U.S. manufacturing sector for the period 1946-57, into inter-industry change and intra-industry change.[2] Intra-industry change refers to technical change within each industry and inter-industry change refers to change resulting from the shifting of resources, mostly capital, from low-productivity industry to high-productivity industry. The finding of Massell's study is that inter-industry change accounts for about one-third of the overall technical change.

The most elaborate effort in breaking the residual measure is represented by Denison's work.[3] He takes changes in employment and hours, education, changes in the age-sex composition, economies of scale, shift in industrial structure and the advance of knowledge into account. First he calculates

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[1]L. R. Christensen and D. W. Jorgenson, "U.S. Real Product and Real Factor Input, 1929-1967", *Review of Income and Wealth*, 1970, p. 47.

[2]B. F. Massell, "A Disaggregated View of Technical Change", *Journal of Political Economy*, 1961, pp. 547-59.

[3]See E. F. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us*, Committee for Economic Development, 1962.

the growth rate of real national income and then the growth rates of all factors. The difference between the growth rate of real national income and the growth rate of all factors is the growth rate of total factor productivity. For the period 1929-57, the finding is that "the increase in the quantity and quality of inputs was responsible for 68 per cent of total growth and the increase in productivity for 32 per cent".[1] Although Denison's analysis involves some weak assumptions,[2] his work does represent an effort towards the reduction of the unknown residual elements.[3] In addition to the study on economic growth of the United States, Denison has also done a similar cross-sectional study of productivity growth for several European countries.[4] Walters of the Economic Council of Canada has applied the Denison approach to the study of Canadian economic growth.[5]

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[1] *Ibid.*, p. 267.

[2] "Undoubtedly his conclusions are questionable, and include some quite unproven assumptions, which we can hardly accept as they stand." See E. Malinvaud's comment on Denison's paper on "Measuring the Contribution of Education and the Residual to Economic Growth", in *The Residual Factor and Economic Growth*, (Paris: Organisation for Economic Co-Operation and Development (OECD), 1964), p. 57.

[3] "Denison, in short, appears to have done what every economist concerned with the subject has hoped would be done, namely, broken down the residual into its component elements." See M. Abramovitz, "Economic Growth in the United States - A Review Article", *American Economic Review*, 1962, p. 767.

[4] E. Denison, *Why Growth Rates Differ* (Washington, D.C.: The Brookings Institution, 1967).

[5] D. Walters, *Canadian Income Levels and Growth: An International Perspective*, Economic Council of Canada Staff Study No. 23 (Ottawa: Queen's Printer).

(c) Production Function Estimation Approach

Although both the crude and refined residual approach assume either implicitly or explicitly a production function, the calculation of growth rate and rate of technical change is done by arithmetic manipulation. Studies which use a specific production function and regression technique in estimating technological change have been more prevalent in recent years. The following covers only a few examples in this field.

The function frequently used is of the Cobb-Douglas form. Brown and Popkin use a Cobb-Douglas function to isolate technological epochs and estimate neutral and non-neutral technical change and economies of scale for the U.S. nonfarm domestic sector for the period 1890-1958.[1] The findings are: (i) three technological epochs are uncovered; 1890-1918, 1918-1937, and 1938-1958; (ii) economies of scale existed in the first epoch; and (iii) the first epoch is characterized by non-neutral technical change while the other two are characterized by neutral technical change.[2] Other works of similar nature by Brown and others can also be found elsewhere.[3]

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[1]M. Brown and J. Popkin, "A Measure of Technological Change and Returns to Scale", *Review of Economics and Statistics*, 1962.

[2]*Ibid.*, p. 402.

[3]See, for example, M. Brown and J. S. de Cani, "Technological Change in the United States, 1950-1960", *Productivity Measurement Review*, May 1962, pp. 26-39. See also M. Brown, *On the Theory and Measurement of Technological Change* (Cambridge, Mass.: Harvard University Press, 1966).

The CES function has also been widely used in estimating productivity growth.[1] An example of the use of a CES function in evaluating technological progress is Ferguson's study on American manufacturing industries over the period 1949-61.[2] The distribution parameter, δ, in the CES production function, is calculated for each year for each industry and a sustained increase in its value is interpreted as an indication of capital-using technical change and a sustained decrease as an indication of capital-saving technical change. The results of Ferguson's study indicate that technological change has been either neutral or capital-using for 16 of the 19 two-digit U.S. manufacturing industries, and the remaining three industries have capital-saving technical change. However, these three industries are relatively large in size compared with the others and so the aggregate technological change may net out to be neutral.[3]

A further development of the production function estimation approach is the use of the embodied technological change model. As we recall, several early studies have attributed 90 per cent of productivity increase to technological change. This casts some doubt on the role of capital formation.

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[1] See M. Nerlove, "Recent Empirical Studies of the CES and Related Production Function", *The Theory and Empirical Analysis of Production*, National Bureau of Economic Research, 1967.

[2] C. E. Ferguson, "Time-Series Production Functions and Technological Progress in American Manufacturing Industry", *Journal of Political Economy*, 1965, pp. 135-47.

[3] *Ibid.*, p. 147.

The understatement of the importance of investment arises from the assumption of disembodied technical change which assumes that "The pace of investment has no influence on the rate at which technique improves."[1] Consequently, the embodied technical change model is developed first in the Cobb-Douglas form and later in the CES form.[2]

However, the results of several empirical studies applied to the American economy disclose that there is no strong evidence to support the embodied technical change hypothesis. Intriligator finds that "neither embodied technical progress nor disembodied technical progress can be considered alone".[3] Berglas has tested several hypothesis, including (1) technological change has to be embodied in capital goods in order to affect production, and (2) technological change need not be embodied in capital goods. Using the data of the United States business sector for the period 1929-60, he finds that "the model in which technology is not embodied in capital goods and in which technological change is approximated by a time trend" have the best performance.[4]

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[1]R. M. Solow, "Investment and Technical Progress", in *Mathematical Methods in the Social Sciences*, K. Arrow, S. Karlin and P. Suppes (eds.) (Stanford University Press, 1960), p. 90.

[2]See *ibid.*, pp. 89-104, and R. M. Solow, "Capital, Labour and Income in Manufacturing", in *The Behaviour of Income Shares* (Princeton: Princeton University Press, 1964).

[3]M. D. Intriligator, "Embodied Technical Change and Productivity in the United States, 1929-1958", *Review of Economics and Statistics*, 1965, p. 69.

[4]E. Berglas, "Investment and Technological Change", *Journal of Political Economy*, 1965, p. 180.

Another study of the vintage Cobb-Douglas model which covers the U.S. private domestic economy 1900-60, is one by Wickens, in which he also finds "no evidence to support the embodiment hypothesis".[1]

(d) Manufacturing Sector and Individual Industries

Most of the work we have reviewed so far focuses on the American economy as a whole. There are, however, studies done for the evaluation of the importance of technological change in the manufacturing sector and at individual industry level. Massell's work on United States manufacturing industries is one of them.[2] Moroney has done some work on United States manufacturing and one of them is to ascertain the behaviour of relative factor shares through an empirical study of the character of technological change.[3] Outside the United States, Lydall uses an equation similar to Solow's 1957 model, to estimate technical progress in the Australian manufacturing industries for the period 1949-50/1959-60.[4] There are also a number of studies done on technical progress in Canadian manufacturing industries which we shall discuss later.

[1]M. R. Wickens, "Estimation of the Vintage Cobb-Douglas Production Function for the United States, 1900-1960", *Review of Economics and Statistics*, 1970, p. 192.

[2]See B. Massell's articles in *Review of Economics and Statistics*, 1960, and *Journal of Political Economy*, 1961.

[3]J. R. Moroney, "Technological Progress, Factor Proportions, and the Relative Share of Capital in American Manufacturing, 1942-1957", *Western Economic Journal*, 1968.

[4]H. F. Lydall, "Technical Progress in Australian Manufacturing", *The Economic Journal*, 1968.

At the industry level, a number of investigations on the topic of productivity growth and technical change appeared in the sixties. The electric power industry of the United States has been given much attention, on which several studies were conducted. Komiya experimented with a substitution model, which was represented by a Cobb-Douglas production function, and a limitational model which assumes output as a log-linear function of inputs, to find the separate effects of economies of scale, factor substitution and technological progress in the United States steam power industry between 1938 and 1956.[1] His conclusion is that the scale effect is a far more important factor in productivity growth than the other two. In a study of productivity in the American electric power industry, 1929-55, Barzel finds that the output-per-unit-of-input technique as a measure of productivity change involves three sources of bias of which economies of scale is an important one.[2] By using a CES production function, Dhrymes and Kurz also find that economies of scale are predominant in the American electric power industry for the period 1937-59.[3]

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[1]R. Komiya, "Technological Progress and the Production Function in the U.S. Steam Power Industry", *Review of Economics and Statistics*, 1962, pp. 156-66.

[2]Y. Barzel, "Productivity in the Electric Power Industry, 1929-1955", *Review of Economics and Statistics*, 1963, pp. 395-408.

[3]P. J. Dhrymes and M. Kurz, "Technology and Scale in Electricity Generation", *Econometrica*, 1964, pp. 287-315. See also M. Nerlove, "Returns to Scale in Electricity Supply", Technical Report No. 96, Stanford University, May 1961.

Studies based on other industries are not many, however. Maddala has used a Cobb-Douglas function and estimated technological change by running single equation least squares and for the United States bituminous coal industry, 1919-54, and he concludes that labour productivity growth is "almost entirely attributable to the increase in the horsepower of equipment per worker".[1] Sahota also uses a Cobb-Douglas function to distinguish the effects of intrafirm technical change, interfirm productivity change resulting from resource shifting and economies of scale in the United States fertilizer mineral industries for the period 1936-60.[2] The intrafirm technical change is found to be explained by improvements in factor qualities. A different approach which is called the engineering production function approach has been used to ascertain the extent and character of technological change in a number of industries. This approach obtains input coefficients from the actual engineering relationship and uses them in a predetermined production function or constructs the production function according to certain engineering relationships. Smith's study of technological change in the American trucking industry is an excellent illustration.[3]

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[1]G. S. Maddala, "Productivity and Technological Change in the Bituminous Coal Industry, 1919-54", *Journal of Political Economy*, 1965.

[2]G. S. Sahota, "The Sources of Measured Productivity Growth: U.S. Fertilizer Mineral Industries, 1936-1960", *Review of Economics and Statistics*, 1966, p. 202.

[3]See V. L. Smith, "Engineering Data and Statistical Techniques in the Analysis of Production and Technological Change: Fuel Requirements of the Trucking Industry", *Econometrica*, 1957.

(e) Studies in Canadian Industries

The studies which we have covered so far are mostly concerned with the American aggregate economy and industries. Although not many, there are a few significant studies of technological change in the Canadian manufacturing industry in the latter half of the sixties. An extensive study on Canadian manufacturing done by Lithwick, Post and Rymes, has two important objectives: first, to determine the nature of the capital formation process; and second, to estimate the contribution of measured factor inputs and technical change.[1] One of the findings in the first section is that no evidence can be found to support the embodied technical change hypothesis. The second section presents detailed estimates of total factor productivity by using an identity similar to Solow's 1957 model and concludes that "total measured factor productivity grew at substantially different rates over the various major groups making up Canadian manufacturing" and the different rates are cyclically sensitive.[2] Another study which focuses on the character of technical progress in Canadian manufacturing was done by Kotowitz.[3] The main findings of this study are that the elasticity of substitution

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[1]N. H. Lithwick, G. Post, and T. K. Rymes, "Postwar Production Relationships in Canada", in *The Theory and Empirical Analysis of Production*, *op. cit.*, pp. 139-273.

[2]*Ibid.*, p. 188.

[3]Y. Kotowitz, "Technical Progress, Factor Substitution and Income Distribution in Canadian Manufacturing, 1926-39 and 1946-61", *Canadian Journal of Economics*, 1969. See also his "Capital Labour Substitution in Canadian Manufacturing, 1926-39 and 1946-61", *Canadian Journal of Economics*, 1968.

between labour and capital is less than unity, implying that the CES production function used is the appropriate one, and technical change in the postwar period is greater than that in the prewar period. Also, technical change is Hicks neutral during the prewar period, and is approximately Harrod neutral in the postwar period.[1] Other works related to technical change in the Canadian context are not many.[2]

(f) Studies of the Steel Industry

There are not many published studies of the Canadian steel industry, let alone any work on the technological change of the industry.[3] There are, however, some econometric and process analyses of the American and Japanese steel industry.[4]

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[1] *Ibid.*, p. 111.

[2] There are, however, an unpublished Ph.D. dissertation "Technical Change in Canadian Agriculture", which uses a Solow 1957 model (L. K. Li, University of Manitoba, 1968), and a paper presented to the 1970 Canadian Economic Association meeting by J. C. Liu, which is entitled "Technical Change and Returns to Scale in the Manufacturing Industry in Canada". There is also an unpublished Master's thesis by Vlassopoules, N.CH., *Technical Change in Canadian Manufacturing Industries, 1946 to 1960* (Montreal: McGill University, 1967).

[3] There are several unpublished theses written on the Canadian steel industry, most of which are concerned with aspects other than productivity and were written some time ago. See B. Borsook's M.A. thesis, Toronto University (1934); E. J. McCracken's M.A. thesis, McGill University (1932); G. P. Hayes' M.A. thesis, Acadia University (1949); F. H. Telmer's M.A. thesis, University of Alberta (1964); and T. M. Russell's Ph.D. thesis, University of Toronto (1968).

[4] A few examples are: C. J. Higgins, "An Econometric Description of the U.S. Steel Industry", in *Essays in Industrial Econometrics*, vol. II, Philadelphia, 1969 (edited by L. R. Klein); T. Watanabe and S. Kinoshita, "An Econometric Study of the Japanese Steel Industry", in *Essays in Industrial Econometrics*, vol. III (edited by L. R. Klein); and C. S. Tsao and R. H. Day, "A Process Analysis Model of U.S. Steel Industry", *Management Science*, June 1971.

The reason for lack of attempts to quantify total factor productivity of the Canadian iron and steel industry is probably unavailability of capital stock data for the industry. The estimation of capital stock is a relatively new venture in Canada. Estimates of capital stock of Canadian manufacturing and those of two-digit industries were not available until Statistics Canada published its reference paper in 1967.[1] Published estimates of capital stock at the three-digit level such as the iron and steel industry are still not available. Fortunately, through the good offices of the Economic Council of Canada and the generosity of Statistics Canada, the author has been provided with unpublished estimates of capital stock for the iron and steel industry, and these are used in the estimation of technical change in subsequent analysis.

E. An Analytical Scheme

(a) Diffusion of New Technologies

The effect of technological change on productivity growth largely depends on the diffusion of new technologies. An understanding of the process of diffusion will help in grasping the mechanism of productivity increase. To this end, Chapter IV will be devoted to a discussion of the determinants of intrafirm, interfirm and interindustry (Canada and the United States) diffusion of new technologies.

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[1]Statistics Canada, Catalogue no. 13-522, *Estimates of Fixed Capital Flows and Stocks, Manufacturing, Canada, 1926-60*, February 1967 (Ottawa: Queen's Printer).

(b) Technological Change

We have thus seen that the prevalent methods of estimating technological change are the residual approach, mainly Solow's and Denison's model, and the production function estimation approach. Thus, the analytical apparatus which will be used to evaluate the importance of technological change in the Canadian iron and steel mills industry will be mainly the residual approach and the production function approach, including models based on the Cobb-Douglas and CES production function.

The essence of Solow's and Denison's approach is basically the same except that the former considers all residual as technical change while the latter attempts to break down the residual by considering additional factors such as education, productivity increase resulting from the reduction of hours of work per worker annually and the like. The Solow model assumes only two factors in the production function:

$$Q = A(t)f(K,L)$$

where Q is net output, K is capital services, L is labour services, A is a constant, and t represents time variable;

and derives the equation:[1]

$$\frac{\dot{A}}{A} = \frac{\dot{q}}{q} - W_k\frac{\dot{k}}{k}$$

where $q = \frac{Q}{L}$, $k = \frac{K}{L}$ and W_k = capital share.

The Denison approach includes additional factors, say education (E) and research and development (R), in the production function, which is written as:

$$Q = A(t)f(K,L,E,R) \ .$$

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[1]The Derivation of Solow's equation:

Differentiate the following equation with respect to t

$$Q = A(t)f(K,L)$$

get: $$\frac{dQ}{dt} = A\frac{\partial f}{\partial K}\cdot\frac{dK}{dt} + A\frac{\partial f}{\partial L}\cdot\frac{dL}{dt} + f(K,L)\frac{dA}{dt}$$

$$\dot{Q} = A\frac{\partial f}{\partial K}\dot{K} + A\frac{\partial f}{\partial L}\dot{L} + f(K,L)\dot{A}$$

$$\frac{\dot{Q}}{Q} = A\frac{\partial f}{\partial K}\frac{\dot{K}}{Q} + A\frac{\partial f}{\partial L}\frac{\dot{L}}{Q} + \frac{f(K,L)\dot{A}}{Q}$$

Since: $Q = A(t)f(K,L)$ hence $$\frac{\dot{Q}}{Q} = A\frac{\partial f}{\partial K}\frac{\dot{K}}{Q} + A\frac{\partial f}{\partial L}\frac{\dot{L}}{Q} + \frac{\dot{A}}{A} \qquad (1)$$

Let: $W_k = \dfrac{\frac{\partial Q}{\partial K}\cdot K}{Q}$ $\quad W_l = \dfrac{\frac{\partial Q}{\partial L}\cdot L}{Q}$ and $\frac{\partial Q}{\partial K} = A\frac{\partial f}{\partial K}$, $\frac{\partial Q}{\partial L} = A\frac{\partial f}{\partial L}$

Substitute all these relationships in (1), get:

$$\frac{\dot{Q}}{Q} = W_l\frac{\dot{L}}{L} + W_k\frac{\dot{K}}{K} + \frac{\dot{A}}{A}$$

Assume $W_l + W_k = 1$ obtain $\frac{\dot{q}}{q} = \frac{\dot{A}}{A} + W_k\frac{\dot{k}}{k}$ where $q = \frac{Q}{L}$ and $k = \frac{K}{L}$.

Note that if the production function is assumed in Cobb-Douglas form, the derivation of Solow's equation will be simpler. See A. A. Walters, *An Introduction to Econometrics* (London: Macmillan, 1968), pp. 314-15.

Following the same method as Solow, the following equation can be derived:[1]

$$\frac{\dot{Q}}{Q} = W_K\frac{\dot{K}}{K} + W_L\frac{\dot{L}}{L} + W_E\frac{\dot{E}}{E} + W_R\frac{\dot{R}}{R} + \frac{\dot{A}}{A}$$

where the W's represent factor shares. The above equation can be rewritten as:

$$1 = \frac{W_K\frac{\dot{K}}{K}}{\frac{\dot{Q}}{Q}} + \frac{W_L\frac{\dot{L}}{L}}{\frac{\dot{Q}}{Q}} + \frac{W_E\frac{\dot{E}}{E}}{\frac{\dot{Q}}{Q}} + \frac{W_R\frac{\dot{R}}{R}}{\frac{\dot{Q}}{Q}} + \frac{\frac{\dot{A}}{A}}{\frac{\dot{Q}}{Q}}$$

of which each term on the right represents the contribution of the factor to output growth in percentage term. Of course some of the factor shares such as that of education are not observable and so an indirect approach has to be adopted. For instance, the effect of education on productivity increase can be ascertained if its effect on labour is known.

The main emphasis is on obtaining an accurate measure of technological change by careful measurements of inputs and output. The measurement of labour input will incorporate some quality adjustment element and capital input will be expressed by the "service" concept. The Solow model, crude as it is, enables us to construct a technological index and to examine the nature of technological change. The results obtained can also be used to test the existence of technological breaks by

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[1]The identity which Lithwick, Post and Rymes use in their study on Canadian manufacturing is similar to this equation. See N. H. Lithwick, G. Post and T. K. Rymes, "Postwar Production Relationships in Canada", in *The Theory and Empirical Analysis of Production*, *op. cit.*, p. 188.

regression technique. The Denison model is complementary to the Solow model but not a substitute. It evaluates the contribution of factors other than capital and labour, and represents a step towards the breaking of the residual.

In addition to the explanation of residual through the Solow and Denison apparatus, an examination of the nature of technological change through production function analysis will be made. The Cobb-Douglas as well as CES production function will be used to analyse topics such as the returns to scale, elasticity of substitution and the rate of technological change. The use of the two types of production function allows a comparative study of the conclusions obtained from the two types of production functions.

Chapter IV

THE DIFFUSION OF TECHNOLOGY

It was indicated in Chapter II that technological change has been increasing in importance since 1946 in the steel industry resulting in unprecedented growth in productivity. Although the basic oxygen furnace and the continuous casting machine have had the most far-reaching effect in steel-making, other minor innovations also contributed to productivity growth. The following list shows various innovations, major as well as minor, introduced in the steel industry since 1946:[1]

	Innovation	Starting date	Company
1.	Basic oxygen furnace	1954	Dofasco
2.	Continuous steel-casting	1954	Atlas
3.	Planetary hot-roll milling	1963	Atlas
4.	Supplementary fuel injection	1963	Algoma
5.	Higher top pressure	1963	Algoma
6.	Curved-mould continuous casting	1964	Atlas
7.	Dual-hearth open-hearth furnace	1964	Stelco
8.	Continuous pickle line	1965	Dofasco

The above list, however, is by no means exhaustive. Nevertheless, it includes all major innovations in the steel-making stage. Also, most items appearing on the list were first adopted in North America by Canadian firms. The introduction of these innovations has produced an enormous effect on productivity growth. Productivity growth, however, is not only a function

[1]Part of the list was provided by J. Gander of the Economic Council of Canada.

of innovations but also of their rates of diffusion. Roughly speaking, the rate of diffusion refers to the speed and extent of response of the industry in adopting an innovation after it has been introduced by the first firm. More precisely, the topic of diffusion is concerned with the following questions:[1]

(1) Why do the uses of some innovations spread faster than others? For instance, why did the use of the basic oxygen furnace spread more quickly than that of the continuous casting machine?

(2) After the first firm has introduced an innovation, how long will it take for other firms in the same industry to follow suit, and why?

(3) Within an individual firm, how soon will it take for the new technique or equipment to replace the old after the first adoption of such technique or equipment? What are the factors governing the replacement of the old by the new technique?

In order to obtain some clue to the diffusion process in the steel industry, a brief factual account may be helpful. Due to the lack of data, innovations other than the basic oxygen furnace and the continuous casting machine will not be discussed.

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[1]These questions are related to the topics "The Rate of Imitation", "The Speed of Response", and "Intrafirm Rates of Diffusion", in E. Mansfield, *op. cit.*

A. <u>The Diffusion of the Basic Oxygen Furnace and the Continuous Casting Machine</u>

Two oxygen vessels were first installed by Dofasco in 1954 and an additional one was added in 1956. The annual capacity of the three oxygen vessels accounted for 74.2 per cent of Dofasco's total annual capacity in 1956. In 1958, two units of oxygen vessel were added to Algoma's then existing 10 units of open-hearth furnace plant, which accounted for a quarter of Algoma's total annual capacity. From 1958 to 1962, although no new oxygen vessel was added the productive capacity of the five oxygen vessels increased from 1.1 million net tons to 2.1 million net tons. The doubling of the capacity could presumably be attributed to other technical improvements such as those listed at the beginning of this chapter in the process of steel-making. In 1963, one more unit of the oxygen vessel was added to Algoma's steel plant and the capacity of the oxygen vessels was brought up to 50 per cent of Algoma's total annual capacity. Cominco Ltd., of Kimberly, British Columbia, acquired a unit of oxygen vessels in 1966, thus bringing the total number of oxygen vessels in Canada up to seven units by the end of 1967. The Steel Company of Canada announced in 1969 that it would add three units of 120 ton oxygen furnaces to replace its eight open-hearth furnaces by 1974. Sydney Steel Corporation also plans to acquire two units of oxygen furnaces by 1974.

Judging from the number of installations, the diffusion of the basic oxygen process is not too impressive -- it was only seven out of a total of 127 furnaces, taking the open-hearth, electric arc and oxygen vessels altogether. These seven oxygen vessels, however, account for nearly one-third of the total annual capacity from 1964 onwards. Since the capacity of the oxygen vessels has usually been nearly fully utilized in Canada, this means that they produce at least about one-third of the actual total production.[1] In addition, some of the existing open-hearth furnaces have been adapted to increase speed and save fuel by installing oxygen lances to blow pure oxygen into the molten metal.[2] Such installations use the same principle as the oxygen vessel. Coupled with other improvements, the capacity and production of the open-hearth furnaces have almost tripled despite the fact that the number of its installations has decreased from 49 units in 1945 to 26 units in 1967. Table IV-1 shows the number of installations, capacity and production of the various types of furnaces used from 1946 to 1969.

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[1]No actual production figure of the oxygen vessels is released but it is reported that they produce one-third of total output. See G. E. Wittur, *Primary Iron and Steel in Canada*, p. 17.

[2]For instance, Sydney Steel Corporation has five of these installations. See *Primary Iron and Steel*, Operators List 1, Part 1, p. 29.

Table IV-1

PRODUCTION AND CAPACITY OF STEEL INGOTS AND CASTINGS BY TYPE OF PROCESSES, 1945-69

(Unit = Net Ton)

	Open-Hearth			Electric Arc			Bessemer Converter			Oxygen Vessels		Total Capacity	Total Produc- tion
Year	No.	Capacity	Production	No.	Capacity	Production	No.	Capacity	Production	No.	Capacity	Production**		
1945	49	2,796,876	2,431,074	81	755,496	445,911	3	8,200	942				3,560,572	2,877,927
1946	49	2,796,876	1,922,526	79	751,941	404,159	3	10,100	600				3,558,917	2,327,285
1947	49	2,801,876	2,462,669	78	747,275	482,542	3	10,100	741				3,559,251	2,945,952
1948	43	3,076,000	2,654,987	76	766,000	545,098	3	10,000	395				3,852,000	3,200,480
[illegible]	[illegible]	3,076,000	2,716,707	76	917,000	473,590	3	10,000	80				4,003,000	3,190,377
1950	44	3,000,500	2,794,330	76	926,000	589,013	3	9,600	232				3,936,100	3,383,575
1951	44	3,000,500	2,947,813	79	985,900	620,675	3	9,600	282				3,996,000	3,568,720
1952	48	3,808,900	3,052,372	77	970,400	650,360	2	4,800	379				4,784,100	3,703,111
1953	46	3,970,800	3,552,445	82	1,016,175	563,369	2	4,800	254			***	4,991,775	4,116,068
1954	42	3,862,200	2,426,694	82	987,675	444,841	2	4,800	95	2*	350,000	323,400	5,204,675	3,195,030
1955	41	4,127,000	3,619,704	82	1,036,900	591,403	2	4,800	165	2	350,000	323,400	5,518,900	4,534,672
1956	37	4,319,000	4,175,784	82	964,450	640,011	2	4,800	307	3	525,000	485,100	5,813,250	5,301,202
1957	34	4,546,000	3,871,773	86	1,061,800	540,316	1	300	20	3	710,000	656,040	6,318,100	5,068,149
1958	34	4,546,000	2,865,710	86	1,030,200	468,096	1	300	20	5	1,110,000	1,025,640	6,686,500	4,359,466
1959	30	4,522,900	3,951,556	89	1,037,500	619,364	1	300	7	5	1,440,000	1,330,560	7,000,700	5,901,487
1960	30	4,522,900	3,632,351	92	1,468,200	716,837	1	300	-	5	1,580,000	1,459,920	7,571,400	5,809,108
1961	31	5,090,900	3,889,677	92	1,469,550	772,631	1	300	-	5	1,870,000	1,826,000	8,430,750	6,488,307
1962	31	5,090,900	4,238,372	95	1,413,850	775,958	0	-	-	5	2,100,000	2,159,204	8,604,750	7,173,534
1963	31	5,465,900	4,985,389	92	1,463,340	872,855	0	-	-	6	2,550,000	2,338,826	9,479,240	8,197,070
1964	30	5,981,500	5,335,680	97	1,827,336	1,007,297	0	-	-	6	3,100,000	2,785,482	10,908,836	9,128,459
1965	30	6,331,500	5,553,155	97	1,916,270	1,282,615	0	-	-	6	3,550,000	3,232,572	11,797,770	10,068,342
1966	26	6,470,000	5,266,886	94	2,084,410	1,355,512	0	-	-	7	3,630,000	3,377,733	12,184,410	10,020,131
1967	26	6,470,000	5,225,772	94	2,292,010	1,266,405	0	-	-	7	3,630,000	3,208,655	12,392,010	9,700,832
1968		6,970,000	6,189,450		2,334,375	1,552,508				7	3,800,000	3,509,038	13,114,375	11,250,996
1969		6,970,000	5,292,069		2,471,375	1,739,186				7	3,800,000	3,275,297	13,241,375	10,306,552

*Oxygen vessels were installed by Dofasco in 1952 but production is not available.

**These figures are estimated by Mineral Resources Branch, Department of Energy, Mines & Resources.

***The figures from 1954-60 are weighted by 92.4 per cent.

Source: Statistics Canada, *Iron and Steel Mills* (various issues), and *Primary Iron and Steel*, December 1969, and October 1970.

Since the actual production figures of the oxygen vessels are unfortunately not separately released, estimates have to be used in their place. If the estimated production figures of oxygen furnaces are reliable, we can see that with the gradual increase in number of oxygen vessels, their share in total output has also been increasing impressively. Since some open-hearth furnaces are equipped with oxygen lances, part of the increase in capacity and output of the open-hearth furnace must also be attributed to the principle of pure oxygen blowing. Thus, the total effect of using pure oxygen in steel-making is greater than the capacity and production figures of the oxygen vessel as shown in Table IV-1.

The diffusion rate of basic oxygen furnace can be seen in Table IV-2. One thing which can be noted in the table is that the increase in BOF (basic oxygen furnace) capacity has frequently been a function of its size per heat in net tons rather than the number of furnaces. For instance, Dofasco has been using three units of BOF since 1956 but its BOF capacity has increased more than four times between 1956 and 1968 while the size per heat of its BOF's has tripled.[1] Note also that capacity increase can be achieved without an increase in the size of furnace. Again, for instance, Dofasco had three units of BOF which were 100 net tons per heat from 1961 to 1965 but

1 Dofasco's BOF capacities in 1956 and 1968 are 525,000 net tons and 2,270,000 net tons, respectively. See Statistics Canada, Catalogue no. 41-203, 1956 issue, p. J-17, and 1968 issue, p. 14.

its BOF capacity was increased every year. These increases were probably due to the other technological improvements in connection with the BOF.

The other major innovation is the use of the continuous casting machine. Atlas was the first company which installed a continuous casting machine in North America in 1954. By the end of 1969, there were 15 units of machines with 41 strands altogether and the annual capacity of these machines was 2,306,500 tons. Table IV-3 shows the process of its diffusion.

A few observations can be made based on Table IV-3. First, most of the early users of continuous casting machines were small firms except Stelco. Second, the percentage of CCM (continuous casting machine) capacity rises slowly but steadily. Third, the type of mould of the machine was mainly vertical in the earlier years and curved in recent years.

Comparing Tables IV-2 and IV-3, we note the following. First, the fast-users of BOF are also the slow-users of CCM. In fact, Dofasco does not have a continuous casting machine even at the present time. Second, the diffusion of both BOF and CCM increased in momentum only after 1960, despite the fact that they were both first introduced in 1954. From Table IV-2, we can see that nearly two-thirds of the present BOF capacity was built during the period 1961-68. In the case of CCM, about 90 per cent of the present capacity was built after 1960.

Table IV-2

THE DIFFUSION OF THE BASIC OXYGEN FURNACE IN THE CANADIAN STEEL INDUSTRY

Year	Company	No. of Furnace	Size Per Heat (net tons)	Capacity		Total BOF Capacity of the Industry / Total Ingots and Casting Capacity of the Industry
				Increase	Total	
1954	Dofasco	2	40	350,000	350,000	6.7
1955					350,000	6.3
1956	Dofasco	3	50	175,000	525,000	9.0
1957	Dofasco	3	60	185,000	710,000	11.2
1958	Algoma	2	80	400,000	1,100,000	16.5
1959	Algoma	2	100	200,000		
	Dofasco	3	60	140,000	1,440,000	20.6
1960	Dofasco	2	60	140,000	1,580,000	20.9
		1	90			
1961	Algoma	2	100	100,000		
	Dofasco	3	100	190,000	1,870,000	22.2
1962	Algoma	2	106	200,000		
	Dofasco	3	100	30,000	2,100,000	24.4
1963	Algoma	3	106	150,000		
	Dofasco	3	100	300,000	2,550,000	26.9
1964	Algoma	3	106	250,000		
	Dofasco	3	100	300,000	3,100,000	28.4
1965	Algoma	3	110	150,000		
	Dofasco	3	100	300,000	3,550,000	30.1
1966	Cominco	1	18	80,000	3,630,000	29.8
1967					3,630,000	29.3
1968	Dofasco	3	150	170,000	3,800,000	29.0
1969					3,800,000	28.9
1974	Stelco*	3	120			
	Sysco*	2				

*Denotes planned addition.

Notes: (1) The last but one column is obtained by dividing the total BOF capacity by total steel ingot and castings capacity shown in Table IV-1.

(2) The number of major firms is 5. They are Algoma, Dofasco, Stelco, Sysco and Cominco.

(3) Although there were no increase in the BOF capacity in 1955, 1967 and 1969, the diffusion rates of the BOF fell for these years because the total capacities had risen.

Source: Statistics Canada, Catalogue no. 41-203, "Steel Furnaces in Canada" (various issues), and Canadian Mineral Yearbook, 1969, "Iron and Steel Mills".

Table IV-3

THE DIFFUSION OF CONTINUOUS CASTING MACHINE

Year	Company	No. of Machines Increase	No. of Machines Total	No. of Strands Increase	No. of Strands Total	Type of Mould Increase	Industry Capacity Increase	Industry Capacity Total	CCM Cap. / Ingot Capacity %
1954	Atlas	1	1	3	3	vertical	93,500	93,500	1.9
1955								93,500	1.8
1956								93,500	1.7
1957								93,500	1.6
1958								93,500	1.5
1959								93,500	1.4
1960								93,500	1.3
1961								93,500	1.2
1962	Stelco	1	1	2	2	vertical	128,000	221,500	2.7
1963	Western	1	1	1	1	vertical	120,000	341,500	3.8
1964	Lake Ontario	2	2	6	6	vertical	300,000		
	Atlas	1	2	1	4	curved	75,000	716,500	6.9
1965	Dosco	1	1	4	4	curved	150,000	866,500	7.7
1966	Stelco	1	2	6	8	curved	250,000		
	Manitoba	2	2	4	4	curved	160,000		
	Newfoundland	1	1	2	2	straight	60,000	1,336,500	11.3
1967	Algoma	1	1	4	4	curved	400,000	1,736,500	14.5
1968	Algoma	1	2	2	6	curved	200,000		
	Burlington	1	1	3	3	curved	120,000	2,056,500	16.2
1969								2,056,500	16.1
1970	Burlington	1	2	3	6	curved	250,000	2,306,500	17.6

Sources: (1) Primary Iron and Steel: *Operators List 1, Part 1*, January 1970, p. 17. Mineral Resources Branch, Department of Energy, Mines and Resources.

(2) The diffusion ratio of CCM is obtained by dividing the industry capacity of CCM by the total ingot capacity available from Statistics Canada, Catalogue no. 41-203.

B. The Co-Existence of Outdated and New Technologies

It is shown in Table IV-2 and IV-3 that although the BOF and CCM were first introduced in 1954, they were not widely adopted until late 1960. As previously noted, the BOF has much more advantages than the open-hearth furnace with respect to capital and operating costs. But even today, the open-hearth furnace is still being used alongside with the BOF.

In the discussion of Salter's theory of diffusion in the previous chapter, the abandonment of old equipment and the adoption of the new was said to depend on the surplus over operating costs, which in turn depends on the factor prices. On the other hand, new investment is a function of interest rates. The higher operating costs of the marginal plant implies that the marginal plant must have a much lower labour productivity than the plant employing the best-practice technique. In other words, the labour requirement of each unit of output of the marginal plant must be higher than the latter. Thus, if the price of labour is high relative to the price of capital (interest rates), then the marginal plant will be abandoned earlier. On the other hand, more new investment will be made since capital is relatively cheap. Thus, a rising wage trend relative to interest rates will speed up the process of replacement investment. If we are comparing two economies, then the one with rapidly rising wage rates will have a greater rate of replacement investment, more up-to-date techniques and therefore higher productivity. Note that it is not the relative wage rate but the relative growth rate of the wage rate between the two economies which is important. For instance, as we shall see later, the diffusion of BOF in the United States had been lagging behind other countries with lower wage rates, such as Canada and Japan. Maddala and Knight also find no evidence to support the relative factor prices thesis in the diffusion of BOF.[1] It is intuitively clear that as wage rate rises, the surplus over operating costs falls.

> "... quasi-rent of machine falls to zero after *T* time-periods from installation. The decline in quasi-rent arises because of an increasing wage rate *w(t)*, taken under perfect competition as applying to labour on machines of all vintages."[2]

It is also clear that the effect of a rising wage rate is greater if the labour share is larger. The economic life of machines will become shorter if both the growth rate of the wage rate and the labour share are greater. Allen expressed this relationship as:[3]

$$T = \frac{1}{\lambda} \log \left(\frac{Q_t}{w(t) L_t} \right)$$

where Q represents output, w wage rate, and L labour input. This means that the economic life of machines, T, depends on the growth rate of the wage rate (λ) and the labour share in

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[1] G. S. Maddala and P. T. Knight, "International Diffusion of Technical Change - A Case Study of the Oxygen Steel-Making Process", *Economic Journal*, September 1967, p. 544.

[2] R.G.D. Allen, *Macro-Economic Theory* (New York: MacMillan, 1967), p. 294.

[3] *Ibid.*, p. 295.

output. The greater the value of λ and/or the labour share, the shorter the economic life of machines will be and therefore the faster the rate of diffusion.

Applying the above theory to the study of Canada-United States diffusion of the basic oxygen furnace and the continuous casting machine, one finds that the growth rate of the wage rate in the Canadian steel industry has been higher than that in the American steel industry.[1] The labour share is believed to be higher in the Canadian steel industry too, since the wage rate is lower which encourages the use of more labour in Canada than in the United States while the interest rate is higher.[2] Thus, the greater growth rate of the Canadian wage rate with the expectation of a continued greater growth rate in the future and the larger labour share in the Canadian steel industry than in the United States constitute an explanation of the faster diffusion rate of both BOF and CCM in Canada.

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[1]The growth rates are calculated as:

	1959-60	60-61	61-62	62-63	63-64	64-65	65-66	66-67	67-68	68-69
Canada (%)	4.6	5.0	3.2	3.7	2.4	5.5	4.7	6.8	6.4	7.4
U.S. (%)	0.5	4.5	4.3	2.2	2.6	2.8	3.4	2.8	5.7	7.0

Source: Column (5B) of Table V-1 and Column (10) of Table V-2 of Chapter V.

[2]Column (9) of Table V-1 and Column (7) of Table V-2 show that labour shares are slightly higher in the American steel industry than in the Canadian steel industry. The inconsistency probably arises from the fact that the wage rate is much higher in the United States and so the wage bill is bigger but the labour input measured in man-hours is not as much as that in Canada.

C. Why Did BOF Spread Faster than CCM

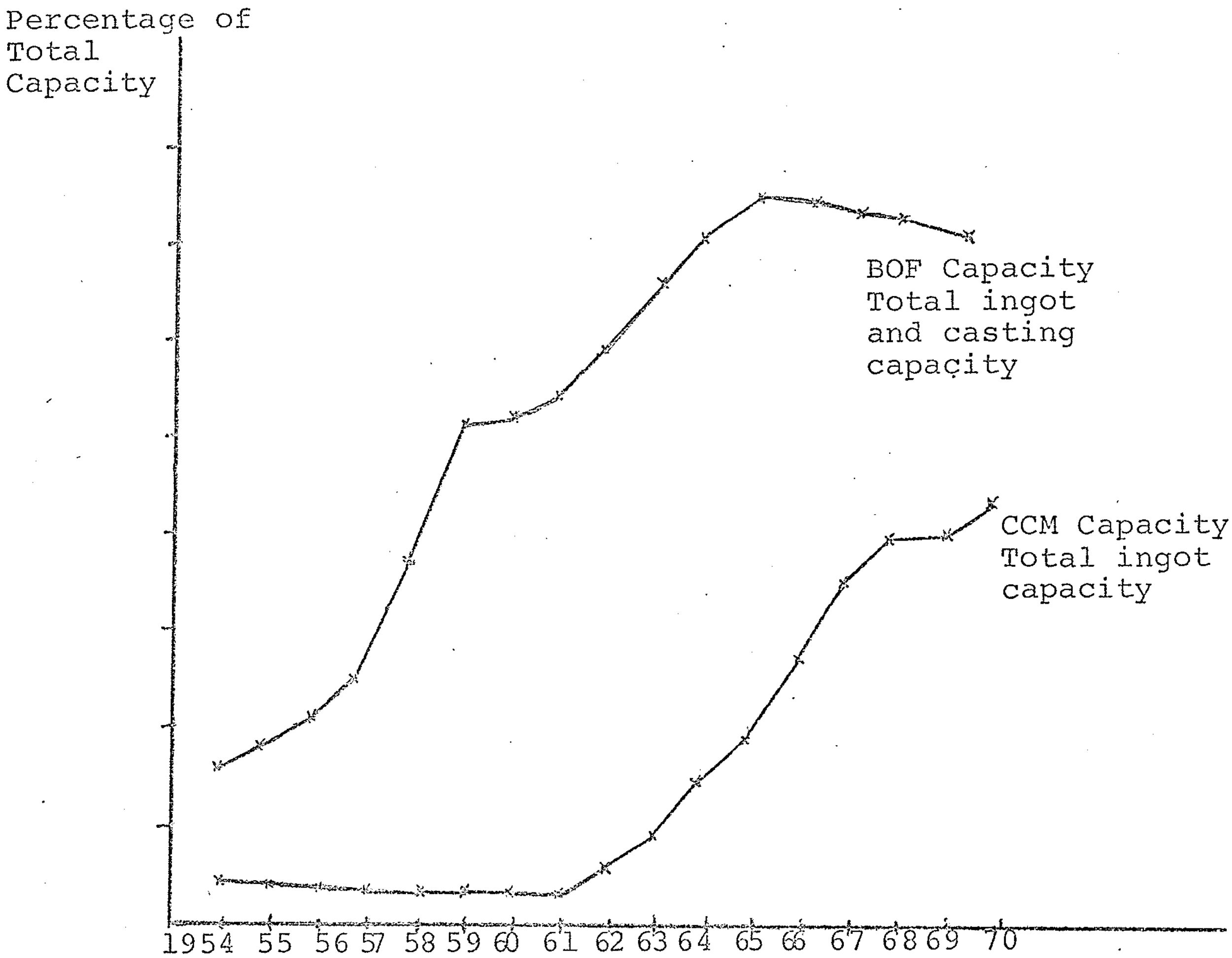
Tables IV-2 and IV-3 show the diffusions of the basic oxygen furnace and the continuous casting machine in Canada. If we use the ratio between total BOF capacity and total ingots - castings capacity as the measure for diffusion of BOF and the ratio between CCM capacity and ingot capacity as the measure for diffusion of CCM, Diagram IV-1 can be drawn.

It is clear from Diagram IV-1 that the diffusion of CCM occurred later than that of BOF and it is worth investigating why this is so. As we noted in Chapter III, Mansfield argues that the rate of imitation, represented by the ratio between the number of firms which have adopted the innovation and the total number of firms in a particular industry, should be higher if the profitability is greater and the amount required to invest is smaller.

It is plausible to suggest that the rate of imitation is a function of profitability and size of investment required for the innovation. Profit is the difference between revenues and costs and therefore a function of product price and factor prices. The amount of investment required is the new capital cost in Salter's terminology. One thing which ought to be pointed out is that there might exist some relationship between profitability and size of investment. The latter actually involves the difficulty in getting funds and the risk of investment.

Diagram IV-1

DIFFUSION OF BOF AND CCM IN CANADA



Source: See Table IV-2 and IV-3.

As a rule, the greater the amount of investment required, the greater the risk involved. But a higher profitability provides a justification for the investor to take some more risk and vice versa. Thus, there is a compensatory effect between profitability and size of investment required and so they are not really independent of each other.[1]

In regard to the diffusions of BOF and CCM in Canada, profitability is more important as a factor than size of investment since the capital costs of these two innovations are less than those of the old equipment. Though the relative profitabilities of the two innovations are not exactly known, their absolute magnitudes of profitability are reflected in their induced savings in capital and operating costs. The BOF is said to require only half the capital investment of the open-hearth furnace and save operating costs of $3 to $10 per ton, while the CCM enjoys a 30 to 50 per cent saving in capital costs and average operating cost savings of $4 to $6 per ton.[2] It does seem from these cost-saving figures that the profitability of the BOF is greater than that of the CCM.

However, the reason why the diffusion of CCM has been lagging behind that of BOF probably lies more in the imperfect substitutability of CCM for the traditional ingot preparation

[1]This implies that the problem of multicollinearity would arise if the relationship was fitted in a regression equation as Mansfield did. See Mansfield, *op. cit.*, p. 140.

[2]W. Adams and J. B. Dirlam, "Steel Imports and Vertical Oligopoly Power", *American Economic Review*, September 1964, pp. 646-47.

process. As we noted previously, the disadvantage of the early CCM was the low tonnage it handled each time and so it was more suitable for small firms than large firms. It is shown in Table IV-3 that the first CCM installed by Atlas in 1954 has only a quarter of the annual capacity of a CCM installed by Algoma in 1967. We also note from the table that the time lag between the first and second installation of the machine was eight years, and all early adopters were small firms except Stelco. Note also that the type of mould has been changed from vertical to curved and the capacity of the machine has become greater. It can be said with certainty that the early machine had some technical difficulties and modifications were carried out from its first installation to the mid-1960s.[1]

In sum, though the difference in profitability between BOF and CCM has some effect on the slow diffusion of CCM, the more important factor is probably the imperfect substitutability of the CCM for the traditional process.

D. Size of Firm, Profitability and the Speed of Response

It is shown in Tables IV-2 and IV-3 that small firms have been leading in adopting both BOF and CCM. The reason small firms adopted the CCM was that the small tonnage which the machine handles was particularly suitable and economical for them. In the case of BOF, however, the same argument is

[1]See G. A. Hone and D. S. Schoenbrod, "Steel Import and Vertical Oligopoly Power: Comment", *American Economic Review*, March 1966, p. 159.

not very convincing since the advantage in terms of cost and time savings has far outweighed the tonnage consideration. For instance, the costs of using two units of BOF which have a total capacity equivalent to a big open-hearth furnace are still less than those of the simple open-hearth furnace they replace. Yet Dofasco, a relatively small firm compared with Algoma and Stelco in 1954, was the pioneer in adopting BOF for commercial use in North America. The same pattern of diffusion exists in the United States -- small firms assumed the leading role in using both BOF and CCM. This raises the question whether the size of firm has anything to do with the speed of response of individual firms to innovation.

Mansfield argues in his book that the greater the profitability and the larger the firm, the shorter will be the period of waiting, in adopting an innovation. In other words, the speed of response of individual firms to innovation will be greater if the size of firm is larger and the profitability is greater. The reason suggested by Mansfield is:

> "Because they have more units of any particular type of equipment, large firms are more likely at any point in time to have some units that will soon have to be replaced. Thus, if an innovation occurs that is designed to replace this type of equipment, they probably can begin using it more quickly than smaller firms. Moreover, large firms, because they encompass a wider range of operating conditions, have a better chance of containing those conditions for which the innovation is applicable at first."[1]

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[1]E. Mansfield, *Industrial Research and Technological Innovation*, p. 156.

The above quotation, though it sounds plausible, is not correct. When an innovation occurs, all existing machines become obsolete. It is not simply that a few old-fashioned machines are to be replaced. If the gap in productivity between the new machine and the old is sizable, the problem under consideration is how to replace all or at least most machines. The reason is apparent since the replacement of a few old-fashioned machines cannot have much effect on the eliminating of the productivity gap for a large firm as a whole. On the other hand, it is not profitable to scrap all the existing machines either. They will be kept as long as they are producing positive rents. Moreover, there is uncertainty about the future improvement of the innovation. A big firm, with all its vested interests and established market share, is more likely to adopt the policy of "wait and see".

For small firms, things are different.[1] They are eager to expand and to account for a larger market share whenever they can. When an innovation occurs, in addition to the replacement by new machines of old-fashioned machines, there is room for the firms to install additional new machines, not just replacements. Thus, small firms appear aggressive and outward looking while big firms tend to be conservative and inward looking. In conclusion, the speed of response of individual firms [illegible] innovation is [illegible]mined by the

[1]Mansfield did suggest several conditions under which small firms may adopt innovations earlier than big firms. See, *ibid.*, p. 180.

firms to innovation is determined by the profitability of the innovation and the size of firm. However, contrary to what Mansfield believes, the larger the size of firm, the longer will be the period of delay. This principle is believed to be applicable in the steel industry as well as industries with the same nature.

E. The Intrafirm and Interfirm Diffusions

After a firm has adopted an innovation for the first time, how fast will it substitute the new machine or equipment for the outdated machines and equipment within itself? Why are the diffusions of an innovation in some firms faster than those in others?

For the intrafirm diffusion of BOF in the Canadian steel industry, factors such as unused capacity, age structure of the existing capital stock, market share, liquidity ratio and profitability of using BOF seem to be important. When a steel firm is considering expansion of its production, new investment in BOF would be delayed if there was ample unused open-hearth capacity. Although the productivity of the under-utilized open-hearth furnace is much lower than that of the new BOF, it is still profitable as long as the operating costs per unit of product, by using the currently unused capacity, is less than the sum of capital and operating costs per unit product by using a new BOF. Second, the age structure of the existing furnaces reflects the weighted average of furnace productivities, assuming that a furnace installed at time *t* is embodied with the latest technology available at time *t*. Because of the different technologies embodied, and wear and tear, the productivity gap between a young stock of open-hearth furnaces and the BOF is smaller than that between an old stock and the BOF. The greater the gap, the sooner will the rent yielded by old furnaces be eliminated. Hence, the older the existing stock, the faster will be the intrafirm rate of diffusion. Third, market share is also related to diffusion of BOF. A firm with a small share in the market will be more eager in searching for a way to increase its share than a firm with a big share in the market.[1] Fourth, a firm's liquidity, represented by the ratio between current assets and current liabilities, measures the firm's financial situation and the ability to obtain investment funds. The ease of obtaining funds certainly speeds up the pace of diffusion if the firm desires it. The final factor -- profitability needs no more mentioning here.

Statistical data do provide some support to the above argument. As shown in Tables IV-4 and IV-5, and also in Diagram IV-2, Dofasco has a higher diffusion rate of the use of BOF than Algoma. In 1946, Dofasco had four units of open-hearth furnaces and five units of electric furnaces. In fact, the four units of open-hearth furnaces were discarded in 1956 and an electric furnace was discarded in 1962. In contrast, Algoma added two units of open-hearth furnace to its then existing 12-unit stock of open-hearth furnaces in 1953. When BOF was

[1]Although the steel industry is an oligopolistic industry in which price cutting is not profitable, some hidden price reduction practices can take place. For instance, special discount is given or the extra charge levied according to the size and specification of the order is reduced.

installed by Dofasco in 1954, about 20 per cent of Algoma's open-hearth capacity was just one year old. This obviously discouraged Algoma from installing BOF right away. Thus, Algoma waited until 1958 to install two small units of BOF after four small units of open-hearth furnace had been removed. Further increase of BOF capacity and discarding of open-hearth furnace took place after 1958.

In Diagram IV-2, the broken lines show the percentages of unused capacity for Algoma and Dofasco. Except for a few years such as 1963-66, Algoma's unused capacity seems to have been greater than Dofasco's. However, the difference is not large enough to support any firm conclusion.

Market share, which is generally proportional to firm size and hence production capacity, is regarded as a significant factor in BOF diffusion. Of the three largest producers, Stelco has had the biggest share. Algoma is second and Dofasco is the third. The tables show that Dofasco had had only half of Algoma's production capacity from 1946 to 1952. The desire for capturing a larger market share by a small firm like Dofasco is believed to be one of several important factors in speeding up the diffusion rate of BOF. The calculation of firm's liquidity, which is another factor, shows that Dofasco's liquidity is slightly greater than Algoma's.[1] The final factor -- the profitability of BOF to each firm, though difficult to calculate, is also believed to be an important factor.

[1]The liquidity factor, represented by the ratio between current assets and current liabilities, is found to be: Algoma 3.1 and 3.0, Dofasco 3.9 and 3.2, both for 1967 and 1968, respectively. See Annual Reports of these companies for 1967 and 1968.

Table IV-4

INTRAFIRM DIFFUSION OF BOF AND UNUSED CAPACITY
DOMINION FOUNDRIES AND STEEL, LIMITED

"unit: Thousand net tons"

	Capacity & Number of Steel Furnaces						
	Open Hearth	Electric	Basic Oxygen	Total	BOF/ Total %	Steel Production ingots & castings	Unused capacity as % of total capacity
1946	202.90 (4)	115.15 (5)		318.05			
1947	202.90 (4)	115.15 (5)		318.05			
1948	202.90 (4)	172.90 (5)		375.80			
1949	202.90 (4)	172.90 (5)		375.80			
1950	202.90 (4)	175.40 (5)		378.30			
1951	202.90 (4)	175.40 (5)		378.30			
1952	253.20 (4)	175.40 (5)		428.60			
1953	253.20 (4)	175.40 (5)		428.60			
1954	253.20 (4)	182.00 (5)	350 (2)	785.20	44.6		
1955	253.20 (4)	182.00 (5)	350 (2)	785.20	44.6		
1956		182.00 (5)	525 (3)	707.00	74.3		
1957		185.00 (5)	710 (3)	895.00	79.3		
1958		185.00 (5)	710 (3)	895.00	79.3		
1959		185.00 (5)	840 (3)	1,025.00	82.0	884	13.8
1960		185.00 (5)	980 (3)	1,165.00	84.1	992	14.8
1961		115.00 (4)	1,170 (3)	1,285.00	91.1	1,126	12.4
1962		50.00 (4)	1,200 (3)	1,250.00	96.0	1,243	0.6
1963		50.85 (4)	1,500 (3)	1,550.85	96.7	1,391	10.3
1964		50.85 (4)	1,800 (3)	1,850.85	97.3	1,584	14.4
1965		50.85 (4)	2,100 (3)	2,150.85	97.6	1,785	17.0
1966		50.85 (4)	2,100 (3)	2,150.85	97.6	1,877	12.7
1967		50.85 (4)	2,100 (3)	2,150.85	97.6	1,879	12.6
1968		50.85 (4)	2,270 (3)	2,320.85	97.8	2.180	6.1

Sources: (1) Statistics Canada, Catalogue no. 41-203 (various issues).

(2) Algoma's steel production figures are obtained from *Annual Report*, Dominion Foundries and Steel, Limited, 1968, p. 18.

(3) Unused capacity as percentage of total capacity = $\frac{\text{Total capacity - production}}{\text{Total capacity}}$

Table IV-5

INTRAFIRM DIFFUSION OF BOF AND UNUSED CAPACITY
ALGOMA STEEL CORPORATION

	Capacity & number of steel furnaces				Steel Production	
	Open Hearth	Basic Oxygen	Total	BOF/ Total %	Steel Ingots	Unused capacity as % of total capacity
1946	760 (12)		760			
1947	760 (12)		760			
1948	1,000 (12)		1,000			
1949	1,000 (12)		1,000			
1950	866 (12)		866			
1951	866 (12)		866			
1952	920 (12)		920			
1953	1,120 (14)		1,120			
1954	1,120 (14)		1,120		566	49.5
1955	1,120 (14)		1,120		990	11.6
1956	1,120 (14)		1,120		1,105	-1.3
1957	1,200 (10)		1,200		1,066	11.2
1958	1,200 (10)	400 (2)	1,600	25.0	962	39.9
1959	1,000 (6)	600 (2)	1,600	37.5	1,372	14.3
1960	1,000 (6)	600 (2)	1,600	37.5	1,278	20.1
1961	900 (6)	700 (2)	1,600	43.8	1,650	3.1
1962	900 (6)	900 (2)	1,800	50.0	1,759	2.3
1963	1,150 (6)	1,050 (2)	2,200	47.7	2,092	4.9
1964	1,150 (6)	1,300 (3)	2.450	53.1	2,301	6.1
1965	1,150 (6)	1,450 (3)	2,600	55.8	2,486	4.4
1966	1,150 (6)	1,450 (3)	2,600	55.8	2,347	9.7
1967	1,150 (6)	1,450 (3)	2,600	55.8	2,073	20.3
1968	1,150 (6)	1,450 (3)	2,600	55.8	2,261	13.0

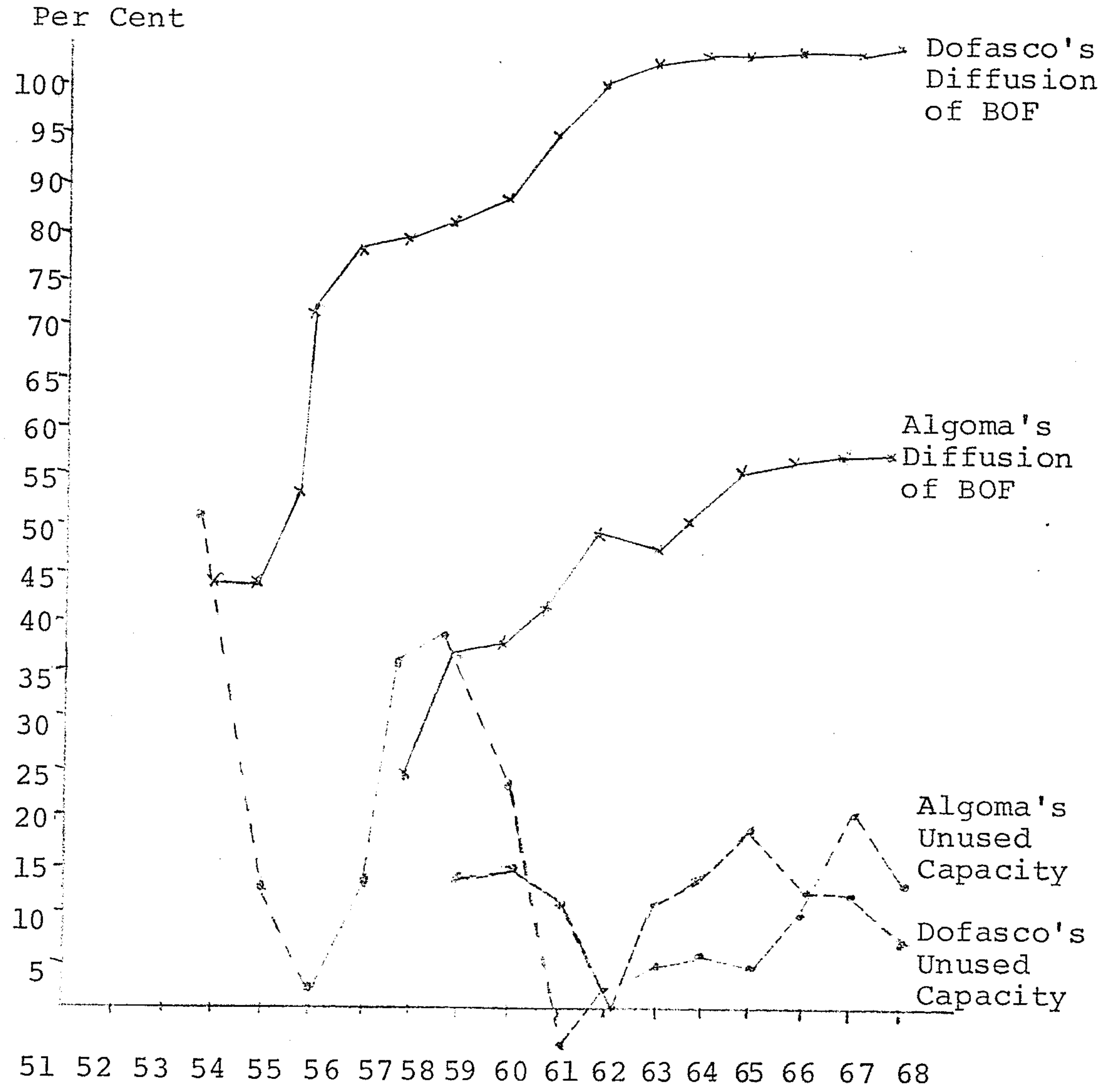
Sources: (1) Statistics Canada, Catalogue no. 41-203 (various issues).

(2) Algoma's steel production figures are obtained from *Annual Report*, Algoma Steel Corporation, 1962, pp. 18-19, and 1970, pp. 18-19.

(3) Unused capacity as percentage of total capacity is obtained by using this formula: $\frac{\text{Total capacity - production}}{\text{Total capacity}}$

Diagram IV-2

INTRAFIRM DIFFUSION OF BOF AND UNUSED CAPACITY



Source: Tables IV-4 and IV-5.

F. The Industry-Wide Diffusion of BOF

So far, we have discussed the intrafirm and interfirm patterns of diffusion of innovations. Next, we want to look at the cross-sectional industry diffusion of new technologies. We simply ask the question: what are the factors responsible for the differences in diffusion rates of a certain innovation in two industries of the same nature? More explicitly, what are the factors which make the diffusion of BOF in the Canadian steel industry differ from that in the American steel industry?

Several factors are important in this connection. First, the growth of market implies that shortage of capacity will emerge soon. This induces producers to expand production capacity and so innovation will be introduced faster under this circumstance than otherwise. In fact, the growth of the Canadian steel industry is frequently attributed to the growth of the steel market. The growth of the economy as a whole and the spread in the use of steel were responsible for the growth of market. The setting-up of automobile plants in Canada under the Canada-U.S. Automobile Agreement provided some spur to market growth. The expansion of consumer durable goods industries was also important in stimulating the growth of the steel industry.

The second factor is the profit rate of steel firms. It is important in connection with diffusion of technologies since profit or net earning is an important source of funds which accounts for 30 to 60 per cent of total funds needed for investment purpose. For instance, profits as a source of fund account for approximately 60 per cent, 50 per cent and 30 per cent of total available funds at Dofasco, Stelco and Algoma, respectively, in 1969.[1]

Competition in the industry is another important factor in technological diffusion. This relates to the composition of the industry -- whether it is composed of a large number of small firms or mainly a small number of large firms. The size of firm has long been a critical topic in discussion of innovation. The issue here is whether competitive forces, presumably prevailing in a structure composed of many efficient firms, are conducive to technological innovation and diffusion.

Competition is an important assumption in Salter's theoretical analysis of the diffusion process. As new technology is used, the unit cost of product, which depends on the movement of relative input prices, falls. It is the competition of sellers which forces the price to decline. Consequently, producers using outdated machines or equipment are compelled to substitute new machines or equipment for the old since the rent yielded by the latter has vanished. If competition was weak, then the pace of technological diffusion would apparently be slower than otherwise.

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[1]See *Annual Reports* of these companies, 1969. Total available fund is the sum of net profit, charges not requiring cash outlays (including depreciation and taxes deferred to future years), shares issued for cash and long-term bank credit.

Besides firm size, several other factors may also have a direct relationship with competition. The location of steel firms more or less determines the boundary of the market for each firm. This is because the heavy transportation costs of steel makes the penetration beyond one's market unprofitable. Thus, competitive forces are weaker in the case where firms are loosely scattered about than where firms are clustered. In Canada, two of the three largest steel firms are located in Ontario's manufacturing belt. Moreover, import competition, mainly from the United States, Japan and the continental European countries, has been constantly strong. Thus, competitive forces are believed to be effective.[1]

Restrictive practice of steel firms such as price fixing which lessens the degree of competition has seldom been heard in Canada.[2] Purchase and control did take place, however. Stelco purchased Premier Steel Limited in 1962. Other firms acquired by Stelco are the Canadian Drawn Steel Company (in 1961) and Page-Hersey Tubes Limited (in 1964). Algoma, being itself controlled by Mannesmann International Corporation of Germany, holds 43.5 per cent of the Dominion Bridge Company Limited shares in 1964. The latter operates a steel-rolling mill --

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[1]In fact, the lack of competition, combined with other causes, though it enabled the former Dosco to survive with obsolete equipment and machines for some time, led to the eventual shutdown of the firm at Sydney, Nova Scotia.

[2]In the United States, U.S. Steel was charged with monopolizing the iron and steel industry in 1920.

Manitoba Rolling Mill at Selkirk, Manitoba. Recently, Mannesmann merged with August Thyssen-Hutte of Germany, which is the parent company of Canadian Phoenix Steel and Pipe Ltd. Thus, Algoma has some influence on Phoenix Steel indirectly.

However, the purchase and control mentioned above have not lessened the competitive nature of the Canadian steel industry. In a study of the economic character of the steel industry, Elver derives the following conclusion:[1]

> "... no evidence or reference to unacceptable behavior that would suggest, on balance, the absence of effective competition. There are no artificial barriers to entry by new firms, no interlocking directorships or common sources of financial control, and no indication of price-fixing although a normal price-leadership situation exists."

In examining the degree of competition in the Canadian steel industry, one has to be aware of the fact that the Canadian market is a part of the North American steel market.[2] Thus, the high concentration ratio, represented by the ratio between a firm's production capacity and the total capacity of the industry, does not necessarily imply the lack of competition.[3]

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[1]R. B. Elver, *Economic Character and Change in the Canadian Steel Industry Since 1945*, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa, pp. 26-27.

[2]Tariff does not determine the boundary of the market and has not much effect on the Canada-United States trade in steel products. It is said that "in most cases the tariff changes represent only a fraction of the normal price fluctuations occasioned by market conditions." See U.S. Senate, *Steel Imports*, December 1967, p. 309.

[3]"Because the market limits the number of plants, the industry is highly concentrated." See Elver, *op. cit.*, pp. 26-27.

If we take the North American market as a whole, the share of the Canadian firms as a group is a negligible fraction compared with the shares of the big firms in the United States.

The final factor is the growth rate of the wage rate. As we saw in Section B of this chapter, the wage rate in the Canadian steel industry has been rising rapidly. The greater the rate of increase in the wage rate, the earlier will the surplus over the operating costs be eliminated and hence the faster the rate of diffusion.

In sum, the hypothesis that the growth of the market, the increase in the wage rate, the mild increase in profit ratios of the industry and the effective competition are the main factors which stimulated the rapid diffusion of technologies in the Canadian steel industry, can be established. More weights might have to be attached to the growth of the market.

G. Diffusion of New Technologies in the United States

(a) Why Did American Firms Have a "late start" in Adopting Innovations

Canada was the first adopter of two major technological innovations -- the BOF and CCM in North America. The American major steel firms followed in adopting the innovations after a lag of several years.[1] It is worthwhile to enquire why the bigger American steel industry lagged behind its Canadian counterpart.

Two possible explanations for this are: (i) the American steel industry had made a sizable investment in plants and equipment in 1951-53, and by the time the BOF and CCM were proved to be successful in 1954, the American industry had no more room for expansion; and (ii) the early versions of both BOF and CCM were of small sizes and thus not suitable to the large American firms of the American steel industry.[2]

The first theory seems plausible if we look at the American investment expenditure series in Table IV-6. The three years, 1951, 1952 and 1953, witnessed an upsurge in investment expenditure, and this fits in nicely to the theory that by 1954 when Canada first installed its BOF, there was no provision left for further expansion.[3] But if we look at the Canadian series as well, the same upsurge existed for the

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[1]McLouth, a small firm, introduced BOF in 1955, but major firms such as Bethlehem and U.S. Steel did not adopt BOF until 1961 and 1963, respectively. The first commercial CCM went into operation in 1962. See Adam and Dirlam, "Steel Import and Vertical Oligopoly Power", *American Economic Review*, September 1964, p. 647.

[2]One more theory is that Americans always think they are "number one" and do not believe that others can do better than they. Both BOF and CCM were developed in Europe.

[3]*Business Week* reported that "the industry bought 40 million tons of the wrong kind of capacity -- the open-hearth furnace" instead of the BOF in the period 1951-53. See November 16, 1963 issue.

three years. This shows that the investment upsurge of the period 1951-53 alone cannot explain the lag of BOF diffusion in the United States. But why did the Canadian industry still have room to expand? The answer lies in the fact that the Canadian steel industry was a young industry in its prime and was growing with its increasing share in the North American market, while the American counterpart was long established. In other words, the Canadian steel industry was enjoying a higher degree of returns to scale than the American steel industry, and this permitted the former to increase its share in the North American steel market.

The second theory also has its truth. From the experience of BOF diffusion in Canada, we note that the size of the early BOF was small and it has been increased since. Also, the design and size of CCM has been changed. Because of the low capacity of the early BOF, the American firms believed that it would be more economical to produce large tonnages of steel by using a few open-hearth furnaces than a larger number of BOF's. Some element of "waiting" was involved in the decision to defer the use of BOF since they also believed that BOF with higher capacity would soon be developed.[1] The same reason explains the delay in adopting CCM. In addition to low capacity, the original CCM is said to have suffered from some technical difficulties.[2]

[1] R. E. Slesinger, "Steel Imports and Vertical Oligopoly Power: Comment", *American Economic Review*, March 1966, p. 154.

[2] G. A. Hone and D. S. Schoenbrod, "Steel Imports and Vertical Oligopoly Power: Comment", *American Economic Review*, March 1966, p. 159.

Table IV-6

CAPITAL EXPENDITURE IN STEEL INDUSTRY --
CANADA AND UNITED STATES

(Million $)

	United States	Canada
1946		6.7
1947		15.2
1948	770	19.3
1949	600	11.6
1950	600	6.9
1951	1200	50.3
1952	1510	72.9
1953	1210	49.9
1954	750	33.5
1955	860	34.5
1956	1270	61.7
1957	1720	71.0
1958	1190	55.9
1959	1040	74.7
1960	1600	114.8
1961	1130	67.2
1962	1100	112.9
1963	1240	107.3
1964	1600	206.1
1965	1823	152.4
1966	1953	210.6
1967	2146	122.9
1968	2307	65.3
1969	2047	102.4

Sources: (1) The Canadian figures are obtained from *Private and Public Investment in Canada*, Department of Trade and Commerce (various issues).

(2) The United States figures of 1948-63 are obtained from *Report to the President on Steel Prices*, April 1965, p. 61, and those of 1964-69 are obtained from *Report to the President on the Economic Position of the Steel Industry*, p. 25.

In fact, the two theories do not conflict but are complementary. A tentative theory can be formulated as follows. The late start in adopting both the BOF and CCM in the United States is due to the fact that huge investments were made in installing the traditional machines and equipment immediately before BOF and CCM came into being, and also the belief that the use of the low-capacity early models was not as economical as that of the old installations in large-scale production. And the reasons why Canadian firms were able to adopt these innovations faster than the American firms are that the Canadian firms were relatively small and that the Canadian steel industry was growing with its increasing share in the North American steel market. [1]

(b) The Interfirm Diffusion of BOF

The diffusion of the BOF provides an excellent illustration of interfirm diffusion pattern in the United States. In 1955, McLouth Steel, a firm with less than 1 per cent of American ingot capacity, was the first firm in the United States to install a BOF. None of the major firms took any initiative to adopt the BOF until 1957 when Jones and Laughlin Company installed its first basic oxygen furnace. The two biggest

[1] The increase in the Canadian share in the North American market can be illustrated by the following figures;

	1955	1960	1965	1969	
Canadian domestic shipments	3.1	3.7	6.5	7.2	(million tons)
U.S. shipments	84.7	71.1	92.7	93.9	
Canadian share(%)	4.0	4.9	6.5	7.1	

See Submission op.cit. Table 7 and Report to the President on Steel Prices op.cit. Table 8.

firms, U.S. Steel and Bethlehem, adopted the BOF in 1963 and 1961, respectively, followed by Republic in 1965.

Table IV-7 shows the existing and future BOF capacity in the American steel industry. Note that the early BOF, which McLouth installed in 1955, was later adapted to handle larger tonnage and so it is not in the table.

Those firms with double asterisks are the largest firms in terms of ingot capacity, and those with an asterisk are large firms. All the rest are small firms. We thus notice that the same kind of interfirm diffusion pattern of BOF existed in the United States as in Canada. Small firms took the lead while big firms lagged behind. There was a lag of six years between McLouth's first installation of BOF and Bethlehem's, one of the two largest firms. The lag between McLouth and U.S. Steel, the remaining largest firm, was eight years.

The theory that the delay between a firm's adoption date and that of the first firm is related to the profitability of the innovation to the firm and firm size is applicable in this case. From 1955 to 1959, the size of various BOF used in the United States was not more than 110 net tons per heat. The smallness led big firms to believe that the BOF was not economical and, hence, not profitable for them. But the small size was particularly suitable for small producers and in view of the tremendous savings both in capital and operating costs, the BOF was regarded as profitable.

Table IV-7

THE EXISTING AND FUTURE BOF CAPACITY IN THE UNITED STATES

Start up Date	Company	No. of BOF & Output Per Heat (Net Tons)	Annual Capacity Existing	Annual Capacity Announced Addition
1957	*Jones & Laughlin	2 x 80	1,000,000	
1958/60 1969)	McLouth	3 x 110 2 x 110	2,800,000	
1958	Kaiser	3 x 110	1,500,000	
1959	Interlack	2 x 75	750,000	
1961	Jones & Laughlin	2 x 225	2,250,000	
1961	**Bethlehem (Pueblo)	2 x 120	1,200,000	
1962	*National Steel (Great Lakes)	2 x 300	3,600,000	
1963	**Armco	2 x 180	2,000,000	
1963	**U.S. Steel (Duquesne)	2 x 220	2,500,000	
1964	Ford Motor	2 x 250	2,600,000	
1964	Wheeling-Pittsburgh	2 x 200	1,800,000	
1964	Wisconsin Steel	2 x 140	1,200,000	
1964/66	Bethlehem (lackawanna)	3 x 300	4,700,000	
1965	*Republic (Warren)	2 x 190	2,100,000	
1965	Republic (Gadsden)	2 x 190	1,500,000	
1965	U.S. Steel	3 x 210	4,000,000	
1965	Wheeling-Pittsburgh	2 x 250	2,600,000	
1966	Allegheny Ludlum	2 x 80	500,000	
1966	Bethlehem (Sparrows Point)	2 x 200	2,800,000	
1966	*Inland	2 x 255	3,500,000	
1966	Republic (Cleveland)	2 x 240	2,800,000	
1967	Granite City	2 x 230	2,200,000	
1967	National Steel (Weirton)	2 x 335	3,500,000	
1968	Alan Wood	2 x 140	1,250,000	
1968	Bethlehem (Bethlehem)	2 x 250	2,500,000	
1968	Crucible Steel	2 x 105	900,000	
1968	Jones & Laughlin	3 x 200	3,000,000	
1969	*Armco (Middleton)	2 x 200	2,000,000	
1969	U.S. Steel	3 x 200	3,000,000	
1970	Bethlehem (Burns Harbour)	2 x 250	2,000,000	
1970	National Steel (Great Lakes)	2 x 200	2,000,000	
1970	Republic (Buffalo)	2 x 100		1,000,000
1970	U.S. Steel (Lorain)	2 x 220		2,800,000
1970	*Youngstown	2 x 265	3,000,000	
1971	U.S. Steel (Gary)	3 x 200		4,000,000
1971	U.S. Steel (Braddock)	2 x 220		2,250,000
1973	Inland	2 x 210		2,200,000

*Large.

**Largest.

Source: *Metallurgical Bulletin Monthly*, February 1971, p. 24.

The second factor -- firm size -- certainly has some effect on interfirm diffusion of BOF. U.S. Steel and Bethlehem accounted for 28.2 per cent and 15.5 per cent of the total ingot capacity in 1960, respectively, and the eight big firms accounted for 76 per cent of the total ingot capacity.[1] Big firms were therefore not as anxious as small firms in reaping any additional windfall, if any. Adams and Dirlam have even suggested that "the structural and behavioral characteristics of oligopolized industries prevent the dominant firms from pioneering."[2]

In summary, big firms lagged behind small firms in the adoption of the BOF process in the United States, and the explanation is that the early BOF was considered as uneconomical and unprofitable by big firms; second, big firms tended to be more cautious and conservative in adopting new production techniques and equipment.

(c) <u>The Diffusion of BOF in the Industry -- A Comparison with Canada</u>

The above section discussed the reason why big firms were slow in adopting the BOF. The present section will examine the rates of BOF diffusion in the United States and compare with those in Canada.[3] Diagram IV-3 shows the diffusion of BOF in both countries.

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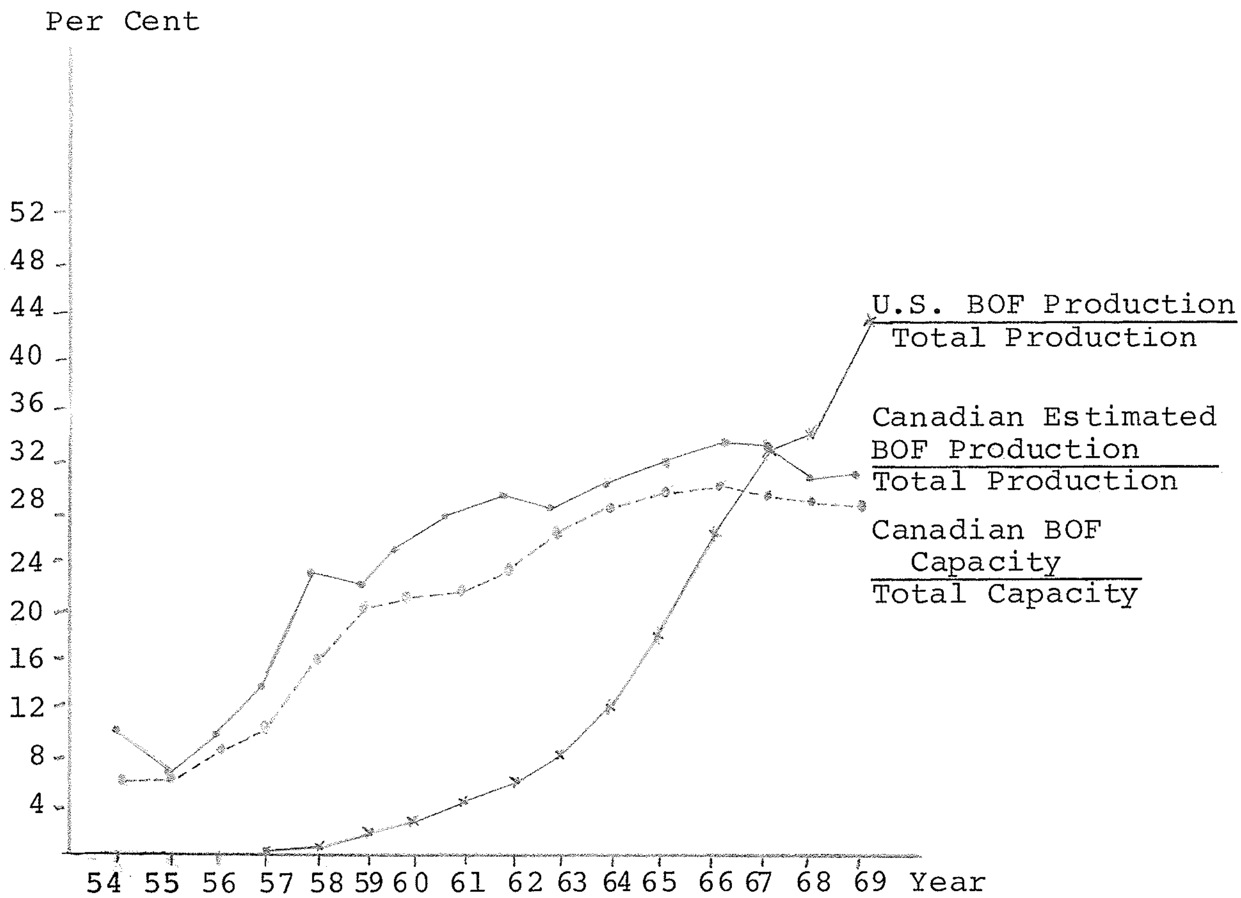
[1]J. Bain, *Industrial Organization*, 2nd edition, p. 140.

[2]W. Adams and J. B. Dirlam, "Big Steel, Invention, and Innovation", *Quarterly Journal of Economics*, May 1966, p. 188.

[3]Intrafirm diffusion of BOF will not be discussed because data are not available.

Diagram IV-3

DIFFUSION OF BOF IN THE UNITED STATES AND CANADA



Sources: (1) U.S. figures 1955-66 are from J. Singer, *The Impact of Trade Liberation: 2*, p. 20, Table 9. 1967-69 figures are from the *Report to the President on the Economic Position of the Steel Industry* from the Cabinet Committee on Economic Policy, July 6, 1971, p. 29, Table 14. Figures for the overlapping years from these two sources are slightly different.

(2) Canadian figures are calculated from Table IV-1.

It can be noted from Diagram IV-3 that the diffusion rates of BOF were lower in the United States than in Canada before 1967. After 1967, the diffusion rates in the United States became greater. Why were the rates lower in the United States before 1967? The small size of BOF which was not profitable to the American steel industry, dominantly composed by big firms, seems to explain part of the phenomenon. However, the smallness of BOF is by no means the most satisfactory answer. National Steel is shown in Table IV-7 to have installed two units of 300 net tons per heat BOF in 1962, which is almost the largest size of BOF the United States has possessed so far. This shows that the small-size thesis was no longer valid, at least, from 1962 onwards. Then, why did the American industry take five more years to catch up to the Canadian diffusion rate in 1967?

The reason lies in the fact that the American steel industry was in a stage of slow growth, the industry's profit rate was declining, and competition was inadequate. The slow growth of the steel industry can be inferred from the following paragraph:

> "During the postwar period, steel has been losing markets to competitive products. In 1947, the relative importance of primary iron and steel in the index of industrial production was 7.8 percent; by 1964 it had fallen to 5.2 percent - in 17 years the importance of primary iron and steel in industrial production had dropped by one-third."[1]

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[1]*Report to the President on Steel Prices*, the Council of Economic Advisers (headed by G. Ackley), April 1965, p. 22.

On the contrary, the Canadian steel industry has experienced a rapid growth. Domestic shipments of rolling mill products represents the actual and realized demand from the domestic industry. The shipment figures are [1] :

	1946	1956	1966	1969	
Canada	1.9	3.9	6.4	7.2	(million tons)
U.S.	63.1*	83.3	90.0	94.0	

* 1947

It is clear that the Canadian growth rate is greater than that of the United States. As mentioned previously, the rapid growth is attributed to the expansion of steel-consuming industries such as construction and consumer durable industries. The automotive product agreement with the United States provided further stimulation to growth.[2]

The declining profit rate is another factor which hindered the rapid technological innovations in the American steel industry since profits are an important source of investment funds. Also, the declining profit trend casts a pessimistic picture and makes executives more cautious in

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[1] Canadian figures: 1946 is from J. Singer, *op. cit.*, p. 10; 1956-69 is from *Submission to the Standing Senate Committee on Banking, Trade and Commerce* by Algoma, Dofasco and Stelco, May 1970, Table 7; American figures: *Report to the President on Steel Prices*, p. 23, and *Report to the President on the Economic Position of the Steel Industry*, p. 6.

[2] The shipments of rolled steel products to the automotive and aircraft industries as percentages of total net shipments are :

1964	1965	1966	1967	1968	1969
7.33	8.26	9.02	10.05	10.06	10.62

The percentages of 1965 and later years are greater than that of 1964. See Statistics Canada, Cat. 41-001, various issues.

planning further expansion. A few figures might be helpful. For the United States, profits after tax as percentage of total revenue was 6.1 per cent in 1947. A slight rise followed in 1949-50 as a result of the Korean War, and the rate stood at 8 per cent in 1950. In 1951, the rate went down to 5.8 per cent. Another round of slight increases occurred in the period 1955-57. From 1958 onwards, the profit rate has been declining, with some minor exceptions around 1964-66, to 2.7 per cent in 1970.[1] A comparison between the Canadian profit rates and American profits rates, as averages of the periods 1962-65 and 1962-64, respectively, is shown as follows:[2]

	Ratio of Profits After Taxes to Total Assets	Ratio of Profits After Taxes to Total Shareholders Equity	Ratio of Profits After Taxes to Total Revenue	Profits After Taxes per Short Ton of Crude Steel (U.S.$/ short ton)
Canada	7.2%	11.1%	8.9%	$11.45
U.S.*	4.5%	6.7%	5.3%	$ 7.27

*1962-64.

The above comparison shows that the American profit rates of the steel industry has fallen far behind that of Canada. This explains partly why the American steel industry was lagging behind Canada in BOF diffusion before 1967.

[1]See *Report to the President on Steel Prices*, p. 36, and *The Steel Industry Today: A Report to the Cabinet Committee on Economic Policy*, submitted by Domestic Member Companies of American Iron and Steel Institute, May 1971, p. 25.

[2]J. Singer, "The Structure and Performance of the Canadian Primary Iron and Steel Industry", *The Impact of Trade Liberalization: 2*, p. 51, Table 26.

The third factor is competition. The American steel industry is highly concentrated. In terms of steel ingot capacity, the two largest firms, namely, U.S. Steel and Bethlehem, accounted for 43.7 per cent of total capacity in 1960. The eight major firms accounted for 76 per cent while the remaining 72 small firms accounted for only 24 per cent.[1] In terms of raw steel output, the four largest firms accounted for 54 per cent of total output and the eight largest firms 75 per cent of total output in 1967. The evolution of the concentration ratio in terms of value added in the steel industry are as follows:

Year	Four Largest Firms %	Eight Largest Firms %
1947	50	66
1954	55	71
1958	53	70
1963	49	68

Source: *Report to the President on Steel Prices*, the Council of Economic Advisers, April 1965, p. 33.

Thus, we see that the concentration ratio, either expressed in terms of capacity, output or value added, has been quite high and has remained more or less unchanged. Although the number of firms in the United States is much more than that in Canada, this does not mean that the American steel industry has been more competitive than the Canadian industry. The reason is that a large number of them are small firms and they account for only 10 per cent of the total mill product shipment while

[1] J. S. Bain, *Industrial Organization*, 2nd edition, p. 140.

the 20 largest firms account for 90 per cent.[1] The small firms apparently produce only negligible effects on the market.

The condition of entry to an industry can reveal the degree of competition within the industry. In the steel industry, the entry of small firms is not really difficult, as exemplified by the recent rise of the so-called mini mill,[2] which uses the electric furnace and a high proportion of scrap. But for a big, integrated firm, the barrier to entry is high. Apart from the heavy capital costs required, the access to high-grade iron ore and the economies of large-scale production constitute the barrier. High-grade reserves of iron ore are held by established big firms, and the economies of scale enjoyed by existing big integrated firms are more than enough to scare off potential entrants. The barrier to entry has weakened only after the introduction of cost-saving technological innovations in the industry.[3] In addition to the barrier to entry, restrictive practices such as price-fixing and price-leadership were prevalent. The basing point pricing system is a typical example.

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[1] *Report to the President on the Economic Position of the Steel Industry*, p. 35.

[2] See A. T. Demaree, "Steel: Recasting an Industry under Stress", *Fortune*, March 1961, p. 141.

[3] *Ibid.*, p. 76.

In other words, the competitive forces of the American steel industry are weak. The lack of strong competitive forces is one of the factors which led to the slow diffusion of technological innovations, exemplified by the diffusion of BOF in our case. It also explains why BOF diffusion in the United States lagged behind that of Canada's before 1967. The theory that the lack of competition leads to slow diffusion of innovations is advanced in Adams and Dirlam's study in which they claim that technological diffusions, including BOF and CCM, were speeded up beginning in 1962 "only after the import threat became serious".[1] Again, as we discussed in earlier sections, the growth rate of the wage rate in the Canadian steel industry has been greater than that in the American steel industry and this is believed to be responsible for the faster diffusion of new technologies in Canada. In sum, the combination of the slow growth of steel market, the slower growth rate of the wage rate, the declining profit rate of the industry and the lack of competition explain why the United States lagged behind Canada in the diffusion of BOF.

(d) Age of Capital Stock and Unused Capacity

Besides the above four factors, two others, namely, the average age of existing capital stock and the proportion of capacity unused, seem to have some influence on the diffusion

[1]The United States was traditionally a net-exporter of steel products but it has become a net-importer since 1959. See W. Adams and J. B. Dirlam, "Steel Imports and Vertical Oligopoly Power", *American Economic Review*, September 1964, p. 647.

of new technologies. We have included the "age" variable as a factor of consideration in our discussion of Canadian intrafirm diffusion. It is also true for industry-wide diffusion since an industry is an aggregation of individual firms. An industry with a young average age of existing capital stock will hesitate to replace all of it by new machines and equipment. However, in comparing two industries which are in different development stages, it may not be necessary that the one with younger average age of existing capital stock will always have slower diffusion of new technologies than another with older average age. When an innovation occurs, it is true that the industry with an older age of stock will "respond" earlier than another industry with a younger age of stock, assuming other things being equal. But as the diffusion goes along, the industry at its prime of growth, although it possesses a relatively young age of existing capital stock as a result of the newly added new machines and equipment, will still press for further additions.

Unused capacity is another factor which might be considered in the diffusion of new technologies. When the underutilization rate of capital stock is high, the incentive to add new stock is weak. But if a careful calculation reveals that the sum of the operating and capital costs per unit of product by using new technology in the foreseeable planning horizon is less than the present operating cost per unit product, then unused capacity would not constitute a hindrance to technological diffusion. In fact, it could be true that the greater the proportion of unused capacity, the more urgent will be the need to replace the old equipment by the new. The reason is that if the expected savings of operating costs and time by using the new equipment is substantial, then the competitive position of steel producers in terms of the speed of product delivering and price can be strengthened. Thus, there are two forces operating at the same time. On the one hand, a high proportion of unused capacity may discourage the addition of new equipment. On the other hand, it may also put greater pressure on the replacement of the old equipment by the new. The actual outcome depends on the relative strengths of the two forces.

For the study of the relationship between unused capacity and diffusion behaviour, the following figures provide a comparison of capacity-output utilization ratio between the Canadian and the American steel industries.

	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Canada	82.2	91.2	80.2	65.2	84.3	76.7	77.0	83.4	86.5	83.7	85.3	82.2
U.S.	93.0	89.8	84.5	60.6	63.6	66.8	65.0	63.0	68.0	77.0	78.0	77.0

Source: Canadian figures are from Table V-3. U.S. figures are from J. Singer, *op. cit.*, p. 18, Table 7.

Note: The capacity-output utilization ratio will be shown to equal capital utilization ratio under some assumption in Chapter V.

We noted previously that the first BOF was adopted in the United States in 1955. The diffusion of BOF speeded up from 1961 onwards and the proportion of BOF capacity in total steel capacity became greater than that of Canada in 1967. What we are concerned with here is whether the diffusion of BOF is affected by unused capital capacity, represented by the output-capacity utilization rates shown above. It is surprising to note that from 1955 to 1957, the utilization rates were high in the United States, meaning that the unused capital capacity was low, yet only two units of 80 tons per heat BOF were added by Jones and Laughlin within this period. A few more units of BOF were installed from 1958 on and the pace of diffusion accelerated after 1961. But the output-capacity utilization rates of the 1958-63 period in the United States were around 60 per cent, meaning that about 30-40 per cent of capacity was unused. Nevertheless, it was this period which witnessed the rapid diffusion of BOF. Thus, the conclusion is that unused capacity has been a positive factor in BOF diffusion in the United States.

H. Summary and Conclusion

This chapter has been mainly devoted to an enquiry into the diffusion of new technologies, mainly represented by the diffusions of basic oxygen furnace and continuous casting machine, in the Canadian steel industry. With respect to diffusion of BOF and CCM in Canada, the findings are: (a) the diffusion of BOF has been faster than that of CCM since BOF saves more capital cost per ton of raw steel than CCM and hence is more profitable than CCM. The other reason could be that the early CCM was not as perfect a substitute for the traditional technology as in the case of BOF. (b) The delay in using a certain innovation by a firm is related to the profitability of the innovation to the firm and the size of the firm. Contrary to Mansfield's belief, it is argued that the larger the size of firm, the longer would be the period of delay. This is confirmed by the fact that Dofasco, a small firm in Canada, adopted BOF much earlier than Stelco. (c) The average age of existing capital stock, unused capacity, market share, firm's profit rate and liquidity ratio are considered as determinants of intrafirm diffusions.

For the industry-wide diffusion, market growth, the growth rate of wage rate, industry's profit rate, competition, average age of capital stock and the capacity-output utilization ratio, are considered to be important variables. A comparison with the diffusion pattern of BOF in the United States yields the following conclusions:

(1) The small sizes of early BOF and CCM were suitable for the scale of operation of Canadian firms at the time they appeared but not economical for the large scale production of American firms. This explains the lead of Canadian firms in adopting them and partly also their rapid diffusions.

(2) The cause of delay in the use of BOF in the United States partly lies in the fact that the existing capital stock was very young. Major investments in the open-hearth furnace were made immediately before BOF was adopted in North

America. Although similar investments were made in Canada about the same time, the Canadian steel industry was growing and so space was available for the immediate addition of BOF.

(3) Other factors which delayed the innovations were the American steel industry's declining profit rate and its lack of competition in the early period. Diffusion became faster only after import competition was felt. The capacity-output utilization ratio has also affected the pace of BOF diffusion. In the case of the United States, the low utilization ratio coincides with the adoption of the basic oxygen furnace.

(4) The divergence in the behaviour of BOF diffusion in the two countries can be partly explained by the growth rates of the wage rates in the two industries. The growth rate of the wage rate has been greater in Canada and this shortens the economic life of machinery and equipment which prompts the introduction of the innovations.

Productivity growth is not only a function of the availability of new technology but more important, also a function of the diffusion of technology. Have the differences in the diffusions of BOF and CCM between Canada and the United States produced differing effects on the net output growth of the steel industries in the two countries? Have there been any notable changes in the production relationship of the two industries during the process of technological diffusion? These are the topics which will be discussed in subsequent chapters.

Chapter V

THE RESIDUAL MEASURE OF TECHNOLOGICAL CHANGE -- SOLOW APPROACH

As was indicated in Chapter III, the measurement of technological change will be carried out by using Solow, Denison and production function approaches. The purpose of this chapter is to discuss several conceptual problems of measurement, the data requirement and the application of the Solow model to the study of technological change in the Canadian steel industry for the period 1946-69. For comparative purpose, some references to the American steel industry will also be made.

A. The Rate of Technological Change

A rise in labour productivity could be due to a rise in capital-labour ratio and/or an advance in technology. The Solow approach presented in this chapter is to answer the question: how much of the rise in labour productivity of steel production is attributable to the increase in capital-labour ratio and how much is attributable to the advance in technology?

Technological change is defined here as a residual measure which accounts for what is left over after deducting a weighted growth rate of capital per labour unit from the growth rate of net output. In an industry such as the iron and steel mills,[1] the basic factors of net output are labour, fixed capital and working capital. Assume the production function to be of the form:

$$Q = min\ [A(t)f(K,L);\ B(t)g(I)] \qquad \text{(Equation 5.1)}$$

where Q is net output, K denotes fixed capital, L denotes labour and I represents working capital. $A(t)$ and $B(t)$ are two shift factors. Working capital includes stocks of goods in process and warehouse stocks of finished goods. Of the three inputs, labour and fixed capital are substitutable for each other to a certain extent but neither labour nor fixed capital is substitutable for working capital. Since (K,L) and (I) are not substitutable, it implies that the smaller one, or the minimum one in the case of more than two factors, will constitute the limiting factor. As working capital itself is created in the production process, its quantity can be increased at will. Thus, working capital does not constitute a limiting factor. But the creation of working capital depends on the availability of labour and fixed capital. In other words, working capital becomes a limiting factor only at a given capital and labour combination. Thus, the limiting factors are in fact labour and fixed capital. Then, net output, Q, becomes a function of labour and fixed capital

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[1]According to "Standard Industrial Classification", the industry titled "iron and steel mills" includes establishments which manufacture pig irons and ferro-alloys, ingots and steel castings, hot and cold rolled steel and the operation of coke ovens in connection with blast furnace. See Statistics Canada, Catalogue no. 41-203, 1963 issue, p. 3. The term "iron and steel mills" is interchangeably used with "the steel industry".

alone. Thus, if the following is true:

$$B(t)g(I)>A(t)f(K,L)$$

then the production function can be written as:

$$Q = A(t)f(K,L) \quad . \qquad \text{(Equation 5.2)}$$

Two assumptions are made. First the production function represented by Equation (5.2) is homogeneous of degree one and, second, perfect competition prevails. The first assumption implies the existence of constant returns to scale. That is,

$$\lambda^r Q = A(t)f(\lambda K, \lambda L)$$

where r equals to unity in the present case. The second assumption implies that the two factors K and L are paid their respective marginal products. The assumption of constant returns to scale in turn imply that the sum of the shares of capital and labour is always equal to one:

$$W_K + W_L = 1 \ .$$

As we have shown in Chapter III, if we differentiate Equation 5.2 with respect to t and use the marginal productivity relationship, we would obtain the relationship

$$\frac{\dot{A}}{A} = \frac{\dot{q}}{q} - W_K\frac{\dot{k}}{k} \qquad \text{(Equation 5.3)}$$

where $q = \frac{Q}{L}$, $k = \frac{K}{L}$, $W_K = \frac{\frac{\partial Q}{\partial K}\cdot K}{Q}$ and $\frac{\dot{A}}{A}$ represents the rates of technological change. The meaning of the above model can also be illustrated as follows. First, rewrite the production function of Equation (5.2) as:

$$q = A(t)f(k,1) \ .$$

This means that output per man-hour is a function of technological change and capital per man-hour. Thus, the movement between two points on a q-k space is a mixture of the shifting of the curve (technological change) and the movement along the curve (change in capital per man-hour, k). The purpose of Solow's model is to disentangle the technological change factor from the mixture.

(a) <u>Overestimation of Capital Stock</u>

Before calculating the rates of technological change by using Equation (5.3), a discussion on the nature of capital stock data might help us in grasping the true meaning of technological change so derived. Our capital stock data are constructed by the perpetual inventory method by Statistics Canada. Generally speaking, the perpetual inventory method adds purchases of capital goods over a number of years to obtain an industry's capital stock in a particular year. The number of years depends on the average economic life assumption of capital goods.[1] In the iron and steel industry, apart from machinery, most capital equipment vary in size and design.

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[1]For a description of the perpetual inventory method, see Statistics Canada, Catalogue no. 13-522, *Methodology: Fixed Capital Flows and Stocks in Manufacturing*, pp. 42-53.

Accordingly, their costs are different. In deriving a series of capital formation, capital expenditures of various projects are added for each year. A number of problems might arise in this connection. As mentioned above, production equipment such as a blast furnace or a steel furnace is not a machine which can be bought and put into immediate active production. It usually takes more than one year to complete the project and put it into actual use. Even a new installation of some kind, which consists of a group of machines and equipment, requires an experimental period. In any event, a time lag between the spending of capital expenditures on new projects and the actual use of these projects exists.[1] However, the way our capital stock data are constructed, no recognition is taken of this fact. The capital expenditure of a certain year is counted as the capital formation of that year. But the construction or equipment represented by the additional capital expenditure does not contribute to the production of the year when the capital expenditure is recorded. The overestimation of capital stock entails the overestimation of capital services going into production. As a result, recorded total productivity of a particular year when the additional capital expenditure is recorded has a downward bias, for the net output remains unchanged, or rises slower than does the total input services. On the other

[1] An excellent example is that The Steel Company of Canada announced in 1969 the initiation of a project to replace eight open-hearth furnaces by three units of oxygen furnaces. The project will not be completed until 1974.

hand, recorded total productivity rises more than it should when the project which was started a few years ago is finally completed and put into actual production, since not all of the services provided by the newly completed project are counted as additional inputs for the year in question. All these will contribute to the violent fluctuation of the rates of technological change $\left(\frac{\Delta A}{A}\right)$ and the technological index $\left(A(t)\right)$, if they are not corrected.

Another possible source of overestimation is the inclusion of repair expenditures in capital formation. Repair expenditures, which are spent to maintain the normal working efficiency of capital equipment, cannot be counted as capital formation since, strictly speaking, there is no increase in capital stock or capital service. Nevertheless, there are cases where innovations are introduced with respect to repairs. If a part of some equipment is to be changed, the latest design is frequently adopted if it is mechanically possible. In reality, it is difficult to sort out the proportions between pure repair and repair with innovation.

A similar problem arises when expenditures used to install pollution control facilities are included in capital formation. Pollution control, either adopted voluntarily, or when compulsory, prevents contamination but contributes nothing to the actual production *per se*. Recorded total factor productivity falls since the expenditure on pollution control is counted as part of the input service. However, this problem is not serious for the period which we are concerned with, for pollution control is a relatively new event. Even if some expenditures on pollution control[1] existed for some years in the sixties, the amounts are believed to be negligible compared with other major expenditures.

A compensatory factor to the overestimation of capital stock might be the increasing use of shift work, if it exists at all. The increase in the number of shifts -- usually from two to three shifts -- increases the intensity of capital use which is equivalent to an increase in capital stock. But the advantages of increasing shift work would be reduced if depreciation of capital equipment accelerates when the intensity of use is increased.[2] The counterbalancing force of shift work is further weakened since steel production in Canada has always operated on a three-shift basis, and it has been impossible to increase the number of shifts. Coke oven, blast furnace and steel furnaces (except electric furnaces) are operated 24 hours a day and continuously throughout the year in order to preserve the heat until they need relining. It is true that works in the rolling mill stage could be slackened or increased depending on the demand condition.

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[1]Both Dominion Foundries and Steel Ltd. and The Steel Company of Canada Ltd. reported that they have spend $14 million each for pollution control in the sixties. See Dofasco's *Annual Report, 1969*, p. 7; and Stelco's *Annual Report, 1966*, p. 14.

[2]T. Haavelmo, *A Study in the Theory of Investment* (Chicago: Chicago University Press, 1960), p. 84.

Nevertheless, there is no strong indication that shift work has increased the intensity of use of capital stock in the steel industry.

(b) Utilization of Capital Stock

Thus, if the shift work factor exists, it cannot be expected to have exerted adequate correcting effect to the overestimation of capital stock. The overestimation caused by the time lag between investment and project completion can only be corrected by reconstructing the capital stock data on an individual establishment basis, which is an enormous task in itself.

In addition to the overestimation problem, there is the underutilization problem of the completed capital stock. As is well known, production falls during recessions and rises when strong demand is anticipated. The fluctuation in the degree of capital utilization is particularly obvious during business cycles. The fluctuation in the utilization rates of capital causes violent fluctuations in the productivity movement as does the overestimation of capital. The only way to correct for underutilization of capital stock is to multiply the capital stock or capital service series by the capital utilization rates.

For the Canadian steel mill industry, capital utilization rates are not available, but capacity output utilization rates for steel furnace are available in various issues of *Census of*

Manufacture (Statistics Canada, Catalogue no. 41-203). Capacity output is defined as "the production flow associated with the input of fully utilized manpower, capital, and other relevant factors of production" and capacity output utilization is the ratio between actual output to capacity output.[1] Under the assumption that capital suffers the same degree of unemployment as labour capacity output utilization is the same as capital utilization. The unemployment of labour should refer to the ratio between the actual man-hours employed by the industry at a specific time period, and the man-hours needed to operate all productive facilities when the industry is in peak production condition. Let L be the actual man-hours employed and $\overline{L}$ be the man-hours needed to operate all capital equipment, including structures and machines at peak periods. The degree of labour utilization is then equal to $L/\overline{L}$. By assuming that it equals the degree of capital utilization, i.e.,

$$\frac{K}{\overline{K}} = \frac{L}{\overline{L}} = \lambda \qquad \text{(Equation 5.4)}$$

where K is the actual capital service used and $\overline{K}$ is the total capital service available, capacity output utilization can be shown to equal capital utilization. Write a general neo-classical production function as:

[1]See L. R. Klein, "Some Theoretical Issues in the Measurement of Capacity", *Econometrica*, 1960, p. 275; and L. R. Klein and R. S. Preston, "Some New Results in the Measurement of Capacity Utilization", *American Economic Review*, 1963, p. 42.

$$Q = f(K,L) \qquad \text{(Equation 5.5)}$$

for the actual production relationship. The capacity output production function can be written as:

$$\bar{Q} = f(\bar{K},\bar{L}) \;. \qquad \text{(Equation 5.6)}$$

The assumption of Equation (5.4) implies

$$\bar{K} = \frac{K}{\lambda} \quad \text{and} \quad \bar{L} = \frac{L}{\lambda} \;. \qquad \text{(Equation 5.7)}$$

Substitute (5.7) into (5.6), we get:

$$\bar{Q} = f\left(\frac{K}{\lambda},\frac{L}{\lambda}\right)$$

$$\bar{Q} = \frac{1}{\lambda}f(K,L) \;.$$

By virtue of Equation (5.5), it becomes:

$$\bar{Q} = \frac{1}{\lambda} \cdot Q \;.$$

Hence, $\lambda = \dfrac{Q}{\bar{Q}}$. Thus, $\dfrac{Q}{\bar{Q}} = \dfrac{K}{\bar{K}}$.

It is obvious that steel furnaces are only one of the many kinds of capital equipment in steel production. However, it is also the most important kind of capital equipment. Moreover, there exist, more or less, fixed proportions between the capacities of various kinds of capital equipment. The original design of, for instance, blast furnaces and steel furnaces, must be such that the total output of blast furnaces, say 200 tons of pig iron a day, is exactly absorbed into the steel furnace. Otherwise, either persistent underutilization of the steel furnace or production bottlenecks might arise. Thus, it seems to be appropriate to assume that all other capital equipment will be used to the same extent as steel furnaces. We may therefore use the capacity output utilization rates of steel furnaces as a proxy for total fixed capital utilization rates. The series will be used to multiply the capital service series to obtain an adjusted capital service series. This series will then be used to calculate rates of technological change and the technological index.

B. Data Requirements

(a) The Data for the Canadian Steel Industry

The data for the steel industry are relatively complete compared to other industries. However, there have been changes in classification and reporting procedures which require some adjustments.

Certain changes in classification, definition and procedures took place in 1960, 1961 and 1962.[1]

(i) 1960 -- a revised Standard Industrial Classification;

(ii) 1961 -- a new definition of establishment; and

(iii) 1961 -- an extension of the definition of establishment to include the non-manufacturing activities of manufacturing establishments.

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[1]See Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1963, Concepts and Definitions.

(i) Revised Standard Industrial Classification (SIC)

Statistical data covering the period prior to 1960 are based on the 1948 SIC. In 1960, a new Standard Industrial Classification which classified all manufacturing industries into 140 industries, instead of the 135 under the 1948 SIC, was introduced. The implication of the change in SIC for the iron and steel mills industry, is that coke and gas operations in the industry were not counted as a part of the industry before 1960, but it has been so counted since 1960.[1] In Tables 1A and 1B of 1960 issue of *Iron and Steel Mills* (Statistics Canada, Catalogue no. 41-203), the new SIC has been applied to 1959, 1958 and 1957, and this provides a basis of comparison between the old and new SIC. The following table shows the difference before and after the change.

MANUFACTURING ACTIVITY AND OLD ESTABLISHMENT CONCEPT

	Number of Employees			Salaries and Wages ($)		
	Old SIC	New SIC	% Δ	Old SIC	New SIC	% Δ
1957	35,944	37,139	2.32	170,779,346	176,991,352	3.64
1958	30,261	31,346	3.58	148,023,062	153,739,413	3.86
1959	34,942	36,182	3.54	183,000,151	184,459,014	3.53

Note: These data cover only manufacturing activity, not total activity.

Source: Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1960, p. 6, Tables 1A and 1B.

[1]See Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1960, p. 5.

It can be seen from the above table that the effect of the change is between 2 to 4 per cent.

(ii) New establishment definition (1961)

The definition of the reporting unit -- the establishment -- was slightly changed in 1961. The changes before and after 1961 can be illustrated in the following quotation:[1]

> "Prior to 1961, some establishments were required to submit two or more separate reports when they were engaged in activities which were classifiable to different industries. Beginning with 1961, separate reports for such activities are required only in cases where accounting records can provide the necessary input and output elements of principal statistics."

Other aspects of the change include the exclusion of those establishments which are engaged in activities other than manufacturing. Generally speaking, the change in the definition has narrowed the scope of coverage since it discards those units which are too small and lack those principal statistics cited in the new definition of establishment, and also those units which are not engaged in manufacturing activity. The effect of the change in definition can be seen from the comparison in the following table.

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[1]The establishment is defined as "The smallest unit which is a separate operating entity capable of reporting all the following principal statistics: Materials and supplies used, Goods purchased for resale as such, Fuel and power consumed, Number of employees and salaries and wages, Inventories, Shipments or sales." See Statistics Canada, Catalogue no. 41-203, 1962 issue, p. 25.

COMPARISON OF PRINCIPAL STATISTICS, IRON AND STEEL MILLS, CANADA, BEFORE AND AFTER THE CHANGE IN THE DEFINITION OF ESTABLISHMENT

(Basis: 1960 SIC)

	Definition		Employees	Salaries and Wages	Value Added by Manufacture	Selling Value of Factory Shipments
				($)	($)	($)
1957	New	42	36,004	171,992,639	--	711,115,773
	Old	50	37,139	176,991,352	--	733,603,689
1958	New	42	30,570	149,773,487	311,393,545	594,796,122
	Old	50	31,346	153,739,413	--	610,843,551
1959	New	40	35,320	185,273,835	403,392,320	789,810,663
	Old	48	36,182	189,459,014	--	808,797,661
1960	New	39	35,364	188,582,471	367,993,864	734,483,217
	Old	48	36,472	193,892,738	375,384,276	756,456,392

Source: Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1961, p. 8, Table 18; and 1960 issue, Table 1B, p. 6.

We thus see that the new definition has reduced the number of establishments. Accordingly, the figures under the new concept are less than those under the old concept.

(iii) Manufacturing activity and total activity

Another change also occurred in 1961. Before 1961, the figures reported cover only manufacturing activity. Total activity is the sum of manufacturing activity and nonmanufacturing activity, and it relates to "all operational data and excludes such nonoperational items as rent, interest and dividends".[1] The following provides a comparison of the principal statistics in 1961 under the manufacturing and total activity concept.

[1]See Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1962, Explanatory Notes.

	Number of Employees	Salaries and Wages	Value Added
		($)	($)
Manufacturing activity	34,546	193,112,000	411,494,000
Total activity	34,749	193,712,000	405,187,000

Source: Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1962, Tables 1 and 1A, p. 4.

The number of employees and salaries and wages under total activity concept are both greater than their corresponding figures under the manufacturing concept. However, the value added figure is smaller than that under manufacturing activity concept. Value added is obtained by subtracting all expenses from the value of production.[1] If the value added of the nonmanufacturing sector is less than its expenditures, then the value added of total activity is less than that of the manufacturing activity. This could be due to other reasons as well.[2]

[1]It is actually the value of shipment adjusted for inventory changes.

[2]"This total value added figure may, in some cases, be less than value added by manufacturing activities as a result of expenditures associated with non-manufacturing exceeding revenues from such activities or because of a decrease in inventory of goods not of own manufacture exceeding the mark-up on the sale of such goods." See Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1963, p. 29, Concepts and Definitions.

The effect of SIC change is to increase the relevant figures since coke and gas operation related to steel production has now been added to the industry. On the other hand, as we have seen, the new establishment concept has reduced the number of establishments and hence the related figures. Though these two changes produce a compensation effect, a gap still remains. Moreover, the shift from a manufacturing activity basis to a total activity basis produces another gap. Three adjustments are necessary to accommodate these three changes, since the data prior to 1960 were based on the old SIC, covered only manufacturing activity, and were under the old establishment concept. However, the data for 1957 and 1961, which are based on the new SIC - the new establishment concept (although they are still confined to manufacturing activity) can be obtained from Statistics Canada (Catalogue no. 41-203, 1962, p. 4, Table 1). This provides a link between the data based on the old SIC-old establishment concept and those based on the new SIC-new establishment concept, thus reducing the number of adjustments to two, namely, SIC-establishment concept adjustment and manufacturing-total activity adjustment.

(iv) Labour service

Labour service is measured by man-hours paid. Prior to 1960, no "actual" man-hour figure was published in *Iron and Steel Mills* (Statistics Canada, Catalogue no. 41-203), and since 1960 only man-hours of production workers have been published.

A way to get a complete series of annual man-hours is to multiply the series of average weekly hours of production workers and nonproduction workers separately by the numbers of employees in each category and by 52 weeks, and then add the two series. The average weekly hours of production worker can be obtained from *Review of Man-Hours and Hourly Earnings* (Statistics Canada, Catalogue no. 72-202, various issues), while that of nonproduction workers and their numbers are available in *Earnings and Hours of Work in Manufacturing* (Statistics Canada, Catalogue no. 72-204). Following Griliches, another way is to divide the salaries and wages series by the series of hourly earnings of production workers.[1] The resulting series represents the total man-hours paid in terms of production workers' man-hours. Note that the average hourly earnings of nonproduction workers such as administrative personnel are generally higher than those of the production workers. If marginal productivity theory is valid, this means that a man-hour's work of a nonproduction worker contributes more than that of a production worker. This implies that a man-hour of the former is equivalent to more than one man-hour of the latter. By dividing the salaries and wages series by the average hourly earning series of production workers, we have converted the man-hours paid of nonproduction workers into production

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[1]See Z. Griliches, "Production Functions in Manufacturing: Some Preliminary Results", *The Theory and Empirical Analysis of Production* (edited by M. Brown) (New York: National Bureau of Economic Research, 1967), p. 280.

workers' man-hours. This conversion represents a cross-sectional adjustment of labour quality since the greater contribution obtained from the better quality of the nonproduction workers than those of the production worker has been taken into account. The Griliches' method of measuring labour input is adopted since his measurement includes some labour quality adjustment.[1]

The data for salaries and wages are obtained from various issues of *Iron and Steel Mills* (Statistics Canada, Catalogue no. 41-203). To be useful, three adjustments have to be made. The first adjustment is to eliminate the gap between the data based on the old SIC-old establishment concept, and the new SIC-new establishment concept. For example, the figures are $170,779,346 (old SIC-old establishment concept) and $171,993,000 (new SIC-new establishment concept) for the year 1957. The ratio is 1.0071. Assuming that the same relationship is maintained, the data based on the old SIC-old establishment concept are multiplied by 1.0071 from 1946 to 1956. We then have a series of SIC adjusted, establishment concept corrected salaries and wages from 1946 to 1961. The figures for 1957-61 based on the new SIC-new concept are published in the 1962 issue of *Iron and Steel Mills*. But all these data cover only manufacturing activity. Hence, the second adjustment is to

[1] There are two categories of labour, namely, production worker and salaried worker in the steel industry. By dividing the total wage and salary bill by the hourly employment cost or earnings of the production worker, we have converted the salaried workers' man-hours into production workers' man-hour equivalents. Since their hourly earnings differ, their qualities are different if the marginal productivity theory holds. Through Griliches' method, they are converted into a basic unit of labour with the same quality.

link these data with those which cover total activity. The latter can be found in the 1968 issue of *Iron and Steel Mills*. The figure which covers manufacturing activity only for 1961 is $193,112,000 and that which covers total activity for the same year is $193,712,000. The ratio of these two figures is 1.0031. The SIC-establishment corrected series (1946-61) is then multiplied by 1.0031 and linked with the series 1961-69 which covers total activity. However, these figures are underestimated because they do not take account of workers' supplemental benefits provided by employers such as medical care. There are two figures which take account of these benefits and are available in Statistics Canada publications. They are the figure for 1949 ($85,000,000) and that for 1961 ($204,500,000).[1]

SALARIES AND WAGES

(Dollars)

	Including Supplemental Benefits	Excluding Supplemental Benefits	Ratio
1949	85,000,000	83,806,228	1.01424
1961	204,500,000	193,712,000	1.05569

[1]The figure for 1949 is obtained from Statistics Canada, Catalogue no. 13-513, *Supplement to the Inter-Industry Flow of Goods and Services*, 1949, Table 1. The second figure is from Statistics Canada, Catalogue no. 15-501, *The Input-Output Structure of the Canadian Economy*, 1961, p. 316.

The figures which exclude supplemental benefits are the end results of the second adjustment. The annual growth rate is derived from the two ratios and interpolated for the missing years between 1949 and 1961. The same growth rate is used to extend the series both before 1949 and after 1961. Hence, a series of ratios from 1946 to 1969 is constructed and used to multiply the salaries-wages series resulting from the second adjustment. The resultant series is the corrected salaries and wages in current dollars.

The next step is to obtain a series of average hourly earnings of production workers. This series is published in *Review of Man-Hours and Hourly Earnings*[1] (Statistics Canada, Catalogue no. 72-202, various issues). The division of the corrected salaries and wages by the hourly earnings of production workers yields the series of production worker man-hour equivalents. This means that the man-hours of salaried workers are converted into production workers man-hour equivalents.

(v) Capital service

Unpublished capital stock data in constant 1961 dollars were provided by Statistics Canada, with a breakdown into machinery-equipment and construction. They have been adjusted for SIC and other changes and so the data are consistent throughout the whole period. We have followed

[1]The figures for 1946-50 are supplied by Mr. Ouellette, Employment Section, Labour Division, Statistics Canada.

Griliches' argument that gross capital stock is the relevant concept for production function analysis.

> "But the value of old machines will decline because their expected life span is declining, because better new machines have become available, and because the quality of their services deteriorates as they age. Only the last one is a legitimate deduction to be made from a *service*-oriented measure of capital. It is true that there is less life left in an old machine, but that does not mean that its product during the current year is necessarily any worse for that."[1]

In deriving a measure of capital service from machinery-equipment and construction, the durability problem has to be taken into account. The life assumption of machinery-equipment is 15 years and that of construction is 30 years. Both Haavelmo and Griliches have stressed the importance of the durability problem in constructing an accurate capital series. What Haavelmo suggested is to group the various kinds of capital according to their durabilities and consider a change in the average durability of capital as a relative change in volume of the various kinds of capital.[2] Griliches, however, observes, "A $100 machine that will last five years will have roughly twice as large an annual flow of services (in dollars) than another $100 machine whose expected length of life is ten years."[3] In our case, since an item of

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[1]See Griliches, *op. cit.*, p. 314.

[2]T. Haavelmo, *op. cit.*, p. 98.

[3]See Griliches, *op. cit.*, pp. 314 and 320.

construction such as a building is assumed to last two times as long as a piece of machinery or equipment, this implies that the service provided by the latter in a year is roughly twice as valuable as that provided by the building if the two items cost the same.

Thus, in combining the service of construction and that of machinery and equipment, the latter should receive a greater weight than the former. It is assumed here that service flow of capital is proportional to capital stock. The method of deriving the appropriate weights is as follows.[1] Assuming a discount rate, the present value of the flow of annuity which covers a specified period of time can be calculated. The weight is then obtained by dividing unity by the present value of the item in question. In our case, the discount rate is the average interest rate of ten industrials over the period 1948-69, provided by the Bank of Canada in unpublished form. It is 5.1061 per cent. The present value of $1 annuity over the period of 15 years is given as:

$$Y_{15} = 1 + \frac{1}{(1+r)^1} + \frac{1}{(1+r)^2} + \ldots + \frac{1}{(1+r)^{14}} = 10.83183$$

$$W_1 = \frac{1}{10.83183} = 0.09232 \ .$$

Similarly, the present value of $1 annuity over the period of 30 years is:

[1]See also Griliches, *op. cit.*, pp. 314 and 320.

$$Y_{30} = 1 + \frac{1}{(1+r)^1} + \frac{1}{(1+r)^2} + \ldots + \frac{1}{(1+r)^{29}} = 15.96396$$

$$W_2 = \frac{1}{15.96396} = 0.062641 .$$

W_1 and W_2 are the weights used to multiply the values of machinery-equipment and construction, respectively.

$$K = W_1 \text{. machinery-equipment} + W_2 \text{. construction}$$

$$\frac{K}{W_1} = \text{machinery-equipment} + \frac{W_2}{W_1} \text{ construction.}$$

Let $\frac{K}{W_1} = K^*$. Then K^* is the measure of total capital service in the iron and steel mills industry.

(vi) Value added and labour share

In addition to man-hours and capital service, we also need value added in constant dollars. This is provided by the index of real domestic product in the steel industry published in *Index of Real Domestic Product by Industry (1961 Base)* (Statistics Canada, Catalogue no. 61-506; and Statistics Canada, Catalogue nos. 61-510 and 61-005. The latter two publications are the revised issues of the original publication.)

To convert the index into value added in constant 1961 dollars, the figure of value added in 1961 is needed. This figure is $350,200,000 taken from Statistics Canada (Catalogue no. 61-510, p. 87). Note that this figure is less than the corresponding figure which is reported in Statistics

Canada (Catalogue no. 41-203).[1] The reason is that those figures reported in Catalogue no. 41-203, still include the cost of advertising, insurance and other business expenses,[2] while the figure reported in Catalogue no. 61-510, does not include these items. Thus, a new series of value added in constant dollars, which is net of these items, is obtained by multiplying the series of real domestic product index of iron and steel mills by $350,200,000, and dividing by 100.

The above describes the procedure of obtaining a series of value added in constant dollars. For the purpose of calculating labour share, we need a series of value added in current dollars, since our data for salaries and wages are in current dollars. Similar to the above procedure, several adjustments have been made to obtain a consistent measure of current dollar value added. The original data of value added in current dollars are obtained from *Iron and Steel Mills* (various issues). There are three adjustments to be made. First, an adjustment is needed to accommodate the SIC-establishment concept change. The data of value added of manufacturing activity based on the old SIC-establishment concept are available from 1946 to 1959. Those based on new SIC-new establishment concept are available for 1958, 1959, 1960 and 1961. The data of the two overlapping

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[1]The corresponding figure is $405,187,000.

[2]See Statistics Canada, Catalogue no. 41-203, *Iron and Steel Mills*, 1963 issue, Concepts and Definitions.

years, namely 1958 and 1959, provide links between the data based on the old SIC-establishment concept and the new, and 1958 was chosen as the link. The ratio of the figures for 1958 is 1.02121 which is used to multiply the data based on old SIC from 1946 to 1957. We then have a series of value added of manufacturing activity which is corrected for the SIC-establishment concept change. Second, we have to derive a series of value added of "total activity" from the available series of value added of "manufacturing activity". In the 1962 issue of *Iron and Steel Mills* (p. 4). the value added of manufacturing activity is reported as $411,494,000 and that of total activity is reported as $405,187,000. As previously noted, one of several reasons why the latter is smaller than the former is that the expenditure of the nonmanufacturing sector is greater than its revenues. The ratio of the latter to the former is 0.98467. Thus the series covering 1946 to 1961, which is SIC-establishment concept corrected, is multiplied by 0.98467. This gives us a series of total activity value added from 1946 to 1961. The value added of total activity of the subsequent years can be obtained from the 1968 issue of the same publication (Catalogue no. 41-203). We thus have a complete series of value added of total activity from 1946 to 1969. Finally, the series is adjusted for intermediate service inputs inclusion. It has been noted previously that the value added figures reported in *Iron and Steel Mills* still include the cost of advertising and other intermediate inputs. Two value added figures which do not include these items are the value added of 1946, which is $130,000,000, and that of 1961, which is $350,200,000.[1] These two figures are, of course, less than the corresponding figures which include intermediate service inputs.

	Value Added (Including intermediate service inputs)	Value Added (Excluding intermediate service inputs)	Ratio
	($)	($)	
1946	136,908,935	130,000,000	0.94953
1961	405,187,000	350,200,000	0.86429

Similar to the procedure taken to adjust the salaries and wage series, a complete series of ratios is constructed from the two ratios in the above table by interpolation using the growth rate. The total activity-SIC-establishment corrected series of value added is multiplied by this series of ratios. The resultant series is the final value added data in current dollars.

Using the salaries-wages and value added data, labour share is calculated simply as the ratio of the former to the latter. Capital shares are obtained by subtracting labour shares from unity.

[1]The first figure is obtained from Statistics Canada, Catalogue no. 13-513, 1949, Table 1; and the second is from Catalogue no. 61-510, p. 87. Although there were conceptual changes between the reports of the two years, major changes were in public administration and defence. As far as the iron and steel mills industry is concerned, the data of the two years are comparable. See Statistics Canada, Catalogue no. 61-510, pp. 11 and 15.

THE DATA FOR THE CANADIAN STEEL INDUSTRY, 1946-69

Year	(1) Value Added (Net Output)	(2) Gross Capital Stock	(3) Capital Service	(4) Salaries and Wages	(5A) Hourly Earnings Production Worker	(5B) Hourly Employment Costs, Production Workers	(6) = $\frac{(4)}{(5A)}$ Man-Hours Production Workers Equivalents	(7) Unadjusted Man-Hour	(8) Value Added (Net Output)	(9) Labour Share	(10) Steel Industry Selling Price Indexes
	Constant 1961 Canadian $	Constant 1961 Canadian $		Current Canadian $					Current Canadian $		
1946	128,873,600	224,500,000	198,300,000	51,230,787	0.84	0.89	60,989,032	57,776,775	69,880,040	.7331	50.0
1947	168,446,200	242,300,000	215,300,000	61,348,624	0.96	1.03	63,904,817	61,610,708	90,008,355	.6816	55.3
1948	177,901,600	269,600,000	241,000,000	78,991,734	1.09	1.18	72,469,481	69,477,841	120,509,401	.6555	63.4
1949	179,652,600	291,200,000	260,900,000	84,999,629	1.19	1.30	71,428,260	68,085,485	129,999,141	.6538	68.9
1950	191,559,400	301,500,000	270,700,000	87,811,391	1.27	1.40	69,142,828	65,810,953	146,454,407	.5996	72.1
1951	227,630,000	333,400,000	297,400,000	111,989,978	1.43	1.60	78,314,670	72,924,027	197,014,126	.5684	80.2
1952	228,680,600	400,900,000	356,700,000	128,748,727	1.60	1.80	80,467,954	77,574,486	218,017,840	.5905	85.0
1953	227,980,200	465,700,000	416,400,000	134,709,683	1.70	1.94	79,240,990	76,318,029	200,956,312	.6703	87.3
1954	196,112,100	506,500,000	454,600,000	113,391,451	1.71	1.97	66,310,790	62,552,061	199,894,060	.5673	85.9
1955	279,809,000	532,600,000	479,300,000	143,110,040	1.81	2.11	79,066,320	76,359,574	256,290,711	.5584	87.2
1956	341,445,000	566,400,000	511,200,000	170,862,752	1.97	2.32	86,732,361	85,197,944	318,972,826	.5357	92.7
1957	299,070,800	618,500,000	560,000,000	179,774,673	2.15	2.55	83,602,173	80,098,928	309,313,061	.5811	98.9
1958	248,992,200	672,300,000	609,100,000	157,041,453	2.25	2.70	69,796,241	66,397,085	271,552,163	.5783	99.7
1959	340,044,200	729,100,000	661,200,000	194,906,598	2.36	2.86	82,587,542	78,819,908	348,959,145	.5585	100.2
1960	315,880,400	813,700,000	739,900,000	199,039,209	2.44	2.99	81,573,446	76,874,550	315,764,972	.6303	100.6
1961	350,200,000	894,800,000	815,400,000	204,499,821	2.54	3.14	80,511,741	76,056,725	350,199,072	.5840	100.0
1962	381,367,800	963,800,000	879,800,000	221,541,373	2.60	3.24	85,208,220	80,471,889	387,063,287	.5724	99.8
1963	424,792,600	1,043,500,000	952,900,000	242,501,102	2.67	3.36	90,824,383	85,929,599	429,930,467	.5640	99.6
1964	483,626,200	1,164,100,000	1,064,300,000	269,749,696	2.71	3.44	99,538,633	94,787,785	479,391,553	.5627	99.3
1965	535,105,600	1,304,200,000	1,195,200,000	296,383,486	2.83	3.63	104,729,147	100,335,063	546,457,236	.5424	101.4
1966	528,101,600	1,423,000,000	1,306,500,000	321,401,323	2.94	3.80	109,320,178	101,359,606	542,402,444	.5926	101.7
1967	483,276,000	1,487,400,000	1,367,600,000	328,621,867	3.11	4.06	105,666,195	97,515,444	511,115,009	.6430	103.4
1968	554,016,400	1,499,600,000	1,379,000,000	349,405,988	3.28	4.32	106,526,216	99,485,545	564,316,998	.6192	103.0
1969	557,868,600	1,528,000,000	1,405,000,000	362,071,267	3.49	4.64	103,745,349	92,880,464	579,585,637	.6247	106.7

(1) Statistics Canada, Catalogue no. 61-506, Table 1, p. 26; Catalogue no. 61-510, Table 1, pp. 24 and 87; Catalogue no. 61-005, Table 1, pp. 10-11.

(2) Provided by Statistics Canada (unpublished).

(3) Derived from (2).

(4) Statistics Canada, Catalogue no. 41-203, 1954 issue: Table 2, p. J-4; 1954 issue: Table 2, p. J-5; 1960 issue: Table 1A, p. 6; 1968 issue: p. 2; and 1969 preliminary issue.

(5) Statistics Canada, Catalogue no. 72-202, 1945-54 issue: Table 1, p. 11; 1957-67 issue and 1967-69 issue. Also, Steel and Inflation (PIC), p. 36.

(6) Obtained by dividing (4) by (5).

(7) Statistics Canada, Catalogue no. 72-202 (same as (5)), and Catalogue no. 72-204, 1947 issue: pp. 24-25; 1951 issue: pp. 14 and 17; 1954 issue: pp. 8 and 15; 1957 issue: pp. 20 and 24; and 1969 issue: pp. 10 and 14. The data for 1948, 1961 and 1968 are not available and are therefore interpolated.

(8) Statistics Canada, Catalogue no. 41-203, 1950 issue: p. J-5; 1954 issue: p. J-5; 1960 issue: p. 6; 1962 issue: p. 4; and 1968 issue: p. 2; and the 1969 preliminary issue.

(9) Obtained by dividing (4) by (8).

(10) M. C. Urquhart, *Historical Statistics of Canada*, p. 239, and Statistics Canada, Catalogue no. 62-002 (various issues).

(b) The Data for the American Steel Industry

For the purpose of comparison, similar tests using statistical data, for the American steel industry, will be conducted. The value added and gross fixed plant and equipment figures are available in current dollars[1] and these were deflated by a wholesale price index of finished steel mill products and a wholesale price index of metalworking machinery and equipment, respectively, to obtain figures in constant 1961 dollars. Total man-hours worked and wages and salaries, which include supplemental payments and other fringe benefits, were also obtained from the same sources.[2] The capacity utilization ratios of the years 1947-67 are reported in Singer's study[3] and those for the years 1968-70 were estimated by assuming that the increase in electric furnaces capacity is offset by the decline in open-hearth furnace capacity, since published data on capacity for these three years were not available. The data for average hourly earning of wage-earners for the years 1946-66 were obtained from *Steel Imports*

[1]Value added and gross fixed plant and equipment data are obtained from *Steel Imports*, p. 172, and *Annual Statistical Report*, 1970, AISI, pp. 10 and 12. The wholesale price index of finished steel mill products is taken from *Steel Imports*, p. 165, and *The Steel Industry Today: A Report to the Cabinet Committee on Economic Policy*, submitted by Domestic Member Companies of AISI, p. 32. The wholesale price index of metalworking machinery and equipment is compiled from the *Statistical Abstract of the U.S.*

[2]Total man-hours worked in 1947-66 can be found in *Steel Imports*, p. 467, and those of 1967-70, from *Annual Statistical Report*, 1970, AISI, p. 15. The two sources are consistent so that the continuity of the data is maintained. Wages and salaries data are taken from *Annual Statistical Reports*, AISI (various issues).

[3]J. Singer, *op. cit.*, Table 36, p. 64.

(p. 164), while those for the years 1967-70 were extrapolated by taking an annual growth rate of 8.75 per cent which was the average annual growth rate of the past years. The complete set of data is illustrated in Table V-2.

A few things should be noted, however. As we recall, the derivation of labour measure through the division of wages and salaries, which includes supplemental incomes and fringe benefits, by average hourly earnings of production workers, which does not include supplemental incomes and fringe benefits, performs two functions. First, it converts nonproduction workers' man-hours into production workers' man-hours equivalents. Second, it also converts the increase in labour efficiency into basic efficiency units. As a result, the calculated labour measure in man-hours would be greater than the total man-hours worked, which is the sum of production as well as nonproduction workers' man-hours worked, provided that nonproduction workers have had a higher pay than production workers and labour efficiency has increased through time.

Table V-2

STATISTICAL DATA FOR THE UNITED STATES STEEL INDUSTRY, 1947-70

Year	(1) Value Added Current $ (billions)	(2) Value Added 1961 $ (billions)	(3) Fixed Plant & Equipment 1961 $ (billions)	(4) Total Hours Worked (millions)	(5) Wages & Salaries Current $ (billions)	(6) Hourly Employ-ment Cost Current $	(7) Labour Share %	(8) Capacity Utiliza-tion Ratio %	(9) Hourly Earnings of Pro-duction Workers Current $	(10) Wholesale Price Index of Finished Steel Mills Products
1947	3.5	7.29	12.67	1167.6	2.4733	1.56	70.67	93.1	1.51	48.0
1948	4.1	7.51	12.86	1219.6	2.7918	1.68	68.09	94.1	1.63	54.6
1949	3.9	6.60	12.95	1073.2	2.6029	1.75	66.74	81.1	1.70	59.1
1950	5.1	8.23	13.19	1214.4	3.0149	1.91	59.12	96.9	1.75	62.0
1951	6.3	9.39	13.19	1344.7	3.7289	2.11	59.19	100.9	1.95	67.1
1952	5.4	7.87	14.75	1189.9	3.6667	2.32	67.90	85.8	2.15	68.6
1953	7.0	9.49	15.58	1344.1	4.3866	2.44	62.67	94.9	2.27	73.8
1954	6.0	7.80	16.03	1117.1	3.8164	2.51	63.61	71.0	2.33	76.9
1955	7.8	9.69	15.75	1285.3	4.7268	2.72	60.60	93.0	2.51	80.5
1956	8.2	9.39	15.64	1261.0	5.0077	2.95	61.07	89.8	2.70	87.3
1957	8.7	9.10	16.50	1222.7	5.2996	3.22	60.91	84.5	2.92	95.6
1958	7.2	7.28	17.36	981.7	4.6932	3.51	65.18	60.6	3.18	98.9
1959	7.6	7.55	17.78	1003.3	5.1343	3.80	67.56	63.3	3.42	100.6
1960	8.0	7.97	18.56	1086.9	5.4605	3.82	68.26	66.8	3.35	100.4
1961	7.6	7.60	19.00	1012.9	5.3517	3.99	70.42	65.3	3.50	100.0
1962	7.7	7.72	19.08	1008.0	5.4808	4.16	71.18	62.6	3.62	99.7
1963	8.3	8.28	19.59	1023.4	5.6055	4.25	67.54	67.5	3.67	100.3
1964	9.1	9.00	20.44	1114.1	6.1361	4.36	67.43	77.0	3.70	101.1
1965	9.7	9.55	21.04	1158.2	6.5222	4.48	67.24	78.3	3.83	101.6
1966	10.1	9.81	21.61	1152.5	6.8039	4.63	67.37	77.1	4.02	103.0
1967	9.2	8.83	21.91	1083.7	6.4964	4.76	70.61	69.5	4.37	104.2
1968	9.9	9.25	22.70	1095.1	7.0401	5.03	71.11	68.3	4.75	107.0
1969	10.2	9.12	22.84	1099.0	7.4957	5.38	73.49	69.4	5.17	111.9
1970	9.8	8.24	22.62	1029.7	7.6405	5.68	77.96	62.2	5.62	119.0

Source: *The Steel Industry Today*, May 1971; *Statistical Abstracts of the U.S. Steel Imports*, U.S. Senate, *Annual Statistical Reports*, AISI.

C. Empirical Results

In this section, the Solow model represented by Equation (5.3) will be tested by using the data for the Canadian steel industry. The data required are capital share, capital service, labour input (man-hours) and capacity-output utilization rate. These data and the calculated results are shown in Table V-3. The sources and derivations of these data were discussed in the last section. Column (5) of Table V-3 is a cumulative measure of technological level. It is derived by the relationship:

$$A_t = A_{t-1}\ (1+z)$$

where $z = \dfrac{A_t - A_{t-1}}{A_{t-1}} = \dfrac{\Delta A}{A}$ and $A_o = 1.$

The figures in Column (6) are labour productivity which is net of technological shift. Thus, the change in the figures in Column (6) is purely a function of the change in the capital-labour ratio. It depicts the relationship:

$$\frac{Q}{L/A(t)} = f(\frac{K}{L}, 1)\quad .$$

The calculation procedures are illustrated by the following example using the data for 1947:

$$q = \frac{Q}{L} = 2.6359$$

$$k = \frac{K}{L} = 2.7886$$

$$\frac{\Delta q}{q} = \frac{2.6359-2.1131}{2.1131} = 0.2474$$

$$\frac{\Delta k}{k} = \frac{2.7886-2.1261}{2.1261} = 0.3116$$

$$W_k = 0.3184$$

$$\frac{\Delta A}{A} = 0.2474 - (0.3184)(0.3116) = 0.1482$$

Table V-3

RATES OF TECHNOLOGICAL CHANGE, 1946-69
The Canadian Iron and Steel Mills Industry

Year	(1) Net Output per Man-Hour (Constant 1961 Canadian $)	(2) Capital per Man-Hour	(3) Capital Share	(4) $\frac{\Delta A}{A}$	(5) $A(t)$	(6) $\frac{Q}{L}/A(t)$	(7) Utilization Rates
1946	2.1131	2.1261	.2669	--	1.0000	2.1131	.6539
1947	2.6359	2.7886	.3184	.1482	1.1482	2.2957	.8277
1948	2.4548	2.7632	.3445	-.0655	1.0730	2.2878	.8309
1949	2.5151	2.9111	.3462	.0060	1.0794	2.3301	.7970
1950	2.7705	3.3654	.4004	.0390	1.1215	2.4704	.8596
1951	2.9066	3.3915	.4316	.0458	1.1729	2.4781	.8931
1952	2.8419	3.4310	.4095	-.0270	1.1412	2.4903	.7740
1953	2.8770	4.3332	.3297	-.0743	1.0564	2.7234	.8246
1954	2.9575	4.2087	.4327	.0404	1.0991	2.6908	.6139
1955	3.5389	4.9811	.4416	.1156	1.2262	2.8861	.8217
1956	3.9368	5.3747	.4643	.0757	1.3190	2.9847	.9119
1957	3.5773	5.3734	.4189	-.0912	1.1987	2.9843	.8022
1958	3.5674	5.6899	.4217	-.0276	1.1656	3.0606	.6520
1959	4.1174	6.7491	.4415	.0720	1.2495	3.2952	.8430
1960	3.8723	6.9588	.3697	-.0710	1.1608	3.3359	.7672
1961	4.3497	7.7943	.4160	.0733	1.2459	3.4912	.7696
1962	4.4757	8.6082	.4276	-.0157	1.2263	3.6498	.8337
1963	4.6771	9.0722	.4360	.0215	1.2527	3.7336	.8647
1964	4.8587	8.9473	.4373	.0448	1.3088	3.7123	.8368
1965	5.1094	9.7393	.4576	.0111	1.3233	3.8611	.8534
1966	4.8308	9.8286	.4074	-.0583	1.2462	3.8764	.8224
1967	4.5736	10.1315	.3570	-.0642	1.1662	3.9218	.7820
1968	5.2008	11.1057	.3808	.1005	1.2834	4.0524	.8579
1969	5.3773	10.5417	.3753	.0530	1.3514	3.9791	.7784

Source: Calculated from Table V-1 by using Equation 5.3.

The rate of technological change $\left(\frac{\Delta A}{A}\right)$, and the technological index $(A(t))$, are plotted in Diagrams V-1 and V-2, respectively. Let us examine these diagrams in turn.

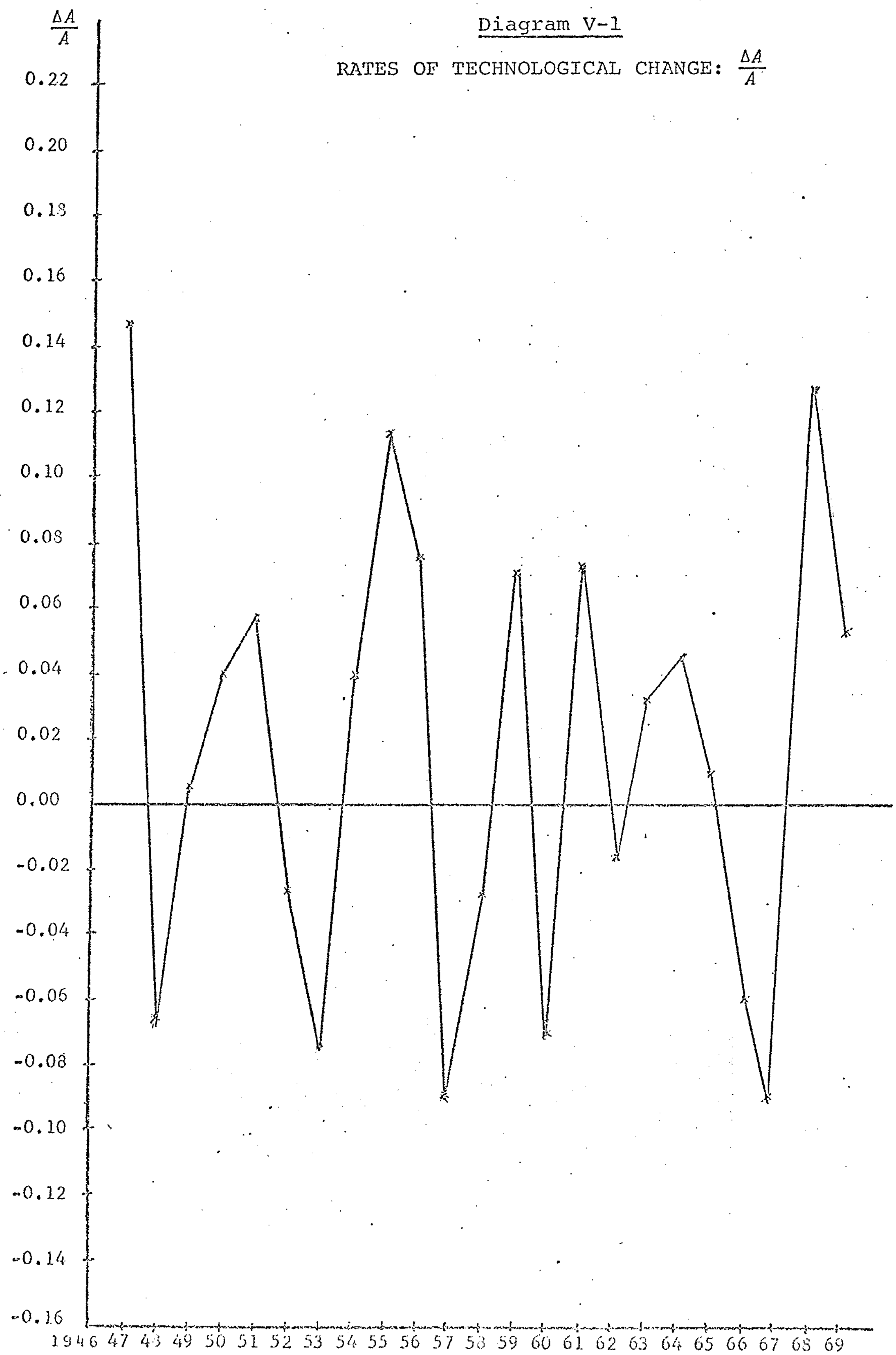
(a) <u>The Rate of Technological Change: $\frac{\Delta A}{A}$</u>

The line in Diagram V-1 shows that the rates of technological change fluctuate around zero and fluctuate violently in some years. The mean of the rates throughout the whole period is .0153. The rate of change between 1954 and 1955 is the highest, and some rates of change in recent years are greater than those of the previous years.

As we noted in Chapters II and IV, major innovations such as the basic oxygen furnace and the continuous casting machine were adopted by the dominant firms of the Canadian steel industry in 1954. Thus, if the whole period is broken into two sub-periods, namely, 1946-54 and 1955-69, the average rate of technical change of the latter period should be greater than that of the former period. The rate of the former period is found to be 0.0141, while that of the latter is 0.0163. This shows that the average rate of change was greater in the 1955-69 period than that of 1946-54, although the difference was small.

Diagram V-1

RATES OF TECHNOLOGICAL CHANGE: $\frac{\Delta A}{A}$



(b) Technological Index: $A(t)$

The clear upward trend of the technological index is represented by the line in Diagram V-2. The rising trend is particularly obvious between 1955 and 1969, after a great dip in 1954. The points representing the years within this period are generally located higher than those representing the years within the previous period, 1946-54.

Assuming technology has been progressing at a constant growth rate, an equation $A(t) = Aoe^{\gamma t}$ has been fitted to the technological index for 1946-69. The result of the regression in the log-linear form is:

$$\text{Log } A(t) = .06437 + .00869t$$

$$\text{Student } t \quad (3.01939) \quad (5.82122)$$

$$\text{D.W.} = 1.7231$$

$$\bar{R}^2 = .5884 .$$

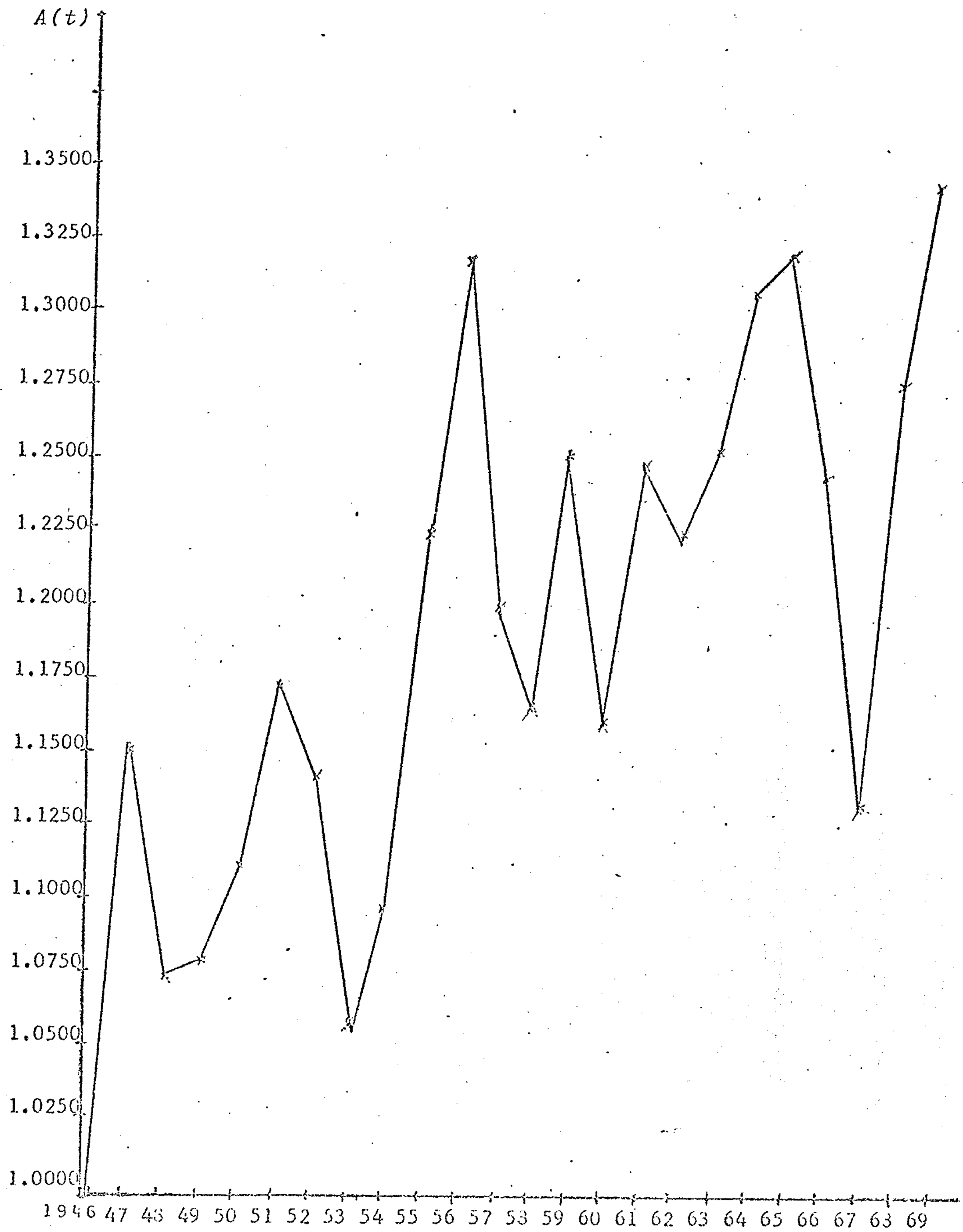
The trend of growth is approximately .9 per cent.

The proportion of labour productivity increase attributable to technological change can also be calculated from the technological index. We note that labour productivity has increased about $2\frac{1}{2}$ times from 2.1131 in 1946 to 5.3773 in 1969. The technological index, on the other hand, has increased about 1.3 times. Thus, the proportion of labour productivity growth which is attributable to technological change is:

$$\frac{1.3514}{2.5447} = 53.11 \text{ per cent.}$$

Diagram V-2

TECHNOLOGICAL INDEX $A(t)$, 1946-69



The remainder, which is 46.89 per cent of labour productivity increase, is due to the increased use of capital per man-hour.

(c) <u>Technological Break</u>

For the purpose of discovering a technological break, a dummy variable, D, is incorporated in a regression equation taking the technological index, $A(t)$, as the dependent variable and time, t, as an independent variable. Assume the technological index is an exponential function of the time variable, the following equation is specified:

$$A(t) = e^{\beta_0+\beta_1 D+\beta_2 t}$$

and its log-linear form is:

$$\ln A(t) = \beta_0+\beta_1 D+\beta_2 t$$

where $D = \begin{cases} 0 & \text{in each pre-technological change year} \\ 1 & \text{in each post-technological change year.} \end{cases}$

The result of the above equation will disclose, first, whether there existed a technological break in the Canadian steel industry within the period 1946-69 and second, the timing of the break if it did exist. In order to avoid bias in selecting the break, an iterative procedure assuming the break occurred in each year separately except 1946 and 1969 was adopted and 17 regressions were run. Out of these regression results, only the one which takes 1955 as the beginning year of the post-technological change period is meaningful in the sense that the coefficient of its dummy variable is significant at the 5 per cent level.

The result is:

$$\ln A(t) = \underset{(3.6130)}{0.0728} + \underset{(2.1414)}{0.0779D} + \underset{(1.6162)}{0.0041t}$$

This means that if we run regressions for the two periods, namely 1946-54 and 1955-69, separately, the results would be:[1]

$$\ln A(t) = 0.0728 + 0.0041t \quad \text{(pre-technological break)}$$

$$\ln A(t) = 0.1507 + 0.0041t \quad \text{(post-technological break)}$$

It can be seen from the above results that the constant term of the equation for the post-technological period is about twice as much as that of the equation for the preceeding period. These results confirm that technology in the Canadian steel industry in the period 1955-69 was distinct from that in the period 1946-54.[2]

D. Technological Change in the American Steel Industry

Two Solow tests using the data for the American steel industry for the period 1947-70 were conducted. The first test uses value added and gross capital stock in constant 1961

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[1] See J. Johnston, *Econometric Methods* (New York: McGraw-Hill, 1963), p. 222.

[2] This means that the intercept has shifted but the slope of the curve remains unchanged. Since most innovations were introduced in 1954 or later, the technological level of the later period must have been higher than that of the early period.

dollars,[1] and derives the labour measure by dividing wages and salaries by average hourly earnings. As indicated previously, the purpose of doing so is to obtain a series of quality-adjusted labour measure. The second test uses the total hours worked instead. The results of these two tests, including labour productivity and technological index, are shown in Table V-4.

The result of the first test shows that labour productivity in the American steel industry has increased from \$4.4507 in 1947 to \$6.0610 in 1970, which is an increase of 1.3618 times, while the technological index has increased 1.1967 times. The increase in labour productivity attributable to technical progress is therefore 87.87 per cent. The second test shows that labour productivity has increased 1.2817 times while the technological index increased 1.1418 times. Thus, the contribution of technical progress to labour productivity growth is 89.08 per cent.

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[1]Since plant and equipment data are not separately shown, and life assumptions of plant and equipment are not available, it is impossible to convert capital stock into capital services. However, similar Solow test using capital stock for the Canadian case has been conducted and the conclusion does not change as far as the comparison between Canada and the United States is concerned.

Table V-4

LABOUR PRODUCTIVITY, RATES OF TECHNOLOGICAL CHANGE AND TECHNOLOGICAL INDEX -- U.S. STEEL INDUSTRY, 1947-70

Year	Capital per Man-Hour $\frac{K}{L}$	Value Added per Man-Hour $\frac{V}{L}$	Test 1 L = Griliches' measure			Capital per Man-Hour $\frac{K}{L}$	Test 2 L = total hours worked			Net Labour Productivity
			Rates of Tech. Change $\frac{\Delta A}{A}$	Technological Index $(A(t))$	Net Labour Productivity V/L $(A(t))$		Value Added per Man-Hour $\frac{V}{L}$	Rates of Technological Change $\frac{\Delta A}{A}$	Technological Index $A(t))$	
	Constant 1961 U.S. $	Constant 1961 U.S.$				Constant 1961 U.S.$	Constant 1961 U.S. $			
1947	7.20	4.4507		1.0000	4.4507	10.10	6.2436		1.0000	6.2436
1948	7.07	4.3847	-.0088	0.9912	4.4236	9.92	6.1578	-.0081	0.9919	6.2077
1949	6.86	4.3106	-.0072	0.9841	4.3804	9.79	6.1498	.0033	0.9952	6.1795
1950	7.42	4.7771	.0749	1.0578	4.5163	10.52	6.7770	.0711	1.0660	6.3575
1951	6.96	4.9104	.0532	1.1140	4.4080	9.90	6.9830	.0547	1.1243	6.2108
1952	7.42	4.6146	-.0815	1.0232	4.5100	10.64	6.6140	-.0768	1.0380	6.3720
1953	7.65	4.9109	.0526	1.0770	4.5597	11.00	7.0605	.0547	1.0948	6.4493
1954	6.95	4.7621	.0031	1.0804	4.4078	10.19	6.9824	.0158	1.1121	6.2787
1955	7.78	5.1455	.0335	1.1166	4.6084	11.40	7.5391	.0330	1.1488	6.5626
1956	7.57	5.0628	-.0058	1.1101	4.5607	11.14	7.4465	-.0035	1.1448	6.5045
1957	7.68	5.0140	-.0153	1.0931	4.5869	11.40	7.4425	-.0098	1.1336	6.5657
1958	7.13	4.9328	.0089	1.1028	4.4728	10.72	7.4157	.0174	1.1532	6.4303
1959	7.50	5.0291	.0028	1.1059	4.5476	11.22	7.5252	-.0004	1.1528	6.5280
1960	7.61	4.8896	-.0324	1.0701	4.5693	11.41	7.3328	-.0309	1.1171	6.5640
1961	8.11	4.9704	-.0032	1.0666	4.6599	12.25	7.5032	.0014	1.1187	6.7072
1962	7.89	5.0990	.0339	1.1028	4.6238	11.85	7.6587	.0301	1.1524	6.6459
1963	8.66	5.3883	.0251	1.1305	4.7665	12.92	8.0418	.0207	1.1762	6.8371
1964	9.49	5.4269	-.0242	1.1031	4.9195	14.13	8.0783	-.0259	1.1458	7.0505
1965	9.67	5.6080	.0270	1.1329	4.9499	14.22	8.2456	.0185	1.1669	7.0661
1966	9.84	5.7961	.0278	1.1645	4.9775	14.46	8.5119	.0270	1.1984	7.1028
1967	10.24	5.9398	.0129	1.1794	5.0361	14.05	8.1480	-.0345	1.1570	7.0421
1968	10.46	6.2410	.0446	1.2320	5.0657	14.16	8.4467	.0345	1.1969	7.0570
1969	10.93	6.2903	-.0041	1.2270	5.1265	14.42	8.2985	-.0225	1.1700	7.0929
1970	10.35	6.0610	-.0247	1.1967	5.0646	13.66	8.0023	-.0241	1.1418	7.0086

Source: See Table V-2.

One has to be cautious in interpreting the contribution of technological change to labour productivity growth. When it is stated that technical change has contributed more than 80 per cent to labour productivity increase in the American steel industry, it does not mean that technological progress in the American steel industry is necessarily greater than that in the Canadian steel industry, of which technological change was found to have contributed about 50 per cent to labour productivity increase. The reason for getting a much higher figure in the American case is due to the small increase in labour productivity from 1947-70 since the ratio between labour productivity in 1970 and that in 1947 is used as the denominator and the technological index of 1970 as numerator in the calculation, although the latter is also small. Thus, we cannot conclude that technological change in the American steel industry has been greater than the Canadian counterpart. Hence, it is only the technological index, $A(t)$, which is relevant in comparing the rate of technological advance between the two industries.

Since the periods covered in the Canadian and the American tests are the same except for one year, (1946-69 for Canada and 1947-70 for the United States), the technological indexes of the two exercises are directly comparable. From Tables V-3 and V-4, we can see that the technological index for the end year in the Canadian case is around 1.3 while the corresponding figures in the American case are both around 1.1. This indicates that technological advance in the Canadian steel industry has been greater than that in the American steel industry.

This observation is further confirmed by running a log-linear equation $\log A(t) = \log A_0 + \gamma t$ where A_0 is a constant and t is a time variable. The results of the American tests are:

Test 1:

$$\log A(t) = 0.00547 + 0.00727t$$

$$\text{Student } t = 0.39082 \quad 7.58775$$

$$\bar{R}^2 = .7441$$

$$\text{D.W.} = 1.2554$$

Test 2:

$$\log A(t) = 0.03998 + 0.00595t$$

$$\text{Student } t = 2.76244 \quad 6.00385$$

$$\bar{R}^2 = .6674$$

$$\text{D.W.} = 1.2792$$

These regression results show that the time trend of growth in the American steel industry is between .595 and .727 per cent. Comparing with the corresponding figure of .869 per cent for Canada, we conclude that technological change in the Canadian steel industry has been greater than that of its American counterpart during the period 1946-47/1969-70.[1]

E. Summary and Conclusion

We have discussed the problems of data requirements and adjustments and found, by using a modified-Solow analytical framework, the following results:

(1) The effect of technological change on the net output growth of the Canadian steel industry has been significant and the average rate of technological change for the period 1955-69 is greater than for the period 1946-54. This is consistent with the fact that innovations were adopted by the Canadian steel industry in 1954.

(2) Labour productivity increased from $2.1 per man-hour in 1946 to $5.4 in 1969 in the Canadian steel industry. The increase was approximately 150 per cent. Technical change

[1] Confidence intervals have been calculated and t tests performed. It is found that the coefficient of Test 2 (.00595) is significantly different from the Canadian coefficient (.00869) at the 5 per cent level. For test procedure, see Johnston op.cit. pp.41-42.

was found to have contributed about 53 per cent to this increase.

(3) A technological break occurred between the period 1946-54 and 1955-69. This implies that the pace of technological advance, and presumably the technological structure, were different for the two periods.

(4) While the increase of labour productivity in terms of value added per man-hour was approximately 150 per cent in Canada, the increase was about 36 per cent[1] for the American steel industry between 1947 and 1970. It was also found that the technological index in 1969 of the Canadian steel industry was greater than its American counterpart in 1970. The time trend of growth was found to be greater in Canada than in the United States. Thus, it is concluded that technological change in the Canadian steel industry has been greater than the American steel industry for the period concerned.

We have seen the enormous effect of technological change on the output growth of the Canadian steel industry. An interesting question is: where has this change come from? A preliminary attempt will be made to search for the possible sources of net output growth in the following chapter.

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[1] (6.0610 - 4.4507)/(4.4507) = 36.18%. See Table V-4.

Chapter VI

THE SOURCES OF NET OUTPUT GROWTH -- DENISON APPROACH

We have found in the last chapter that about 50 per cent of labour productivity growth of the Canadian steel industry for the period 1946-69 is attributable to the residual, which is usually referred to as technological change. The present chapter attempts to break the residual black box by pinpointing the major sources of productivity growth. The basic formula used in evaluating the contributions of production factors is borrowed from Denison.[1] Let G_i be the average annual growth rate of factor i, S_i be the share of factor i in net output and Q_g be the average annual growth rate of net output for a particular time period. The contribution of factor i to the growth in net output is then expressed as:

$$C_i = \frac{(G_i) \times (S_i)}{Q_g} .$$

Thus, before the above formula can be used, the average annual growth rates of various factors and net output as well as the shares of various factors have to be calculated. The share of total labour is shown in Column (9) of Table V-1.

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[1]E. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us* (New York: Committee for Economic Development 1962), pp. 41-42.

The shares of production workers and nonproduction workers are obtained by dividing wages and salaries by current dollar value added, respectively. These are shown in Table A.4 in the Appendix.

A. Contribution of Quality-Unadjusted Labour

In order to quantify the contribution of unadjusted labour, we need a labour employment index series. This series is constructed on the basis of total production man-hour equivalents shown in Column (6) of Table V-1.

However, the employment index is not all. According to Denison, there exists a productivity offset phenomenon as the average annual working hour per employee is changed.[1] The meaning of productivity offset is that as working hours are shortened, labour productivity per unit of time increases since more rest and relaxation are possible. The increase in productivity, however, diminishes as working hours are cut further. With the existence of the productivity offset phenomenon, a 1 per cent decrease in working hours will not reduce the total working hours in terms of productivity by 1 per cent. If the productivity offset is 20 per cent, then a 1 per cent fall (rise) in hours will result in a fall (rise) in hours by .8 per cent in productivity terms.

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[1]Denison, *op. cit.*, p. 38.

In order to evaluate the effect of the productivity offset phenomenon on the overall productivity growth, a series of average annual hours per employee has to be found. It is eventually constructed by averaging the annual hours per employee of production and nonproduction workers, weighted by the numbers of employees in each category. Another series is constructed by fitting a curve through the various peaks of the series of actual average annual hours per employee. The resulting series is called the potential average annual hours per employee series.

We have taken 1961 as the base period. In other words, we have set the standard average annual hours as 2073 (approximately 40 hours a week, see Table VI-1). Any annual hours figure which is greater than this standard figure implies the existence of a negative productivity offset, meaning that the increase in hours beyond the standard results in a fall in productivity. Thus, an hour increase of work will in fact bring only .95 hour increase in real work if the productivity offset is 5 per cent. With further increase in the hours of work, the negative productivity offset increases. Accordingly, the following productivity offset assumptions are made.[1]

[1]The productivity offset assumption is widely used in European studies of labour productivity. According to Denison, the percentages of productivity offset used in France, Germany and Holland are 30, 15 and 25, respectively. In his study of the sources of growth in the United States, Denison assumes 40 per cent of productivity offset at the working hours prevailing in 1957 and interpolates other percentages for other years. Since these percentages are used in the studies of aggregate economy which permit interreaction of the effect of productivity offset, their values are accordingly high. As our study is confined to the steel industry, the productivity offset percentages are assumed as slightly lower. See Denison, *op. cit.*, p. 40, and Denison, *Why Growth Rates Differ*, pp. 59-62.

Table VI-1

EMPLOYMENT, PRODUCTIVITY OFFSET AND ADJUSTED LABOUR INPUT

	Employment Index 1961=100 (1)	Average Annual Hours Per Employee Potential (2)	Average Annual Hours Per Employee Actual (3)	Labour Input Adjusted for Hours (4)	Annual Growth Rates in Net Output (Value Added) (5)
Average Growth					
1946	75.75	2295	2295	73.61	%
1947	79.37	2270	2326	79.38	30.70
1948	90.01	2245	2304	90.67	5.61
1949	88.72	2220	2267	89.15	0.98
1950	85.88	2195	2195	85.29	6.62
1951	97.27	2178	2146	95.34	18.82
1952	99.95	2161	2136	98.37	0.46
1953	98.42	2144	2099	96.02	-0.30
1954	82.36	2128	2072	79.94	-13.97
1955	98.20	2112	2112	98.11	42.67
1956	107.73	2105	2138	109.34	22.02
1957	103.84	2098	2102	103.98	-12.41
1958	86.69	2091	2057	85.24	-16.74
1959	102.58	2085	2105	101.17	36.56
1960	101.32	2079	2060	100.38	-7.10
1961	100.00	2073	2073	100.00	10.86
1962	105.83	2069	2080	106.40	8.90
1963	112.81	2065	2090	114.17	11.38
1964	123.63	2061	2102	126.09	13.84
1965	130.08	2057	2108	133.30	10.64
1966	135.78	2053	2085	137.90	-1.30
1967	131.24	2049	2067	132.40	-8.48
1968	132.31	2045	2084	134.83	14.63
1969	128.86	2041	2077	131.13	0.69
Average Growth Rate	2.73%			3.00%	7.61%

Sources: (1) Constructed from Column (6) of Table V-1 in Chapter V.

(2) Constructed from (3).

(3) Statistics Canada, Catalogue nos. 72-202 and 72-204 (various issues).

(4) Calculated from (1), (2) and (3).

(5) Calculated from (1) of Table V-1.

The average annual hours per employee of production workers is the product of 52 weeks and average weekly hours obtainable from Statistics Canada, Catalogue no. 72-202 (various issues), and that of nonproduction workers is also the product of 52 weeks and average weekly hours obtainable from Statistics Canada, Catalogue no. 72-204 (various issues). This is called annual hours per employee series.

For the period 1955-60, the negative productivity offset is assumed as 5 per cent. The negative productivity offset is assumed as 10 per cent for 1950-54 and it is assumed as 20 per cent for the period 1946-49. From 1961 to 1969, since the annual decrease in hours is small, the positive productivity offset is assumed as zero per cent.

The adjusted labour input, shown in Column (4), is calculated under these productivity offset assumptions. The method of calculation is illustrated by the following example:

$$(4) = \left[(1) + \frac{2073 - (2)}{2073} \times \begin{matrix}\text{productivity}\\ \text{offset}\\ \text{percentage}\end{matrix} \right] \times \frac{(3)}{(2)} .$$

The figure for 1951 in Column (4) is obtained as follows:

$$95.34 = \left(97.27 + \frac{2073 - 2178}{2073} \times 10 \right) \times \frac{2146}{2178} .$$

Column (5) of Table VI-1 shows the annual growth rates in net output (value added) of the steel industry. The average annual growth rate is 7.61 per cent. Similarly, the average annual growth rates of the employment index (Column (1)), and adjusted labour input (Column (4)) are 2.73 per cent and 3.00 per cent, respectively. Since total labour accounts for 60.28 per cent of the total factor input for the period 1946-69, the annual growth of total labour amounts to 1.646 per cent (2.73% x .6028) of total factor input growth if no adjustment for productivity offset is made. If productivity offset is taken into account, then this figure becomes

1.808 per cent (3.00% x .6028). The portion of net output growth which is explained by the growth of total man-hours is:

$$C_{\text{Labour 1}} = \frac{2.73\% \times .6028}{7.61\%} = \frac{1.646\%}{7.61\%} = 21.63\%$$

or

$$C_{\text{Labour 2}} = \frac{3.00\% \times .6028}{7.61\%} = \frac{1.808\%}{7.61\%} = 23.76\%$$

if productivity offset is assumed. Thus, the contribution of productivity offset phenomenon is 2.13 per cent.

B. Education

Education is another element hidden in the residual black box. The contribution of education to productivity growth can be evaluated if accurate school years data and average earnings of workers in the steel industry are available. The data of years of schooling for the steel industry are available from 1941 and 1951 Censuses of Canada, and 1961 Unpublished Table from Statistics Canada. Table VI-2 shows the distribution of workers in various school year categories for 1941, 1951 and 1961.

The weights shown in Column (4) are the average incomes of workers with various years of schooling of the nonfarm labour force in 1961. The reason for using this series as a proxy is that there has been no income-school year data published for the iron and steel mills industry.[1]

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[1]Although there are some income-education-age data published in the *Population Census 1961* (Statistics Canada, Catalogue no. 98-502) by occupation, the closest category which includes furnacemen, moulders, blacksmiths and related metal-workers has only two items -- secondary 1-3 years and 4-5 years. See *Census of Canada*, p. B6-25, Table 6.

Table VI-2

SCHOOL YEARS AND EARNINGS OF STEEL-WORKERS

No. of Years	Census Year 1941 (1)	1951 (2)	1961 (3)	Weights Average Income 25 Years & Older, 1961 (4)
0-4	3,884	3,171	2,055	$
Per Cent	10.71	9.08	5.30	2,758
5-8	15,975	15,177	15,222	
Per Cent	44.05	43.43	39.26	3,705
9-12	14,209	13,854	19,202	
Per Cent	39.18	39.65	49.52	5,000
13+	2,199	2,740	2,294	
Per Cent	6.06	7.84	5.92	7,828
Total	36,267	34,942	38,773	
Weighted Sum	436081	445572	454017	
Index 1961=100	96.05	98.14	100.00	

Sources:

1941, *Census of Canada*, Vol VII, Table 18, pp. 518-27.

1951, *Census of Canada*, Vol. IV, Table 19.

1961, Statistics Canada. Unpublished Table kindly provided by Mrs. Kempster.

Weights are derived from G. W. Bertram, *The Contribution of Education to Economic Growth*, Staff Study, Economic Council of Canada, p. 48.

The study by Podoluk[1] also provides no information at the industry level.

The result indicates that education-earnings indexes were increasing at approximately 0.21 per cent annually between 1941 to 1950 and 0.19 per cent annually between 1951 to 1961.[2] Assuming the rates of increase between 1961 to 1969 were the same as those of 1951 to 1961, an education-earnings index series is constructed with interpolations for all years except 1941, 1951 and 1961. Table VI-3 shows the education-earnings index and the labour input adjusted for education.

The annual growth rate of labour input adjusted for hours of work and education is 3.18 per cent. Since the average annual growth rate of net output is 7.61 per cent, this means that labour input adjusted for education explains 25.18 per cent of the annual growth in net output. This also implies that the contribution of education to the annual growth in net output of the steel industry is 1.42 per cent.[3] The explanation for this low figure which can be found in Table VI-2 lies in the fact that the distribution of workers in various school year groups has changed little from 1946 to 1969.

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[1] J. R. Podoluk, *Earnings and Education*, Statistics Canada, Catalogue no. 91-510.

[2] The method of deriving the indexes shown in Table VI-3 is the same as that used in Griliches' paper "Production Functions in Manufacturing". See p. 312 of NBER, *op. cit.* For example: 10.71 x 2758 + 44.05 x 3705 + 39.18 x 5000 + 6.06 x 7828 = 436081. Take 1961 as the base period, an index is then constructed.

[3] Before education is considered, labour input adjusted for hours of work explains 23.76% of growth. Now labour input adjusted for education has contributed 3.18% x .6028/7.61% = 25.18%. The difference of the two is 1.42%.

Table VI-3

LABOUR INPUT ADJUSTED FOR HOURS OF WORK AND EDUCATION

	Labour Input Adjusted for Hours (1)	Education-Earnings Index (2)	Labour Input Adjusted for Hours of Work and Education (3)
1946	73.61	97.10	71.48
1947	79.33	97.31	77.25
1948	90.67	97.52	88.42
1949	89.15	97.73	87.12
1950	85.29	97.94	83.53
1951	95.34	98.14	93.57
1952	98.37	98.33	96.73
1953	96.02	98.52	94.60
1954	79.94	98.71	78.90
1955	98.11	98.90	97.03
1956	109.34	99.09	108.34
1957	103.98	99.28	103.23
1958	85.24	99.47	84.79
1959	101.17	99.66	100.83
1960	100.38	99.85	100.23
1961	100.00	100.00	100.00
1962	106.40	100.19	106.60
1963	114.17	100.38	114.61
1964	126.09	100.57	126.81
1965	133.30	100.76	134.32
1966	137.90	100.95	139.21
1967	132.40	101.14	133.91
1968	134.83	101.33	136.63
1969	131.13	101.52	133.12
Average Annual Growth Rates	3.00%	0.18%	3.18%

Sources:

(1) Column (4) of Table VI-1.

(2) Derived from the indexes shown in Table VI-2.

(3) $= \frac{(1) \times (2)}{100}$.

C. Labour Shifting Effect

Another possible source of productivity growth is the shifting of labour from small-size establishment to large-size establishment. There is some evidence that the shifting of labour did take place in the steel industry from 1946 to 1969, as shown in Table VI-3.

In order for labour shifting to contribute to productivity growth, two conditions must be satisfied. First, labour must have been shifting from low-productivity establishments to high-productivity establishments through time. It can be seen from Table VI-3 that the total numbers of employees of the group comprising establishments which have less than 200 employees each had been decreasing from 1946 to 1951. From 1952 onwards, the numbers of employees in the smallest group comprising establishments with 5-99 employees each, after some fluctuation in the earlier years, began to decline steadily except in 1965,[1] while those of the three years, namely 1958, 1959 and 1960, are not known. At the same time, the total numbers of employees of the medium group (100-199 employees per establishment) and the largest group (200 and over employees per establishment) have been increasing. Second, labour productivity, represented by value added per employee of the larger establishment has to be different from that of the smaller establishments. This

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[1]The figures for 1965 in Table VI-4 look strange indeed. The author suspects it is due to mistabulation of figures by Statistics Canada. See Statistics Canada, Catalogue no. 41-203, 1965 and 1966 issues.

evidence, shown in Column (4) of Table VI-4, is not clear for the years 1946 to 1951. However, it is shown clearly from 1961 onwards. The reasons might be that large establishments ran into diseconomies of scale in the early years immediately after the war before production techniques and equipment were modernized.

Although the increase in the total numbers of employees of the medium and large establishments does not necessarily come from the contraction of the numbers of employees of the smaller establishments, the actual effect of the relative decrease in the number of less efficient workers and the relative increase of the more efficient workers is equivalent to a net productivity increase of total workers.

In order to find the contribution of the labour shifting effect to total productivity growth, the following equation[1] is used:

$$\text{Labour shifting effect} = \left(\frac{L_1 L_2}{QL}\right)\left(\frac{W_1}{L_1} - \frac{W_2}{L_2}\right)\left(\frac{\dot{L}_1}{L_1} - \frac{\dot{L}_2}{L_2}\right) \quad \text{(Equation 6.1)}$$

where $L = L_1 + L_2$

[1]This expression is derived from an original expression

$$\sum_{i=1}^{2} \frac{Q_i}{Q} \alpha_i \left(\frac{\dot{L}_i}{L_i} - \frac{\dot{L}}{L}\right) = \left(\frac{L_1 L_2}{QL}\right) \left(\frac{\alpha_1 Q_1}{L_1} - \frac{\alpha_2 Q_2}{L_2}\right) \left(\frac{\dot{L}_1}{L_1} - \frac{\dot{L}_2}{L_2}\right)$$

where α_i = labour's share in the ith industry, which is in turn derived from the total factor productivity growth formula ;

$$\left(\frac{\dot{Q}}{Q} - \alpha\frac{\dot{L}}{L} - (1 - \alpha) \frac{\dot{K}}{K} \right)$$

For the details of the derivation, see H.H.Postner's study, An Analysis of Canadian Manufacturing Productivity ;Some Preliminary Results, Staff Study No.31, Economic Council of Canada, Ottawa, 1971, p.58.

Table VI-4

THE SHIFTING OF LABOUR 1946-57, 1961-67 -- IRON AND STEEL MILLS INDUSTRY

	Number of Establishments (1)	Number of Employees (2)	Value Added ** (3)	Value Added Per Employee (4)= (3)/(2)
1946				
5-199	35	2,786	5,957,044	2,138
200+	24	21,410	65,625,016	3,065
1947				
5-199	32	2,460	9,306,621	3,783
200+	26	24,473	83,573,267	3,415
1948				
5-199	26	2,158	10,034,575	4,650
200+	29	27,209	115,242,373	4,235
1949				
5-199	27	2,054	10,452,667	5,089
200+	28	27,031	125,699,961	4,650
1950				
5-199	29	2,446	13,901,907	5,684
200+	26	26,593	140,640,466	5,289
1951				
5-199	25	2,229	11,439,576	5,132
200+	32	31,152	198,032,789	6,357
1952				
5-99	15	703		
100-199	13	1,912	*	*
200+	30	32,375		
1953				
5-99	20	766		
100-199	12	1,706	*	*
200+	30	32,471		
1954				
5-99	25	1,259		
100-199	12	1,730	*	*
200+	14	25,856		
1955				
5-99	21	1,036		
100-199	15	2,264	*	*
200+	14	29,191		

	Number of Establishments (1)	Number of Employees (2)	Value Added ** (3)	Value Added Per Employee (4)=(3)/(2)
1956				
5-99	18	837		
100-199	16	2,360	*	*
200+	16	32,830		
1957				
5-99	19	917		
100-199	16	2,477	*	*
200+	16	32,537		
1961				
5-99	12	633	5,592,000	8,834
100-199	11	1,415	12,826,000	9,064
200+	18	32,635	386,795,000	11,852
1962				
5-99	12	680	6,395,000	9,404
100-199	12	1,598	13,742,000	8,599
200+	17	34,245	431,431,000	12,598
1963				
5-99	9	518	5,139,000	9,921
100-199	12	1,582	18,454,000	11,665
200+	18	36,026	482,175,000	13,384
1964				
5-99	9	504	5,491,000	10,895
100-199	12	1,751	19,120,000	10,919
200+	21	39,173	544,097,000	13,889
1965				
5-99	19	2,184	26,073,000	11,938
100-199	12	3,781	45,460,000	12,023
200+	10	38,226	582,235,000	15,231
1966				
5-99	6	255	2,455,000	9,627
100-199	14	2,130	25,651,000	12,043
200+	23	43,532	626,368,000	14,389
1967				
5-99	6	189	1,957,000	10,354
100-199	17	2,478	30,149,000	12,167
200+	21	41,474	589,955,000	14,225

* -- Not available. ** In current dollars.

(1) The value added figures for 1946-51 are obtained by subtracting costs of materials and costs of fuel-electricity from gross value of product. See Statistics Canada, Catalogue no. 32-201, 1957, p. 15.

(2) The gross value of production figures are not available for 1952-57.

(3) No data are available for 1958-60.

(4) Statistics Canada has ceased to publish these data since 1968.

Source: Compiled and calculated from Statistics Canada, Catalogue nos. 32-201 (1946-57) and 41-203 (1961-67), various issues.

where the subscript *1* represents establishments of which the number of employees is less than 200 each and the subscript *2* denotes those establishments of which the number of employees is more than 200 each. The remaining symbols, namely, W and Q, represent wages and salaries, and net output, respectively. The third bracket on the righthand side of Equation 6.1 measures the relative growth rates of labour employed by the small and large establishments. The second bracket represents the difference in hourly earnings between labour employed by the two types of establishments classified by size, while the first bracket is merely a weight. Thus, if the large establishment increases its use of labour greater than the small establishment, and if workers in the large establishment have higher hourly earnings than those in the small establishment, the labour shifting effect will become positive.

For the purpose of illustration, the labour shifting effect of the period 1961-67 for the Canadian steel industry will be calculated by using Equation 6.1. First, the meaning of the terms:

L_1 = man-hours paid in establishments with less than 200 workers each;

L_2 = man-hours paid in establishments with more than 200 workers each;

$L = L_1 + L_2$;

W_1 = total wages and salaries paid to workers in establishments with less than 200 workers each;

W_2 = total wages and salaries paid to workers in establishments with more than 200 workers each;

$\frac{W_1}{L_1}$ = real hourly earnings for workers in small (<200 workers) establishments;

$\frac{W_2}{L_2}$ = real hourly earnings for workers in big (>200 workers) establishments;

Q = value added in constant dollars.

The data for the above terms are available from *Iron and Steel Mills* (Statistics Canada, Catalogue no. 41-203), for the period 1961-67. The year-to-year labour shifting effects are calculated as:

1961	
	-.000548
1962	
	.000562
1963	
	.000067
1964	
	-.013057
1965	
	.002580
1966	
	-.000722
1967	
Average	-.001853

Since the drastic change in the number of employee of small establishments in 1965 (see Table VI-4) does not seem to be realistic, the year 1965 is excluded from a recalculation which generates the following results:

1961	
	-.000548
1962	
	.000562
1963	
	.000067
1964	
	.000185
1966	
	-.000722
1967	
Average	-.000091

As the average growth rate of net output for the period 1961-67 is 5.83 per cent, the negative contributions of labour shifting effect are -3.18 per cent if the year 1965 is included, and -0.16 per cent if it is excluded.[1] The reason for getting this negative figure is that the average growth rate of labour employed by those establishments with more than 200 workers each is smaller than that with less than 200 workers each. Since the wage rate of the former is higher than that of the latter, this implies that labour with higher productivity has grown slower than labour with lower productivity if the marginal productivity doctrine holds. This is also equivalent to a shifting of labour from high-productivity establishment to low-productivity establishment, which will inevitably result in a negative contribution.

D. Labour Quality Change

Note that the contribution of labour includes the contribution of improvement in labour quality as well as those of production worker growth and nonproduction worker growth. As the hourly earnings of nonproduction worker is generally higher than that of production worker, which implies that the productivity of the former is also higher, a greater growth rate for the nonproduction worker means that the growth rate of overall productivity of labour will be higher in this case than in the case where the growth rates of the two are equal.

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[1] (-.1853)/(5.83) = -.0318 = -3.18% and
(-.0091)/(5.83) = -.0016 = -.16% .

In other words, quality change of labour input is involved. Recently, a number of researchers have questioned the importance of changes in total factor productivity. As they argue, the so-called technical change, which is in fact the residual, would be minimal if "quantities of output and input are measured accurately".[1] In our case, the improvement in labour quality is equivalent to an increase in basic efficiency unit of labour. The failure to take labour quality change into account will result in an exaggeration of the contribution of the unknown factors, i.e., the residual which is labelled as technical change. In order to quantify the contribution of labour quality change and those of other factors, let us write the production function as:

$$Q = f(L^*, K^*)$$

where $L^* = g(L_1, L_2)$

$$L = L_1 + L_2$$

$$K^* = h(K_1, K_2)$$

and the functions f, g and h are homogeneous of degree one.

We can derive the expression which we have shown in Chapter III as:

$$\frac{\dot{Q}}{Q} = W_L \cdot \frac{\dot{L}^*}{L^*} + W_k \frac{\dot{K}^*}{K^*} + \frac{\dot{A}}{A} \quad .$$

[1]D. W. Jorgenson and Z. Griliches, "The Explanation of Productivity Change", *Review of Economic Studies*, July 1967, pp. 249-83.

In the above expressions, L is the sum of production worker man-hours (L_1) and nonproduction worker man-hours (L_2). L^* is the total man-hours after nonproduction worker man-hours have been converted into units which are equivalent to production worker man-hours and other quality adjustment is made. Similarly, K^* is the total capital service which is a function of services of the two components of capital stock, namely, construction, K_1, and machinery-equipment, K_2. Q is net output in constant 1961 dollars. Thus, $\frac{\dot{Q}}{Q}$ is the growth rate of net output. It can also be written as:

$$\frac{\dot{Q}}{Q} = \left(\frac{L^*}{Q}\frac{\partial f}{\partial L^*}\right) \frac{\dot{L}^*}{L^*} + \left(\frac{K^*}{Q}\frac{\partial f}{\partial K^*}\right) \frac{\dot{K}^*}{K^*} + \frac{\dot{A}}{A} \qquad \text{(Equation 6.2)}$$

where $\frac{L^*}{Q}\frac{\partial f}{\partial L^*}$ and $\frac{K^*}{Q}\frac{\partial f}{\partial K^*}$ represent labour share and capital share, respectively. The contribution of total labour after the adjustment for quality change -- which we have calculated as 25.18 per cent[1] -- is in fact the contribution of the first term, i.e., $\left(\frac{L^*}{Q}\frac{\partial f}{\partial L^*}\right) \frac{\dot{L}^*}{L^*}$. If the contribution of total unadjusted labour, $\left(\frac{L^*}{Q}\frac{\partial f}{\partial L^*}\right) \frac{\dot{L}}{L}$, can also be calculated, then the contribution of the quality change of labour due to differing growth of production worker (L_1) and nonproduction worker (L_2) is simply the difference between 25.18 per cent and the value of the contribution of unadjusted labour.

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[1]This is calculated in Section B of this chapter.

Since the function g is homogeneous of degree one, by virtue of the Euler's Theorem,[1] we can write:

$$L^* = \frac{\partial L^*}{\partial L_1} L_1 + \frac{\partial L^*}{\partial L_2} L_2$$

Substitute this relationship into $\left(\frac{L^*}{Q}\frac{\partial f}{\partial L^*}\right)\frac{\dot{L}}{L}$ to get:

$$\left(\frac{L^*}{Q}\frac{\partial f}{\partial L^*}\right)\frac{\dot{L}}{L} = \left(\frac{L_1}{Q}\frac{\partial f}{\partial L_1}\right)\frac{\dot{L}}{L} + \left(\frac{L_2}{Q}\frac{\partial f}{\partial L_2}\right)\frac{\dot{L}}{L} \qquad \text{(Equation 6.3)}$$

Thus, the contribution of total labour growth is the sum of the products of total labour growth rate of total unadjusted man-hours, L (instead of L^*) and the respective shares of production and nonproduction workers. The contribution of production workers is therefore 17.00 per cent and that of nonproduction workers is 3.83 per cent.[2]

The contribution of labour-quality improvement, which is 4.35 per cent, is obtained by subtracting the sum of 17.00 per cent and 3.83 per cent from 25.18 per cent.

In summary, productivity offset phenomenon, if it is considered, explains 2.13 per cent of the net output growth in the steel industry,[3] the improvement in labour quality explains

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[1]See R.G.D. Allen, *Mathematical Analysis for Economists* (London: MacMillan & Co. Ltd., 1962), p. 317.

[2]The calculations are: (.4920) (2.63%)/7.61% = 17.0%
(.1108) (2.63%)/7.61% = 3.83%
The shares of production and nonproduction workers are .4920 and .1108, respectively; and 2.63% is the average growth rate of unadjusted total labour, $\frac{\dot{L}}{L}$.

[3]It is obtained by subtracting 21.63% from 23.76%. Some confusion might arise since negative productivity offset rates are assumed yet it is found that productivity offset has contributed to 2.13% of net output growth. This is simply because 1961 is taken as the base year. If 1946 is the base year, then positive productivity offset rates have to be assumed. These two methods are equivalent to each other.

4.35 per cent and finally, 17.00 per cent and 3.83 per cent of the net output growth are attributable to the growth of production worker and nonproduction worker, respectively.

E. Capital

The other input besides labour is total capital service input. Capital services are comprised of services from construction and machinery-equipment. The relative durability of these two types of capital items has been taken into account in the compilation of capital services.[1] Since construction (structure) is assumed to last longer than machinery-equipment, the service provided by a machine per unit of time must be greater than that provided by a building which has the same cost as the machine. Likewise, a unit of machinery service must have a higher price than a unit of building service. But after we have converted the service of machinery-equipment into that of construction by giving the former a greater weight, all services, either provided by machinery-equipment or construction, now have the same price. If the price of capital service is P_r, the share of construction in total capital expenditure is equal to:

$$\text{Share of construction service} = \frac{\text{Services of construction} \times P_r}{\text{Value added} - \text{Wages and Salaries}}$$

$$= \frac{\text{Services of construction} \times P_r}{\text{Total capital services} \times P_r} = \frac{\text{Services of construction}}{\text{Total capital services}} \quad .$$

[1]For the method of compilation, see Chapter V.

Similarly,

Share of machinery-equipment service

$$= \frac{\text{Services of machinery-equipment} \times P_r}{\text{Total capital services} \times P_r}$$

$$= \frac{\text{Services of machinery-equipment}}{\text{Total capital services}}$$

Thus, the factor shares of machinery-equipment and construction services have been calculated according to the above expressions and shown in Table VI-5. The indexes of total capital service, durability-weighted and underutilization-corrected are shown in Table VI-6. Along with the indexes, average annual growth rates of the various indexes are also calculated.

Since the average annual growth rate of total capital service without utilization adjustment is 8.97 per cent and its average share in net output is 39.72 per cent, the contribution to net output growth can be computed as:

$$\frac{8.97\% \times .3972}{7.61\%} = 46.78\%$$

where 7.61% is the average growth rate of net output.

The evaluation of the contribution of quality (composition) change of capital service is similar to that of the contribution of labour quality change. Recall that K_1 and K_2 are the services of construction and machinery-equipment, respectively. K is the total capital service before durability-weighting is taken into account, and K^* is that after the relative durability of K_1 and K_2 has been taken into consideration.

Table VI-5

CAPITAL SHARES

	Total Capital Share (1)	Share of Machinery-equipment (2)	Share of Construction (3)
1946	.2669	.1926	.0743
1947	.3184	.2342	.0842
1948	.3445	.2580	.0865
1949	.3462	.2613	.0849
1950	.4004	.3043	.0961
1951	.4316	.3215	.1101
1952	.4095	.3023	.1072
1953	.3297	.2473	.0824
1954	.4327	.3286	.1041
1955	.4416	.3379	.1037
1956	.4643	.3586	.1057
1957	.4189	.3265	.0924
1958	.4217	.3293	.0924
1959	.4415	.3458	.0957
1960	.3697	.2919	.0778
1961	.4160	.3305	.0855
1962	.4276	.3415	.0861
1963	.4360	.3485	.0875
1964	.4373	.3507	.0866
1965	.4576	.3695	.0881
1966	.4074	.3307	.0767
1967	.3570	.2910	.0660
1968	.3808	.3105	.0703
1969	.3753	.3059	.0694
Average	.3972	.3091	.0881

Sources:

Column (1) is obtained by subtracting total labour share from unity and is identical to Column (3) of Table V-3. Columns (2) and (3) are obtained by multiplying the percentages of machinery-equipment and construction in total capital services to column (1).

Table VI-6

INDEXES OF CAPITAL SERVICES

	Total Capital Service (1)	Weighted Construction (2)	Machinery and Equipment (3)	Total Capital Service (Under-utilization corrected) (4)
1946	24.3	32.9	22.1	20.7
1947	26.4	33.9	24.5	28.4
1948	29.6	36.1	27.9	31.9
1949	32.0	38.2	30.4	33.1
1950	33.2	38.8	31.8	37.1
1951	36.5	45.3	34.2	42.3
1952	43.8	55.7	40.6	44.0
1953	51.1	62.1	48.2	54.7
1954	55.8	65.3	53.3	44.4
1955	58.8	67.1	56.6	62.7
1956	62.7	69.5	60.9	74.3
1957	68.7	73.7	67.4	71.6
1958	74.7	79.6	73.4	63.3
1959	81.1	85.5	79.9	88.8
1960	90.7	92.9	90.2	90.5
1961	100.0	100.0	100.0	100.0
1962	107.9	105.7	108.5	116.9
1963	116.9	114.1	117.6	131.3
1964	130.5	125.7	131.8	141.9
1965	146.6	137.3	149.0	162.5
1966	160.2	146.7	163.7	171.2
1967	167.7	150.8	172.1	170.6
1968	169.1	151.8	173.6	188.5
1969	172.3	154.9	176.8	174.3
Average Annual Growth Rates	8.97%	7.07%	9.54%	10.69%

Sources:

Computed from capital service data derived from Statistics Canada unpublished capital stock data and capital utilization rates (Column (7) of Table V-3).

Taking the second term of Equation 6.2, similar to the evaluation of the separate contributions of the growth of production and nonproduction workers, the following equation[1] can be written:

$$\left(\frac{K^*}{Q}\ \frac{\partial f}{\partial K^*}\right)\ \frac{\dot{K}}{K} = \left(\frac{K_1}{Q}\ \frac{\partial f}{\partial K_1}\right)\ \frac{\dot{K}}{K} + \left(\frac{K_2}{Q}\ \frac{\partial f}{\partial K_2}\right)\ \frac{\dot{K}}{K} \qquad \text{(Equation 6.4)}$$

where $\left(\frac{K_1}{Q}\ \frac{\partial f}{\partial K_1}\right)$ and $\left(\frac{K_2}{Q}\ \frac{\partial f}{\partial K_2}\right)$ are the shares of construction and machinery-equipment in net output. Note that $\frac{\dot{K}}{K}$ is the growth rate of total capital service before durability-weighting is done, and is therefore different from $\frac{\dot{K}^*}{K^*}$. The former is calculated from Column (2) of Table V-1 as 8.78 per cent while the latter is calculated from Column (3) of the same table as 8.97 per cent. Thus, the contributions of the growth of construction service and machinery-equipment service are:

$$\frac{.0881 \times 8.78\%}{7.61\%} = 10.16\% \quad \text{(construction service)}$$

and

$$\frac{.3091 \times 8.78\%}{7.61\%} = 35.66\% \quad \text{(machinery-equipment service)}$$

where .0881 and .3091 are the average shares of construction service and machinery-equipment service, respectively. The difference between quality adjusted and unadjusted capital services, i.e. $\left(\frac{K^*}{Q}\ \frac{\partial f}{\partial K^*}\right)\ \frac{\dot{K}^*}{K^*}$ and $\left(\frac{K^*}{Q}\ \frac{\partial f}{\partial K^*}\right)\ \frac{\dot{K}}{K}$ is the contribution of capital quality change, which is:

$$\begin{array}{c}\text{Contribution of capital} \\ \text{service quality change}\end{array} = 46.78\% - (10.16\% + 35.66\%) = 0.96\%$$

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[1]See the derivation of Equation 6.3.

The contribution of capital service quality change seems to be negligible, if it is compared with that of labour quality change (which is 4.35%).

Thus far, what we have used in the calculation is the average growth rate of capital service index before underutilization of capital is corrected. If the underutilization-corrected capital service index is used, the contribution of total capital service amounts to 55.85 per cent.[1] This means that if capital service were not underutilized, then the contribution would be 55.85 per cent. But since underutilization does exist, the contribution of total capital service is only 46.78 per cent. Thus, the contribution of underutilization of capital service is -9.07 per cent.[2]

In sum, the contribution of growth of construction and machinery-equipment service to net output growth are 10.16 per cent and 35.66 per cent, respectively, and the contribution of capital service quality change is 0.96 per cent. Total contribution of capital service growth amounts to 46.78 per cent while the underutilization of capital has contributed -9.07 per cent to net output growth over the period 1946-69.

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[1] (10.69% x .3972)/7.61% = 55.85% where 10.69% is the average growth rate of total capital service after underutilization is corrected.

[2] 46.78% - 55.85% = -9.07%.

F. Repair and Pollution Abatement Expenditures

As mentioned in Chapter V, part of repair expenditure might have been included in fixed capital formation[1] as repair work usually incorporates innovations such as the replacement of worn-out parts of equipment by parts with the latest design. However, it is not known what proportion of capital formation is actually repair expenditure, if it is included at all. Moreover, the available repair expenditure data are not complete for the period under review.[2] Thus, there is no way to separate out the contribution of the repair expenditure which has been included in fixed capital formation from total capital contribution.

Pollution abatement expenditure could also be included in capital formation since it is usually a part of company expansion program, which might not have distinguished pollution abatement equipment from production equipment clearly. However, no data are available except some scattered figures appearing in some annual reports of steel companies. Furthermore, the use of pollution abatement equipment is a relatively new event in the steel industry and so the overestimation of the

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[1]In data compilation, repair expenditure is not included in fixed capital formation series. Besides construction and machinery-equipment, the only additional component of fixed capital formation is "capital items charged to operating expenses". See Statistics Canada, Catalogue no. 13-522, *Fixed Capital Flows and Stocks Manufacturing, Canada 1926-1960, Methodology*, p. 57.

[2]The data for the period 1955-69 can be obtained from *Submission to the Standing Senate Committee on Banking, Trade and Commerce*, by Algoma, Dofasco and Stelco, Appendix C, Table 16.

contribution of total capital service due to the inclusion of pollution abatement expenditure, if any, is believed to be small.

G. Research and Development Expenditures

Research and development activity, through its improvement in the productivity of existing inputs, could have contributed to the growth of net output. Its contribution, however, is usually lumped together with the contributions of other unknown factors in the residual. It is desirable to single out the effect of research and development activity from the residual in order to see its contribution to net output growth.

However, again, a complete set of data on research and development expenditures for the steel industry is not available. The following series can only serve as a proxy for the actual research and development expenditures in the steel industry:

1960	1961	1962	1963	1964	1965	1966	1967	1968	Unit: Million $
1.3	1.9	2.5	3.0	3.8	5.6	5.2	5.2	5.4	

Sources: (1) 1960-61: J. Convey, D. K. Faurschou and J. H. Walsh, *A Report to the National Productivity Council on Research and Development in the Canadian Primary Iron and Steel Industry* (Ottawa: Department of Mines and Technical Survey, Mines Branch) March 1963, Table 2, p. 7.

(2) 1963-68: *Industrial Research and Development Expenditure*, Statistics Canada, Catalogue no. 13-532, Table 1, p. 29. The figure for 1962 is interpolated.

Note that the figures reported in Statistics Canada (Catalogue no. 13-532) publication, are actually the expenditures of the primary metal (ferrous) group, while the figures of 1960 and 1961 are those of the steel industry only. The difference is that in addition to iron and steel mills, the industry covered by the publication also includes steel pipe and tube mills, and iron foundries.

If the above series can be used as a proxy for the actual research and development expenditures in the steel industry, and if the rates of return to research and development activity are observable, then the contribution of research and development to the growth in net output can be quantified.[1] But in reality, the rates of returns to research and development activity are not observable. Thus, the contribution of research and development activity cannot be quantified.

H. The Sources of Growth

The contribution of various sources of growth are shown in Table V-7.[2] The whole period is broken down into several sub-periods in order to see the changes in the contributions of various factors through time. For the sake of simplicity, let us look at the contributions of the various

[1]If the rates of returns are observable, we can obtain the factor share of research and development activity, then its contribution can be calculated by: $C_i = (G_i \times S_i)/Q_g$ G_i is the growth rate of R&D, S_i is the factor share and Q_g is the growth rate of net output.

[2]The method is described at the beginning of this chapter.

factors in the whole period 1946-69. Net output represented by value added grew at an average rate of 7.61 per cent and out of this 1.93 per cent is attributable to the growth in total labour and 3.56 per cent to the growth in total capital. Technological change, as a residual measure, therefore accounts for 2.12 per cent. The contributions to the growth in net output are 25.18 per cent for total labour growth, 46.78 per cent for total capital growth and 27.87 per cent for technological change. The contributions of total labour and total capital can be further broken down into various components. The following example illustrates the decomposition :

Labour	
Labour (Hours and Education Adjusted)	25.18%
Labour (Hours Adjusted Only)	23.76%
Education	1.42%
Labour (Hours Adjusted Only)	23.76%
Labour (Employment Growth: production worker and nonproduction worker quality difference adjusted) $\frac{\dot{L}^*}{L^*}$	21.63%
Hours Reduction (Productivity Offset)	2.13%
Labour (Employment Growth): $\frac{\dot{L}^*}{L^*}$	21.63%
Labour (Production worker and nonproduction worker quality difference unadjusted) $\frac{\dot{L}}{L}$	20.83%
Higher productivity of nonproduction workers	0.80%

Total labour quality change = 25.18 - 20.83 = 4.35
(or 1.42 + 2.13 + 0.80)

Capital	
If underutilization not corrected (i.e., it existed)	46.78%
If underutilization corrected (i.e., it did not exist)	55.85%
Underutilization	-9.07%

Underutilization not corrected but quality difference between machinery-equipment and construction adjusted	$\frac{\dot{K}^*}{K^*}$	46.78%
Underutilization not corrected and no quality difference adjusted	$\frac{\mathring{K}}{K}$	45.82%
Quality change		0.96%

We thus see that 5.31 per cent (4.35 + 0.96) of total contribution to net output growth is attributable to factor quality change, which is usually lumped in the residual. Accordingly, technological change for the whole period accounts for 27.87[1] per cent of the total contribution to net output growth. The contributions of various factors including technical change of the sub-periods are obtained in the same way and shown in Table VI-7.

It is interesting to find that the contribution of technological change to net output growth was greater in the early period than the later. For instance, the contributions of the two sub-periods, 1946-57 and 1958-69, are 30.54 and 22.24 per cent, respectively. When the period 1946-57 is further divided into two periods, 1946-51 and 1952-57, we discover that the biggest contribution comes from 1946-51. Undoubtedly, this is attributable to the economies of scale resulting from the postwar expansion and expansion caused by the Korean War. The average growth rate of net output of this period, which is 12.55 per cent, is the highest among growth rates of net output. As we have assumed constant returns to

[1] 2.12/7.61 = 27.87

scale, the effect of increasing returns is absorbed by the technological change component.[1]

I. Conclusion

We have attempted to measure the sources of net output growth for the Canadian steel industry for the period 1946-69 by using a modified Denison framework. Our results show that labour growth had contributed 20.83 per cent and capital 45.82 per cent, indicating the capital intensity of the steel industry. The contribution of labour quality change amounts to 4.35 per cent, while that of capital quality change is 0.96 per cent.[2] The contribution of total quality change in inputs is therefore 5.31 per cent. Technological change, as a residual measure, contributed 27.87 per cent to net output growth.

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[1]From Equation 6.2, we can write the production function as:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - (W_L \cdot \frac{\dot{L}^*}{L^*} + W_k \frac{\dot{K}^*}{K^*})$$

where $W_L + W_K = 1$ constant returns

$W_L + W_K > 1$ increasing returns.

It is then clear that the value of $\frac{\dot{A}}{A}$ under the assumption of constant returns will be greater than that under increasing returns assumption.

[2]The capital quality change here refers to the shift in the composition of capital service between construction (structure) and machinery-equipment. It certainly does not refer to technological change.

Table VI-7

CONTRIBUTIONS OF VARIOUS SOURCES TO THE GROWTH RATE OF NET OUTPUT (VALUE ADDED), THE CANADIAN IRON AND STEEL MILLS INDUSTRY, 1946-69

	1946-51		1952-57		1958-63		1964-69		1946-57		1958-69		1946-69	
Net Output (Growth Rates)	12.55	100.00	6.41	100.00	7.31	100.00	5.01	100.00	9.20	100.00	6.16	100.00	7.61	100.00
		%		%		%		%		%		%		%
Contributions of Factors														
Labour: Total Labour (hour, education adjusted)	3.76	29.96	1.41	21.99	1.39	19.01	1.58	31.54	2.48	26.96	1.48	24.03	1.93	25.18
Higher Productivity of non-production worker	-0.34	-2.71	0.00	0.00	-0.03	-0.41	0.53	10.57	-0.10	-1.09	0.25	4.06	0.06	0.80
Reduction in hours	0.14	1.11	0.31	4.84	0.15	2.05	0.06	1.20	0.23	2.50	0.10	1.62	0.16	2.13
Education	0.14	1.12	0.11	1.71	0.11	1.50	0.12	2.40	0.13	1.42	0.11	1.79	0.12	1.42
Labour Quality Change	-0.06	-0.48	0.42	6.55	0.23	3.14	0.71	14.17	0.26	2.83	0.46	7.47	0.34	4.35
Growth in Unadjusted Total Labour	3.82	30.44	0.99	15.44	1.16	15.87	0.87	17.37	2.22	24.13	1.02	16.56	1.59	20.83
production worker	3.27	26.06	0.82	12.79	0.92	12.59	0.68	13.57	1.87	20.33	0.80	12.99	1.29	17.00
non-production worker	0.55	4.38	0.17	2.65	0.24	3.28	0.19	3.79	0.35	3.80	0.22	3.57	0.29	3.83
Capital Total Capital Service Growth (weighted)	2.98	23.74	4.68	72.99	3.88	53.08	2.73	54.49	3.91	42.50	3.31	53.73	3.56	46.78
Underutilization	-2.60	-20.72	+0.13	+2.05	-1.03	-14.09	+0.68	+13.57	-1.11	-12.07	-0.17	-2.76	-0.69	-9.07
Capital service quality change	0.07	0.55	0.11	1.70	0.06	0.82	0.05	1.00	0.17	1.85	0.07	1.13	0.07	0.96
Unweighted Capital Service Growth	2.91	23.19	4.57	71.29	3.82	52.26	2.68	53.49	3.74	40.65	3.24	52.60	3.49	45.82
Construction	0.74	5.90	1.09	17.00	0.80	10.94	0.51	10.18	0.92	10.00	0.65	10.55	0.77	10.16
Machinery-equipment	2.17	17.29	3.48	54.29	3.02	41.31	2.17	43.31	2.82	30.65	2.59	42.05	2.72	35.66
Technological Change	5.81	46.30	0.32	5.02	2.04	27.91	0.70	13.97	2.81	30.54	1.37	22.24	2.12	27.87

Source: Calculated from Table A.5 in the Appendix by using the formula:

contribution of factor $i = \frac{G_i \times S_i}{Q_g}$

where G_i is the growth rate of the i^{th} factor, S_i is its factor share and Q_g is the growth rate of net output.

Note: The calculation is done by computer which takes 8 digits after the decimal point. Thus, discrepancies could arise if the contributions are calculated by using the figures shown in the table.

Although the approach adopted in this chapter is essentially the same as Solow's approach in the previous chapter, it does represent a small step towards refinement. For instance, the contribution of input quality change, which is usually lumped with technological change, has been separately identified. However, as we have noted briefly, the constant returns assumption might have created an upward bias for the estimate of the contribution of technological change. Thus, the constant returns assumption will be relaxed in the following chapter where the nature of technological change will be investigated by the production function estimation approach.

Chapter VII

PRODUCTION FUNCTION ESTIMATION

The last two chapters have attempted to analyse technological change and other sources of productivity growth in the Canadian steel industry by means of modified Solow and Denison frameworks. The purpose of the present chapter is to make a comparative study of steel production in Canada and the United States by using a production function estimation approach.

We have reviewed briefly the essence of Cobb-Douglas and CES production functions in Chapter III where we noted that the former is a special case of the CES production function. In the present chapter, we shall begin our analysis with a crude Cobb-Douglas production function and then analyse the estimation results of a model derived from a CES production function.

A. Estimation Results of a Cobb-Douglas Production Function

For the purpose of obtaining some indications as to the degree of returns to scale in the Canadian steel industry, a simple Cobb-Douglas production function[1] is specified as :

$$Q = AL^{\alpha}K^{\beta}$$

where Q is net output, L represents labour, K represents

[1] A cobb-Douglas function $Q = AL^{\alpha}K^{\beta}e^{\gamma t}$ has been fitted by both Canadian and American data, however, the estimates for γ are not significant at the 5 per cent level in most cases.

capital,[1] A is the efficiency parameter and α and β are the production elasticities of labour and capital, respectively. Written in a log-linear form, the production function becomes:

$$lnQ = lnA + \alpha lnL + \beta lnK \, .$$

The above function is fitted to the data for the Canadian and American steel industries separately. Essentially, the data used in this chapter are the same as those used in the Solow exercise of Chapter V, and so they can be found in Tables V-1 and V-2. The methods of deriving the labour input for both Canada and United States are also the same, except that the amounts of total wages and salaries are divided by hourly employment costs instead of hourly earnings of production workers.

A stepwise procedure which takes the whole period first and then drops one year at a time has been adopted in fitting the log-linear Cobb-Douglas function. The purpose of doing so is to see the gradual change in production structure as the observation period is lengthened. It would also provide us with alternative results and reduce the sensitivity of the period chosen for investigation.

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[1]We used * to denote quality-adjusted capital and labour as distinct from unadjusted K and L in the previous chapter. In this chapter, since all K and L used are quality-adjusted, the * will be dropped for simplicity sake.

Table VII-1

ESTIMATION RESULTS OF A COBB-DOUGLAS PRODUCTION FUNCTION

The Canadian Steel Industry

Period	Constant	Labour α	Capital β	Returns to Scale $\alpha + \beta$	t values of significance test:differ from unity	$\bar{R}^2$	D.W.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1946-54	-1.8701 (-0.4996)	0.6356 (2.6035)	0.4938 (6.9298)	1.1294	0.6156	0.9352	2.3212**
1946-55	-1.8126 (-0.4525)	0.5753 (2.2354)	0.5475 (8.4664)	1.1228	0.5452	0.9445	2.0045**
1946-56	-3.5834 (-0.8221)	0.6299 (2.1936)	0.5888 (8.6879)	1.2187	0.8926	0.9534	1.5160
1946-57	-3.5754 (-0.8679)	0.6345 (2.3461)	0.5840 (9.7795)	1.2185	0.9467	0.9613	1.7781**
1946-58	-3.5368 (-1.1331)	0.6317 (3.2623)	0.5846 (13.1527)	1.2163	1.2408	0.9630	1.7811**
1946-59	-3.5199 (-1.1798)	0.6257 (3.4097)	0.5893 (15.5449)	1.2150	1.2919	0.9702	1.7754**
1946-60	-3.8295 (-1.2819)	0.6616 (3.6445)	0.5719 (16.5974)	1.2335	1.3998 (10%)	0.9707	1.7892**
1946-61	-3.7017 (-1.3031)	0.6500 (3.8287)	0.5760 (19.4622)	1.2260	1.3868 (10%)	0.9747	1.8980**
1946-62	-3.6976 (-1.3395)	0.6558 (3.9855)	0.5704 (21.6647)	1.2262	1.4678 (10%)	0.9782	1.9153**
1946-63	-3.5881 (-1.3582)	0.6521 (4.1079)	0.5683 (23.5318)	1.2204	1.4965 (10%)	0.9819	1.9068**
1946-64	-3.9667 (-1.6494)	0.6715 (4.5573)	0.5698 (24.5530)	1.2413	1.7983 (5%)	0.9852	1.9247**
1946-65	-4.1744 (-1.9164)	0.6824 (5.0130)	0.5704 (25.4413)	1.2528	2.0785 (5%)	0.9879	1.9237**
1946-66	-3.2144 (-1.5694)	0.6301 (4.8321)	0.5694 (25.1195)	1.1995	1.7356 (5%)	0.9888	1.8934**
1946-67	-2.3554 (-1.0690)	0.5887 (4.1630)	0.5636 (22.8428)	1.1523	1.2346	0.9871	1.5944**
1946-68	-2.3312 (-1.0945)	0.5877 (4.2781)	0.5632 (23.6864)	1.1509	1.2655	0.9885	1.7537**
1946-69	-2.4481 (-1.1230)	0.5878 (4.1781)	0.5691 (23.7211)	1.1569	1.2856	0.9886	1.7001**
1952-69	-2.6358 (-1.0098)	0.5929 (3.3892)	0.5737 (14.6136)	1.1666	1.1270	0.9767	1.5986**
1953-69	-2.3456 (-0.7780)	0.5690 (2.6802)	0.5808 (11.1470)	1.1498	0.8730	0.9737	1.2928
1954-69	-5.0090 (-1.8646)	0.7995 (4.0895)	0.5069 (9.9264)	1.3064	1.9844 (5%)	0.9803	1.7202**
1955-69	-4.3026 (-1.5802)	0.7741 (3.9830)	0.4950 (9.6149)	1.2691	1.7416 (10%)	0.9739	1.8263**
1956-69	-4.3471 (-1.4999)	0.7790 (3.6677)	0.4928 (8.1312)	1.2718	1.6561 (10%)	0.9699	1.7106**

*Reject the null hypothesis.

**Accept the null hypothesis that the error terms are serially independent.

Blank: inconclusive. See Rao & Miller, *op. cit.*, pp. 122-24, and Table 4, p. 228.

Source: Regression results obtained by using Columns (1), (3), (4) and (5B) of Table V-1 and Column (7) of Table V-3 in a Cobb-Douglas production function.

The regression results are shown in Tables VII-1 and VII-2. The results of the Canadian case are good -- the coefficients of labour and capital have the right sign and are highly significant. The coefficients of determination, $\bar{R}^2$, are high and the Durbin-Watson statistics are close to two. Column (4) of Table VII-1 shows the sum of the elasticities of labour and capital, which is an indicator of the degree of returns to scale. It indicates that the returns to scale in the Canadian steel industry are increasing and the magnitude of increasing returns has been maintained within the range of 1.1 to 1.2. Column (5) shows the t values of testing the significance of the returns to scale different from unity.[1] The number beneath indicates the level of significance. It is shown that the returns are not significantly different from 1 for the period 1946-54 but are significant when the later years are included. Thus, it suggests that the returns of the later years are increasing while those of the earlier years are mainly not significantly different from constant returns.

The same stepwise regression procedure is applied to the American case. However, some coefficients of the early period regression are not significant at the 5 per cent level. The few which are shown in Table VII-2 have highly significant coefficients. The sum of input elasticities are less than unity, implying that the returns to scale are decreasing.

---

[1] The standard error of the sum of the two coefficients used in the test is obtained from the formula :

$$\mathrm{var}\ (\alpha + \beta) = \mathrm{var}(\alpha) + \mathrm{var}(\beta) + 2\mathrm{cov}(\alpha\beta)$$

where var denotes variance and cov covariance.

VII 5

Table VII-2

ESTIMATION RESULTS OF A COBB-DOUGLAS PRODUCTION FUNCTION

The American Steel Industry

Period	Constant (1)	Labour α (2)	Capital β (3)	Returns to Scale $\alpha + \beta$ (4)	t values of significance test: differ from unity (5)	$\bar{R}^2$ (6)	D.W. (7)
1947-65	14.0342 (7.6886)	0.2448 (2.4433)	0.7363 (8.3241)	0.9811	0.1729	0.8450	1.0968
1947-66	14.0053 (8.0470)	0.2468 (2.6114)	0.7328 (9.6705)	0.9796	0.1954	0.8632	1.1010
1947-67	13.7689 (8.3878)	0.2609 (2.9505)	0.7209 (10.2140)	0.9818	0.1770	0.8639	1.0818
1947-68	13.8158 (8.7950)	0.2580 (3.0665)	0.7241 (10.9980)	0.9821	0.1798	0.8697	1.1063
1947-69	13.6786 (9.0049)	0.2665 (3.2945)	0.7143 (11.5500)	0.9808	0.1969	0.8718	1.1056
1947-70	13.4701 (9.2301)	0.2781 (3.5848)	0.7106 (11.7181)	0.9887	0.1184	0.8701	1.1075
1954-70	11.4795 (12.6485)	0.4033 (8.2377)	0.5764 (18.0934)	0.9797	0.3801	0.9669	2.1548**
1955-70	11.2929 (11.9229)	0.4149 (8.0462)	0.5655 (16.1747)	0.9804	0.3595	0.9663	2.0669**
1956-70	11.7286 (10.4102)	0.3914 (6.4030)	0.5668 (15.9146)	0.9582	0.6618	0.9637	2.0972**
1957-70	12.5051 (8.3250)	0.3492 (4.2829)	0.5721 (15.5556)	0.9213	1.0296	0.9624	2.0060**
1958-70	10.8744 (3.1918)	0.4379 (2.3648)	0.5603 (12.7719)	0.9982	0.0111	0.9613	1.9352**
1959-70	11.4871 (3.1527)	0.4024 (2.0218)	0.5803 (10.5254)	0.9827	0.1012	0.9527	2.0754**

**See notes attached to Table VII-1.

Source: Regression results obtained by using Columns (2), (3), (5), (6) and (8) of Table V-2.

However, the low t values shown in Column (5) indicate that none of the returns to scale is significantly different from unity. This means that the returns in the American steel industry might have been mainly constant throughout the period. Thus, the major difference between Table VII-1 and Table VII-2 is that the returns to scale in the Canadian steel industry have been increasing in the later years of the period under review while those in the American case have mainly remained constant for the entire period. The increase in the returns to scale in the Canadian case is consistent with the rapid diffusion of new technology in Canada.

B. A Model Derived from a CES Production Function

The Cobb-Douglas production function is a special case of the CES production function. It would be useful to see whether the findings of the last section would be changed if the elasticity of substitution between inputs was no longer constrained to unity. In this section, a model which is derived from a CES production function will be used to study the production patterns of the two steel industries.

(a) The Derivation of the Model

Assume the relevant production function is:

$$Q = \gamma[\delta K^{-\rho} + (1-\delta)L^{-\rho}]^{-\frac{\nu}{\rho}} \qquad \text{(Equation 7.1)}$$

where Q = net output represented by value added,

K = adjusted capital services,

L = adjusted labour services,

ν = returns to scale parameter,

δ = distribution parameter,

γ = efficiency parameter.

Differentiating Equation 7.1 partially with respect to labour, we get:

$$\frac{\partial Q}{\partial L} = (-\frac{\nu}{\rho}) \; [\delta K^{-\rho}+(1-\delta)L^{-\rho}]^{-\frac{\nu}{\rho}-1} (-\rho)(1-\delta)L^{-(1+\rho)}$$

$$\frac{1}{Q}\frac{\partial Q}{\partial L} = \nu(1-\delta)L^{-(1+\rho)} (\frac{Q}{\gamma})^{\frac{\rho}{\nu}} .$$

Taking logarithms on both sides,

$$ln\frac{\partial Q}{\partial L} - lnQ = ln\nu + ln(1-\delta) - (1+\rho)lnL + \frac{\rho}{\nu}lnQ - \frac{\rho}{\nu}ln\gamma$$

$$ln\frac{\partial Q}{\partial L} = [ln\nu+ln(1-\delta)-\frac{\rho}{\nu}ln\gamma] + (1+\rho)ln\frac{Q}{L} + (\frac{\rho}{\nu} - \rho)lnQ \qquad \text{(Equation 7.2)}$$

Assuming competitive labour market such that marginal product of labour equals product wage $\frac{W}{P}$.
Substitute $\frac{W}{P}$ for $\frac{\partial Q}{\partial L}$ and rearrange the terms to obtain:

$$ln\frac{Q}{L} = -\frac{1}{1+\rho} [ln\nu+ln(1-\delta)-\frac{\rho}{\nu}ln\gamma] + \frac{1}{1+\rho}ln\frac{W}{P} - \frac{1}{1+\rho} (\frac{\rho}{\nu}-\rho)lnQ .$$

Assume, further, that Hicksian neutral technical change has taken place. That is, let both capital and labour efficiencies be raised by the same magnitude such that the marginal rate of substitution between capital and labour remains unchanged at the given capital-labour ratio after technical change. Suppose the magnitude of efficiency increase is μ, where $\mu = e^{mt}$, then labour becomes μL and capital becomes μK. Substitute these relationships into Equation 7.2, it becomes:[1]

$$ln\frac{\partial Q}{\partial(\mu L)} = [ln\nu + ln(1-\delta) - \frac{\rho}{\nu}ln\gamma] + (1+\rho)ln\frac{Q}{(\mu L)} + (\frac{\rho}{\nu} - \rho)lnQ.$$

Since $\frac{\partial Q}{\partial L} = \frac{\partial Q}{\partial(\mu L)} \cdot \frac{\partial(\mu L)}{\partial L} = \frac{\partial Q}{\partial(\mu L)} \cdot \mu \cdot \frac{\partial L}{\partial L} = \mu\frac{\partial Q}{\partial(\mu L)}$

thus, $\frac{\partial Q}{\partial(\mu L)} = \frac{\partial Q}{\partial L} \cdot \frac{1}{\mu}$ and $ln\frac{\partial Q}{\partial(\mu L)} = ln\frac{\partial Q}{\partial L} - ln\mu.$

Also, since $ln\frac{Q}{(\mu L)} = ln\frac{Q}{L} - ln\mu$, the equation can be written as:

$$ln\frac{\partial Q}{\partial L} = [ln\nu + ln(1-\delta) - \frac{\rho}{\nu}ln\gamma] + (1+\rho)(ln\frac{Q}{L} - ln\mu) + (\frac{\rho}{\nu} - \rho)lnQ + ln\mu.$$

Rearrange the above equation and substitute $\frac{W}{P}$ for $\frac{\partial Q}{\partial L}$[2] and e^{mt} for μ, we obtain:

$$ln\frac{W}{P} = (ln\nu + ln(1-\delta) - \frac{\rho}{\nu}ln\gamma) + (1+\rho)ln\frac{Q}{L} - (1+\rho)mt + (\frac{\rho}{\nu} - \rho)lnQ + mt$$

$$(1+\rho)lnL = (ln\nu + ln(1-\delta) - \frac{\rho}{\nu}ln\gamma) - ln\frac{W}{P} + (1+\frac{\rho}{\nu})lnQ - \rho mt$$

---

[1] Since Equation 7.2 does not contain a term for capital service, the resultant equation under the assumption of Hicksian neutrality is the same as that under the assumption of Harrod neutral technical change.

[2] Although the returns to scale, ν, may not be constant, labour is still rewarded by its marginal product as long as perfect competition and profit maximization are assumed. However, increasing returns may eventually lead to a monopolistic situation. Thus, unless competition still prevails in the labour market, product wage may not equal marginal product of labour.

$$lnL = \frac{1}{1+\rho}\left(ln\nu + ln(1-\delta) - \frac{\rho}{\nu} ln\gamma\right) - \frac{1}{1+\rho} ln\frac{W}{P} + \frac{1}{1+\rho}\left(1+\frac{\rho}{\nu}\right) lnQ - \frac{\rho m}{1+\rho}t$$

Written in compact form, the equation becomes :

$$lnL = a + b\,ln\frac{W}{P} + c\,lnQ + dt \qquad (7.3)$$

where $a = \frac{1}{1+\rho}\left(ln\nu + ln(1-\delta) - \frac{\rho}{\nu} ln\gamma\right)$, $b = -\frac{1}{1+\rho}$

$c = \frac{1}{1+\rho}\left(1+\frac{\rho}{\nu}\right) = \frac{\nu+\rho}{\nu(1+\rho)}$, $d = -\frac{\rho m}{1+\rho}$

Equation (7.3) states that labour requirement is related to product wage, net output and time in a log-linear relationship.[1] It enables us to calculate the elasticity of substitution, the degree of returns to scale and the rate of technical change. The data used for fitting Equation (7.3) are the same as those in the Cobb-Douglas production function estimation of the previous section. Additional series used are the product wage series for the Canadian and American steel industries which are obtained by deflating hourly employment costs by industry selling price indexes of steel products.

If constant returns to scale are assumed, i.e., $\nu = 1$, Equation (7.3) becomes :

$$ln\frac{Q}{L} = a^* + b^* ln\frac{W}{P} + d^*t$$

The above equation has also been fitted to both Canadian and American data. However, almost all coefficients are not significant at the 5 per cent level. Thus, the following discussion of estimation results is limited to those of Equation (7.3).

---

[1] The alternative forms of Equation (7.3) are :
$lnQ/L = a_1 + b_1 lnW/P + c_1 lnQ + d_1 t$ and $lnQ = a_2 + b_2 lnW/P + c_2 lnL + d_2 t$

The estimator of c_1 in the first equation will be biased and inconsistent if Q on the righthand side is in fact not predetermined. The unscrambled estimates of the parameters of of production function are identical to those obtained by Equation (7.3).

(b) Estimation Results

(i) Canadian case

As in the case of the Cobb-Douglas production function estimation, a stepwise regression procedure is taken for the CES regression. Out of a total of 29 equations fitted in the Canadian case, 7 regressions have all their coefficients significant at the 5 per cent level except the coefficient c for for the period 1960-69 and are shown in Table VII-3.

Before interpreting regression results, the meaning of the parameters in the equation should be noted. The absolute value of b is an estimate of the elasticity of substitution σ which is related to the substitution parameter, ρ, according to the relation $\sigma(1+\rho)=1$.

Thus, the value of b is inversely related to that of the substitution parameter. The former increases as the latter decreases. It is evident that the value of ρ cannot be less than -1 since if it does, the elasticity of substitution becomes negative.[1] The returns to scale parameter, ν, can be smaller or greater than unity but not less than zero. It represents decreasing returns if it is less than unity and

[1] The elasticity of substitution can be defined as : $\sigma = d\ ln(K/L)/d\ ln(MP_l/MP_k)$. Under perfect competition, MP_l/MP_k equals the relative price ratio. A negative σ would imply that when the price of labour falls by one per cent, the K/L ratio increases by σ per cent, which is not consistent with profit maximization.

increasing returns if greater than unity. The parameter *m* is the rate of technical change where exponential growth trend is assumed.

In the Canadian case, some regression coefficients of those periods which include years before 1954 are not significant at the 5 per cent level. This could be due to the effects of the distorted production patterns immediately after the Second World War and during the Korean War period. In any event, the performance of the model for the period beginning in 1954 is satisfactory. All regression coefficients except one are significant at the 5 per cent level. The coefficients of multiple correlation adjusted for degrees of freedom are in the range of 0.90 to 0.95 The Durbin-Watson statistic increases with the decrease in sample size, except in one case. Although only in three cases the Durbin-Watson statistic is greater than its upper value limit, those that fall in the inconclusive range are close to their upper limits.[1] Thus, on the whole, there is no clear sign of autocorrelation.

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[1]The upper limit is 1.84 and the lower limit is 0.59 at the 5 per cent significant level when the sample size is 15 and the number of explanatory variables is 4. See P. Rao and R. L. Miller, *Applied Econometrics* (California: Wadsworth Publishing Company, Inc., 1971), Table 4, p. 228.

Table VII-3

REGRESSION COEFFICIENTS OF THE EQUATION

$$lnL = a + b\ ln\frac{W}{P} + c\ lnQ + dt$$

The Canadian Iron and Steel Mills

	Period	a	b	c	d	$\bar{R}^2$	D.W.	Elasticity of Substi.	Substitution Parameter	Returns to Scale	Rates of Tech.Change
1.	1954-69	8.8907 (6.1005)	-1.9807 (-2.6128)	0.5225 (7.2191)	0.0697 (2.1282)	0.9243	1.1927	1.9807	-0.4951	0.6725	0.0711
2.	1955-69	8.1420 (4.4610)	-1.8360 (-2.3142)	0.5581 (6.4296)	0.0622 (1.7946)	0.9027	1.2515	1.8360	-0.4553	0.6542	0.0744
3.	1956-69	8.6286 (4.9566)	-2.0667 (-2.6415)	0.5366 (6.3092)	0.0743 (2.1511)	0.9134	1.3886	2.0667	-0.5161	0.6971	0.0697
4.	1957-69	10.0516 (4.5634)	-2.2719† (-2.8292)	0.4645 (4.2552)	0.0884 (2.3941)	0.9208	1.7990**	2.2719	-0.5598	0.7037	0.0695
5.	1958-69	10.4988 (5.6795)	-1.8923† (-2.7370)	0.4286 (4.6344)	0.0772 (2.4750)	0.9490	1.5911	1.8923	-0.4715	0.6096	0.0865
6.	1959-69	14.2841 (5.9471)	-2.7459†† (-3.8484)	0.2501 (2.1524)	0.1214 (3.5861)	0.9462	1.8869**	2.7459	-0.6358	0.6995	0.0695
7.	1960-69	14.9297 (6.2008)	-2.8690†† (-4.0752)	0.2173 (1.8599)	0.1289 (3.8401)	0.9486	2.4194**	2.8690	-0.6514	0.7048	0.0694

Note: 1) $a = \frac{1}{1+\rho}[ln\nu + ln(1-\delta) - \frac{\rho}{\nu}ln\Upsilon]$

$b = -\frac{1}{1+\rho}$

$c = \frac{1}{1+\rho}(\frac{\rho}{\nu} - \rho)$

$d = -\frac{\rho}{1+\rho}m$

and $-b$ = *elasticity of substitution*

$\rho = \frac{-(1+b)}{b}$ = *substitution parameter*

$\nu = \frac{1+b}{c+b}$ = *returns to scale parameter*

$m = -\frac{d}{1+b}$ = *rate of technical change*

2) † indicates that the elasticity of substitution is significantly different from unity at the 10 per cent level.

†† significant at the 5 per cent level

Table VII-4

REGRESSION COEFFICIENTS OF THE EQUATION

$$\ln L = a + b \ln \frac{W}{P} + c \ln Q + dt$$

The American Steel Industry

	Period	a	b	c	d	$\bar{R}^2$	D.W.	Elasticity of Substi.	Substi. Parameter	Returns to Scale	Rates of Tech. Change
1.	1947-63	4.6989	-0.3086††	0.7135	-0.0104	0.9599	1.7778**	0.3086	2.2404	1.7076	0.0150
		(3.9098)	(-2.0738)	(12.8597)	(-3.2504)						
2.	1947-64	4.8186	-0.3241††	0.7085	-0.0102	0.9617	1.7940**	0.3241	2.0855	1.7583	0.0151
		(4.3156)	(-2.3536)	(13.6365)	(-3.3393)						
3.	1947-65	4.7867	-0.3025††	0.7099	-0.0102	0.9627	1.8065**	0.3209	2.1162	1.7458	0.0150
		(4.6819)	(-2.4967)	(14.8101)	(-3.5011)						
4.	1947-66	4.6902	-0.3125††	0.7141	-0.0103	0.9631	1.8040**	0.3125	2.2000	1.7119	0.0150
		(4.9203)	(-2.5508)	(15.8971)	(-3.6503)						
5.	1947-67	4.6861	-0.3025††	0.7137	-0.0102	0.9634	1.7382**	0.3025	2.3058	1.6963	0.0146
		(4.9211)	(-2.4801)	(15.9049)	(-3.6267)						
6.	1947-68	4.5751	-0.2838††	0.7180	-0.0103	0.9613	1.6095**	0.2838	2.5236	1.6495	0.0144
		(4.7434)	(-2.3042)	(15.7765)	(-3.5982)						
7.	1947-69	4.5077	-0.2626††	0.7200	-0.0104	0.9546	1.3757	0.2606	2.8373	1.6095	0.0141
		(4.3521)	(-1.9786)	(14.7251)	(-3.3554)						
8.	1947-70	5.2795	-0.3101††	0.6844	-0.0082	0.9324	0.9577*	0.3101	2.2248	1.8432	0.0119
		(4.2736)	(-1.9355)	(11.7210)	(-2.2196)						
9.	1954-70	6.6517	-1.2556	0.6607	0.0186	0.9671	1.2422	1.2556	-0.2036	0.4297	0.0728
		(6.8956)	(-6.3946)	(14.7480)	(3.5218)						
10.	1955-70	6.4912	-1.2538	0.6681	0.0189	0.9681	1.2998	1.2538	-0.2024	0.4333	0.0745
		(6.6603)	(-6.4015)	(14.7633)	(3.5835)						
11.	1956-70	6.9245	-1.2896†	0.6483	0.0203	0.9581	1.4916	1.2896	-0.2246	0.4516	0.0701
		(6.1789)	(-6.3423)	(12.5015)	(3.6151)						
12.	1957-70	7.5083	-1.2714	0.6183	0.0206	0.9357	1.8429**	1.2714	-0.2135	0.4156	0.0759
		(6.0266)	(-6.2597)	(10.4844)	(3.6876)						
13.	1959-70	8.9177	-1.4083	0.5565	0.0240	0.8783	2.3565**	1.4083	-0.2899	0.4793	0.0588
		(7.4944)	(-4.6903)	(8.8623)	(3.6525)						
14.	1960-70	9.1152	-1.4867†	0.5516	0.0251	0.8907	2.4444**	1.4867	-0.3274	0.5205	0.0516
		(7.7676)	(-4.9472)	(8.9766)	(3.8751)						

See notes attached to Tables VII-1 and VII-3. Due to unsatisfactory results, the regression for the period 1958-70 is omitted.

The regression coefficients are used in calculating the values of elasticity parameter, substitution parameter, returns to scale and technical change parameters, which are also shown in Table VII-3. There is a clear trend that the value of substitution parameter decreases towards -1 in the later regressions. This means that the elasticity of substitution has increased, which is also shown in the table. This increased flexibility of combining capital and labour in the production process facilitates the prompt introduction of new technologies.

Although the values of returns to scale are less than unity, which indicate the existence of decreasing returns and is contrary to the findings of the simple Cobb-Douglas production function estimation, the degree of decreasing returns has been diminishing through time. For instance, the value of the returns to scale parameter for the period 1954-69 is 0.6275 but it increases to 0.7048 for the period 1960-69. The rates of technical change, on the other hand, fluctuate within a small range with a mild indication of declining change. This could be true since the major innovation such as the basic oxygen furnace and continuous casting machines were introduced in the early years of the period 1954-69. The elasticity of substitution shows some signs of increase in the later periods. This indicates that technological change in the later years could be non-neutral since a change in the elasticity of substitution permits more flexible input combinations.

(ii) American case

The same model has been fitted by data of the American steel industry. The regression results are shown in Table VII-4.

The coefficients of multiple correlation indicate that the fit of these regressions is good; most of their values are around 0.95 and 0.96. The Durbin-Watson statistics are either greater than or close to the upper limits, except Regression 8.[1] Now if we look at the regression results of Regressions 1 to 8, the facts which strike us are that the elasticities of substitution and the annual rates of technical change are low but the returns to scale are unexpectedly high. Note that the earlier years beginning in 1947 are all included in these eight regressions. The period from the ending of the Second World War to that of the Korean War was the golden age of the American steel industry and expansion took place during that period. Presumably, substantial economies of scale were derived from the expansion.[2] On the other hand, production technology of the early years was certainly not as advanced as that of the later years, so that the possibility of substitution between capital and labour in producing a given quantity of output was very low. In the

[1] A two-stage estimating procedure is used to improve the estimates of Regression 8 but failed. Thus, the estimates of Regression 8 should be interpreted with caution. See Johnston, *op.cit.*, p.195.

[2] The technologically determined economies of scale are regarded as an element of technical change. See M.Brown, *op.cit.*, pp.13-14.

later periods, new technologies allowed a greater elasticity of substitution between inputs which, in turn, stimulated further technical change. Generally speaking, the net output growth of the early years was the result of substantial economies of scale while that of the later years was mainly attributable to technical change. Thus, when all early years are included, the average elasticity of the period is low, although the elasticities of the later years might be high. This explains the low elasticity and limited technical change but high returns to scale, which are shown by Regressions 1 to 8.

As most technological innovations were adopted by the American steel industry in the later years of the period 1947-70, we should expect the elasticities and the rates of technical change to be higher than those of the early years. Since the American steel industry was over-expanded such that the capacity utilization rates were low in the later years, the returns to scale should be small. Regressions 9 to 14 have left out the early years and show consistent results as would be expected. The elasticities and rates of technical change have increased substantially and the returns to scale have fallen drastically.

If Regressions 9 to 14 of Table VII-4 are compared with Canadian regressions in Table VII-3, one discovers that the elasticity of substitution in the Canadian case is much greater than that in the American case, and the gap has become wider in the later years. This is conceivable since major technological innovations were adopted by the Canadian steel industry earlier, and rates of diffusion were greater in Canada. These developments might have eased the substitution between capital and labour. The second feature we discover is that although the returns to scale in both countries are low, they are higher in Canada (.61 to .70) than in the United States (.41 to .52). The final feature to be noted is that the rates of technical change for the series of regressions beginning in 1954 have been declining for both countries, but the decline in the Canadian case is smaller than in the American case. Since the Canadian elasticity of substitution, returns to scale and some rates of technical change are greater than those of the American steel industry, it can be concluded that technological change in the Canadian steel industry in the later years has been greater than its counterpart in the United States.

C. Structural Break

We used a dummy variable to represent technological break in a regression of technological index, $A(t)$, against time variable, t, in Chapter V and found that the break existed between 1954 and 1955 in the Canadian steel industry. In the present section, Chow-test will be conducted to see whether the regression coefficients of various sub-periods are equal to each other and those of the whole period. If we write a regression model in a matrix form for the whole period as:

$$Y = X\beta + U$$

and those of the two sub-periods represented by

$$y_1 = \chi_1\beta_1 + \mu_1$$

$$y_2 = \chi_2\beta_2 + \mu_2$$

we can test the hypothesis $\beta_1 = \beta_2 = \beta$ by comparing the calculated and theoretical F ratios.[1] If the calculated F is greater than the theoretical F, then the hypothesis is rejected, indicating that a break does exist between the two sub-periods.

Table VII-5 shows the sums of squared residuals of various sub-periods and the calculated F ratios for both the Canadian and American steel industries. As the sums of squared residuals are obtained from the regression results of Equation 7.3, which has four regression parameters and 24 observations for the whole period, the degree of freedom for the F statistic is (4, 16). The theoretical F for the degree of freedom (4, 15) at the 0.5 per cent significant level is 5.80.[2] As most calculated F ratios in Table VII-3 are greater than the theoretical F ratio, it can be certain that there had been structural breaks in the two steel industries. The actual

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[1]The calculated F can be obtained from the formula:

$F = \frac{Q_3/k}{Q_2/(m+n-2k)}$ where Q_2 is the sum of sums of squared residuals of the two sub-periods, Q_3 is the difference between the sum of squared residuals of the whole period and Q_2, k is the number of regression parameter, and m and n are the observation numbers of the two sub-periods. See J. Johnston, *op. cit.*, pp. 136-37.

[2]A. M. Mood and F. A. Graybill, *Introduction to the Theory of Statistics* (New York: McGraw-Hill, second edition, 1963), p. 434.

cutting points are indicated by the highest value of calculated F ratios. Accordingly, the structural break occurred between 1959 and 1960 in the Canadian case, and it existed between 1953 and 1954 in the American case.

The reason for labelling the break in this section as a structural break as distinct from technological break discussed in Chapter V, is that the capital service series used in that chapter was adjusted for cyclical factor -- the capacity output utilization ratios while no adjustment can be made here since the capital service does not enter Equation 7.3. Thus, it is natural to find some difference between the timing of the technological and structural breaks.

The results shown in the table should be interpreted with caution. For instance, some of the regression shown are not very significant because of the inadequate degree of freedom. Also, the timing of the break could have been affected by demand and other cyclical factor. For instance, the American structural break of 1953-54 could probably be due to the completion of a series of major investment activity stimulated by the Korean War. However, one thing which we can say for sure is that there had been structural changes in both the Canadian and American steel industries for the period 1946-47/1969-70.

Table VII-5

TESTS OF EQUALITY OF REGRESSION COEFFICIENTS

	Sum of Squared Residuals				Calculated
	Period 1		Period 2		*F*
CANADA					
	1946-52	0.007413	1953-69	0.026419	2.0965
	1946-53	0.007435	1954-69	0.012379	6.4128*
	1946-54	0.012630	1955-69	0.011738	4.4649
	1946-55	0.013608	1956-69	0.009894	4.7767
	1946-56	0.013819	1957-69	0.008821	5.1110
	1946-57	0.014577	1958-69	0.005457	6.2971
	1946-58	0.015451	1959-69	0.003386	6.9524
	1946-59	0.015492	1960-69	0.002762	7.2997**
	1946-60	0.017369	1961-69	0.002541	6.3625
	1946-61	0.017376	1962-69	0.002539	6.3558
UNITED STATES					
	1947-51	0.000504	1952-70	0.013733	4.0107
	1947-52	0.001314	1953-70	0.008489	4.0027
	1947-53	0.001529	1954-70	0.003716	7.9908**
	1947-54	0.002090	1955-70	0.003413	7.4302
	1947-55	0.002864	1956-70	0.003216	6.3474
	1947-56	0.002879	1957-70	0.002896	6.8920
	1947-57	0.003363	1958-70	0.002280	7.1416*
	1947-58	0.004723	1959-70	0.001414	6.2611
	1947-59	0.005377	1960-70	0.001179	5.5927
	1947-60	0.005796	1961-70	0.001028	5.2254
	1947-61	0.005817	1962-70	0.000872	5.4067
	1947-62	0.005910	1963-70	0.000244	6.2156
	1947-63	0.006921	1964-70	0.000242	4.0000
	1947-64	0.006987	1965-70	0.000183	3.9981

**The highest *F* ratio.

*The second highest ratio besides those which are close to the highest ratio.

Source: The sums of squared residuals are obtained from the residual analyses of the regressions shown in Tables VII-3 and VII-4.

D. Conclusion

We have attempted to examine the production structure and the nature of technological change in the Canadian and American steel industries by using a crude Cobb-Douglas production function and a model derived from the CES production function. As the assumption concerning the elasticity of substitution of these two models is not the same, the results cannot be expected to be identical. Nevertheless, some consistent results of the later periods have been found and are briefly listed as follows:

(1) The degree of returns to scale in the Canadian steel industry has been greater than that in the American steel industry.

(2) The elasticity of substitution has become greater in later years in both cases but the value of the elasticity and its magnitude of increase are greater in the Canadian case than in the American case.

(3) The Canadian rates of technical change are greater than the American rates in some cases. Since the changes in the elasticity of substitution and returns to scale are components of technical change, and they are all greater

in the Canadian case, it is concluded that technical change in the Canadian steel industry has been greater than in the American steel industry.

Chapter VIII

SUMMARY AND CONCLUSION

We have now come to a stage where we have to tie the analyses of the previous chapters into a coherent discussion of technological change. We shall begin by presenting a summary of the main themes, and then present the findings and conclusions.

A. A Summary

Astonished by the unprecedented growth of the steel industry, the present thesis was designed to describe its development, to study the diffusion process of new technologies and to evaluate the contribution of technological change as well as the production relationships under the change.

The technique of iron-making was brought into Canada as early as 1736. The making of iron and steel was encouraged by a bounty system and other protective measures in the early years but the greatest stimulation was the outbreak of the two world wars. The period since the end of the Second World War has been a period of rapid growth for the steel industry. Part of the explanation for the expansion of iron and steel production in general is the availability of new techniques of iron ore preparation such as sintering and pelletizing. The economic implications of these new techniques are the reduction of transportation cost per unit of iron content and the use of second-class ore which was not profitable before. In the case of the Canadian steel industry, the growth was accelerated by the prompt adoption of new technologies of steel-making. The two major innovations were the use of the basic oxygen furnace and the continuous casting machine. The effect of these innovations was the saving of raw materials, time, machine motions, capital as well as operating costs.

We have placed much emphasis on the *prompt* adoption of new technologies. What were the factors which made this prompt adoption of new technologies possible? What are the factors which affect the management's decision to increase capital stock by acquiring new machinery and equipment, or to replace the new for the old in general? This is the topic of diffusion of technology. Salter argues that if competition exists, the lower price of the product produced by the new technology will eliminate the quasi-rent on the old capital equipment and hence force the producer to abandon the old technology.[1] Mansfield considers the profitability of the innovation, the size of the investment required by the innovation and the size of firm as the major factors which affect the speed of imitation or diffusion.[2] Allen, argues that the greater the growth rate of the wage rate and/or the labour share in the industry, the shorter the economic life of the capital equipment will be, implying that the pace of diffusion will be faster.[3]

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[1]See the discussion in Chapter III.

[2]See Chapter III.

[3]See R.G.D. Allen, *Macro-Economic Theory*, p. 295.

A closer look at the diffusion patterns of the basic oxygen furnace and the continuous casting machine in Canada reveals that the firms which first adopted the innovations were small firms with small market shares. A similar diffusion pattern existed in the American steel industry -- big firms lagged behind in adopting the basic oxygen furnace and the continuous casting machine. At the industry level, the Canadian steel industry adopted both innovations earlier than the American and maintained a higher diffusion ratio of the basic oxygen furnace until 1967. The divergence in the diffusion ratios for such a length of period was probably due to the facts that the growth rate of the wage rate in the Canadian industry was greater than in the American industry, the Canadian steel market was growing due to the increase in demand, the forces of competition were operating and the profit rate of the industry was relatively higher than in the American industry. The young age of steel furnaces is believed to be one of the factors which delayed the adoption of the basic oxygen furnace in the United States, but it was relatively unimportant in Canada since as the industry was growing, new investment was more important than replacement investment. On the other hand, the timing of the adoption of the basic oxygen furnace in the later period was found to coincide with low-utilization ratios of capital stock. This might be an indication that the low-utilization of capital put pressure on steel producers to replace new equipment for the old in the hope of reducing costs and raising demand.

B. Evaluation of Technological Change

The methods adopted in measuring the effect of technological change on net output growth in the Canadian and American steel industries are mainly:

(1) Solow's approach;

(2) Denison's approach;

(3) Cobb-Douglas production function estimation approach;

(4) CES production function approach.

These approaches can be classified into two major categories, namely, the residual approach and the production function estimation approach. As we mentioned in Chapter III, the Solow and Denison approaches are essentially the same. The difference is that the Denison approach also evaluates the contribution of other factors such as education indirectly while the Solow model considers only capital and labour. Where assumptions are concerned Solow's model assumes neutral technical change and constant returns to scale. The Denison approach also assumes constant returns to scale but no explicit assumption on the nature of technical change is made.

The constant return assumption is relaxed in our Cobb-Douglas and CES production function estimations. Again, as was pointed out in Chapter III, the former is a special case of the latter. The Cobb-Douglas assumes a unitary elasticity of substitution between inputs while the CES assumes a constant elasticity. Technological change is usually represented by an exponential growth rate of time trend. The labour requirement equation, which is derived from a CES function, incorporates a time trend to capture the rate of technological change.

The main criticism on the residual approach is that the contribution of technological change so measured is in fact a measure of ignorance. The Denison approach attempts to reduce the amount of ignorance by considering factors other than capital and labour. However, factors which do not have an explicit market value such as research and development are still difficult to be incorporated in the measurement of the contribution of technological change. The Solow measure has an additional drawback in the comparison between the contributions of technical change to labour productivity growth in two industries. The contribution to labour productivity growth in percentage term is calculated by using the formula:

$$\frac{\text{Technological index}_T}{\text{Labour productivity}_T/\text{Labour productivity}_i}$$

where T denotes the ending year of the period and i the beginning year. For instance, if labour productivity has increased by three times while the technological index has increased by 1.5 times, then the contribution is calculated as 50 per cent. However, if the technological indexes of two industries are the same but the labour productivity ratios are not the same, then the contribution of technological change is greater in the industry with smaller labour productivity growth than the other with greater labour productivity growth. This in fact occurred in our comparison between the contributions of technological change in the Canadian and American steel industries.

One of the limitation of single equation estimation of production function is the simultaneous equation bias. Simultaneous equation bias arises if the estimated equation is a part of a simultaneous equation system. In order to maximize its profit, a firm has to decide on the amounts of capital, labour and output in such a way that the price of an input equals to its marginal product.[1] Thus, the complete system consists of the following equations:

$$Q = f(K,L;t)$$

$$\frac{\partial Q}{\partial L} = \frac{W}{P} \quad \text{and} \quad \frac{\partial Q}{\partial K} = \frac{R}{P}$$

where R represents rental on capital. In our system, after the substitution of the marginal productivity relationship, the equations are:[2]

$$Q = \gamma(\delta K^{-\rho}+(1-\delta)L^{-\rho})^{-\frac{\nu}{\rho}}e^{u_1+gt}$$

$$\ln L = a + b \ln \frac{W}{P} + c \ln Q + dt + u_2$$

$$\ln K = a' + b' \ln \frac{R}{P} + c' \ln Q + d't + u_3$$

Written in a logarithmic form, the production function, becomes:

$$\ln Q = \ln\gamma - \frac{\nu}{\rho}\ln(\delta K^{-\rho}+(1-\delta)L^{-\rho}) + gt + u_1$$

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[1] "This determination is expressed by a system of function relationships; the production function ... is but one of them". See J. Marschak and W.H. Andrews, "Random Simultaneous Equations and the Theory of Production", Econometrica, 1944, p. 144.

[2] The derivation of the capital requirement equation is similar to that of the labour requirement equation. See pp. 213-215.

where the u's represent disturbance terms. In the above system, the product-wage, $\frac{W}{P}$, the rental of capital, $\frac{R}{P}$ and time, t, are given. In the labour equation, L is dependent on the disturbance term u_2 and in the production function Q is a function of L. Since Q is partially determined by L and L is correlated with u_2, Q is thus correlated with u_2 in the labour equation. Similar reasoning can be applied to the capital equation. This violates the crucial assumption that explanatory variables should be uncorrelated with or independent of the disturbance term in order to obtain the best linear and unbiased estimator. The consequence is that the single equation least squares estimators of any of the equations alone will be both biased and inconsistent.[1] However, if the explanatory variables of the estimated equation are fixed or given, then the unsatisfactory nature of single-equation least squares vanishes.[2] It is argued by Walters[3] that:

> "The choice between the single and many equation models must depend on the purposes for which the estimates are required, the availability of data, and relative errors. The results of empirical research in other fields of econometrics suggest that it is dangerous to be pedantic about the superiority of simultaneous equations or single equation methods. It is likely that, if the purpose of the model is to predict output for given quantities of input, the single equation approach will be best."

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[1] For the discussion on simultaneous bias of production function, see J. Marschak and W.H. Andrews op. cit., pp. 164-168, M. Nerlove, Estimation and Identification of Cobb-Douglas Production Functions, Chicago:Rand McNally, 1965, p. 29, A.A. Walters, "Production and Cost Functions: An Econometric Survey", Econometrica, 1963 pp.16-20.

[2] The least-squares estimate is said to approach the true values as the sample variance diminishes i.e., when the sample size is large. See J. Marschak and W.H. Andrews op. cit., pp. 166-168.

[3] A. A. Walters, op. cit., p. 17.

In the estimation of labour requirement equation, the explanatory variables are mainly output, Q and product wage, $\frac{W}{P}$, which is exogenously given in our system. Due to the product-ordering system which is prevalent in the steel industry, the output of a certain period can be planned ahead and roughly regarded as fixed or given.[1] Besides, the capital stock in the short run such as a year can also be regarded as given since the acquisition and installation of additional production equipment usually take more than a year. Thus, while the limitation of the single-equation least squares method is apparently known, the bias resulted in the estimation of the labour equation is expected to be small.

Due to the different assumptions and limitations, the findings of the approaches vary. The main results of the various approaches can be briefly listed as follow:

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[1] It has also been pointed out that steel producers tend to operate as close to capacity as possible as the steel industry is highly capitalized and fixed costs are high. Since capacity does not change drastically in the short run, this implies that producers do have some idea of the amount to be produced. See G.E. Wittur, op. cit., p. 34.

A. Solow's Method

(1) Assumptions: Constant returns to scale, perfect competition and neutral technical change.

(2) Average annual rate of technical change: The average rate of the period 1955-69 (0.0163) is greater than that of the period 1946-54 (0.0141) in Canada.

(3) Technological break: The technological structure in the Canadian steel industry of the period 1955-69 was distinct from that of 1946-54.

(4) Time trend of technological index: The cumulated Canadian technological index is greater than that of the American steel industry. And the time trend of the Canadian technological index is found significantly different from the American (.00869 vs. .00595).

(5) Labour productivity growth: The Canadian labour productivity measured by net output per man-hour grew by 150 per cent for the period 1946/47 - 1969/70.

(6) Contributions to labour productivity growth and to net output growth: 53 per cent of labour productivity growth is attributable to technological change and 47 per cent to the increase in capital per man-hour. In the American steel industry, technological change has contributed 88-89 per cent to labour productivity growth since the latter has been small. The contribution of technological change to total net output growth in the Canadian steel industry is 31.2 per cent.[1]

B. Denison's Method

(1) Assumptions: Constant returns to scale, perfect competition, productivity offset phenomenon, and positive correlation between school years and earnings.

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[1]The Canadian net output was $128,873,600 in 1946 and $557,868,600 in 1969. The ratio is 4.3288 and the ratio of the technological index in 1969 to that in 1946 is 1.3514. The contribution of technological change to total net output growth is then calculated as 1.3514/4.3288, which is 31.2 per cent. See Tables V-1 and V-3.

		%
(2) Sources of net output growth:	Growth in total labour	20.83
	Labour quality change	4.35
	Growth in total capital service (before utilization is corrected)	54.90
	Capital service quality change	0.96
	Underutilization	-9.07
	Technological change	27.87

C. Cobb-Douglas Estimation

(1) Assumption: The elasticity between capital and labour is unity but the returns to scale may not be constant.

(2) Returns to scale: The Canadian returns to scale of the period 1946-69 are not significantly different from constant returns but those of the periods 1954-69 and 1946-66 are significantly greater than unity at the 5 per cent level. This implies that the returns to scale of the period 1954-66 are significantly increasing.

(3) Comparison: The sums of American input elasticities are less than unity, implying the existence of decreasing returns. But the t tests find that none of them is significantly different from unity at the 5 per cent level. Thus, constant returns to scale prevailed in the American steel industry.

D. CES Estimation

(1) Assumption: The elasticity of substitution between capital and labour is a constant, returns to scale may not be constant and technical change is Hicksian neutral.

(2) Elasticity of substitution: The Canadian elasticities are estimated between 1.8 and 2.8. In most cases, they are significantly greater than unity while the elasticities in the American case are low and are not significantly different from one.

(3) Returns to scale: The returns to scale are less than unity in both Canadian and American cases but the Canadian returns are consistently greater than those of the American.

(4) Rate of technological change: The Canadian rates of technological change for the later years are between 6 and 8 per cent while the American rates are between 5 and 7 per cent for the comparable subperiods. The American rate of the period 1947-70 is about 1.2 per cent and those of the early subperiods are around 1.4 per cent.

The differences in findings of the various approaches adopted are obvious. The following discussion will focus on the comparison of findings with respect to the rate of technological change, the returns to scale, the elasticity of substitution and the break in technological structure.

The average rate of technological change in the Canadian case for the period 1946-69 is calculated as 1.53 per cent by using the Solow method. The Denison method calculates the contribution of technological change for the whole period as 27.87 per cent. The annual rate of technological change is thus 1.16 per cent. This is consistent because in the Denison approach the residual is reduced through the quantification of input quality change. However, the rates of technological change estimated by the labour requirement equation are relatively high; they are between 6 and 8 per cent in Canada and between 5 and 7 per cent in the United States. Note that these are the rates in the later periods and are not the average rate of the entire period. The rate for the entire period 1947-70 in the American case is about 1.2 per cent and those for other early periods are around 1.5 per cent.

It is consistent to have higher rates in the later subperiods because new technology was adopted in the later years. Nevertheless, the estimates are still greater than those calculated by Solow's method.[1] The explanation lies in the fact that we use a smaller man-hour series in the estimation of the Cobb-Douglas and the labour requirement equation than what is used in the Solow and Denison chapters.[2] This leads to an upward adjustment of the estimates of the rates of technological change. Although the rates so estimated cannot be strictly compared, some observations can be offered. First, the rates of technological change of the later years are repeatedly shown to be greater than those of the early years. This is true in both Canadian and American cases. Second, the Canadian rates are greater than those of the Americans for the comparable subperiods. An annual rate between 1.0 and 1.5 per cent is believed to be the average rate of technological change in the Canadian steel industry. This means that technological change has contributed about 25 to 35 per cent to net output growth.

Constant returns to scale is assumed in both Solow and Denison approaches. The Cobb-Douglas estimation indicates that while this is true for the American steel industry, the Canadian steel industry shows signs of increasing returns to scale in the period 1954-69. The estimates of the labour requirement equation, however,

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[1] The average rate of technological change in the American steel industry calculated from Table V-4 is 0.84 per cent (Test 1).

[2] Man-hour series is obtained by dividing total wages and salaries by hourly earnings in Chapter V but hourly employment costs are used in Chapter VII. The latter is greater than the former.

show that the returns to scale have been decreasing in both Canada and the United States in recent years. This is in direct conflict with the findings of the Cobb-Douglas function estimation. Moreover, the estimates are low; they are between 0.6 and 0.7 in the Canadian case and are between 0.4 and 0.5 in the American case. Although it may be true that the steel industry may run into decreasing returns, the estimates are too low to be realistic. It seems probable that the Canadian steel industry has enjoyed some degree of increasing returns in recent years as the result of adopting new technology and expansion while the American steel industry has received mild decreasing returns. One thing which can be certain is that the Canadian returns to scale have been greater than the American returns in most cases.

The estimation of the labour requirement equation also indicates that the elasticity of substitution between capital and labour in Canada is much greater than that in the United States. The greater elasticity means that the combination of capital and labour inputs is more flexible in Canada. Thus, it will be easier to substitute one input for another when the relative price of input changes and so there is a greater possibility to minimize costs for a given output.

The test of technological break reveals that the technological structure in the Canadian steel industry of the period 1946-1954 is not the same as that of the period 1955-1969. The break occurred in 1954. This is consistent with the adoption of new technology beginning in 1954 in Canada.

Despite the contradictory estimates, the following observations can be summarized;

(1) The returns to scale in the Canadian and American steel industry are close to constant returns. There are indications that the Canadian returns have been increasing and the American returns decreasing within a narrow range in recent years.

(2) In most cases, the Canadian returns to scale have been greater than the American returns. The Canadian elasticity of substitution is also found to be greater. Increasing returns are elements of neutral technical change and greater elasticity of substitution allows for more flexible combination of inputs and so is more adaptable to technological innovation.

(3) The average rate of technological change in the Canadian steel industry is believed to be between 1.0 and 1.5 per cent. Judging from the technological index and the average rate of technological change in the Solow test, and taking returns to scale as element of neutral technical change, it is concluded that the rate of technological change is greater in the Canadian steel industry than its American counterpart.

(4) Technological change has thus contributed about 25 to 35 per cent of total net output growth in the Canadian case. Input quality improvement contributed about 5 per cent to net output growth.

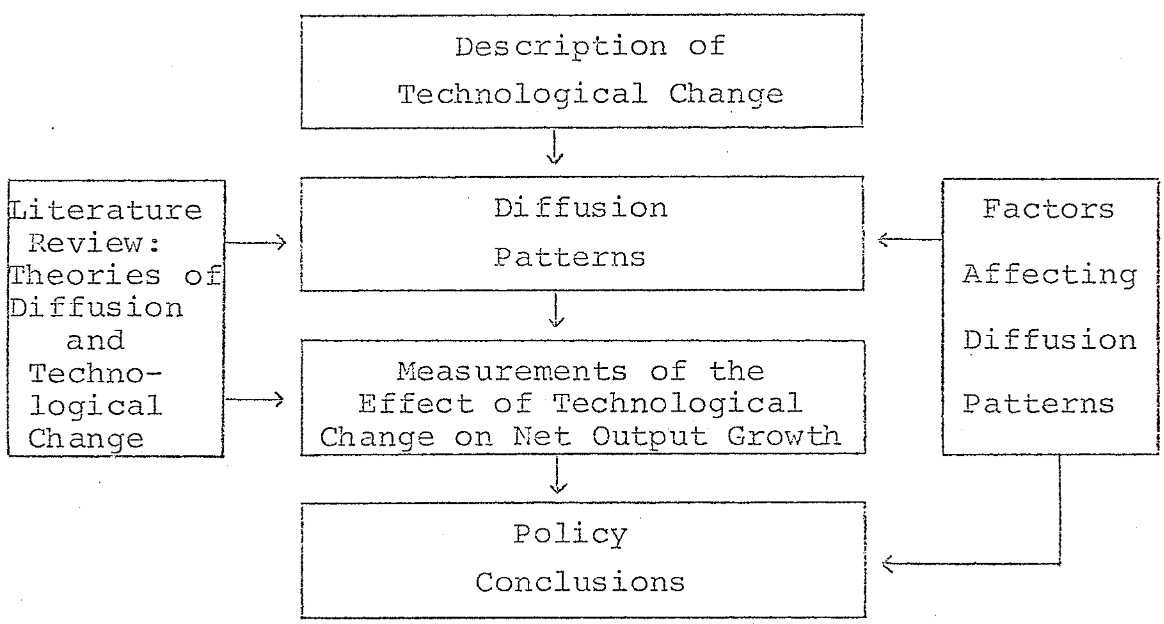
(5) Technological break occurred in 1954 or 1955, which is consistent with the timing of the rapid diffusion of new technology in the Canadian steel industry.

C. Conclusion

We have repeatedly found the positive relationship between the diffusion of new technologies in steel-making and the growth in net output. The stream of thoughts in this work can be illustrated by the following flow chart.

Diagram VIII-1

A FLOW CHART OF THOUGHTS

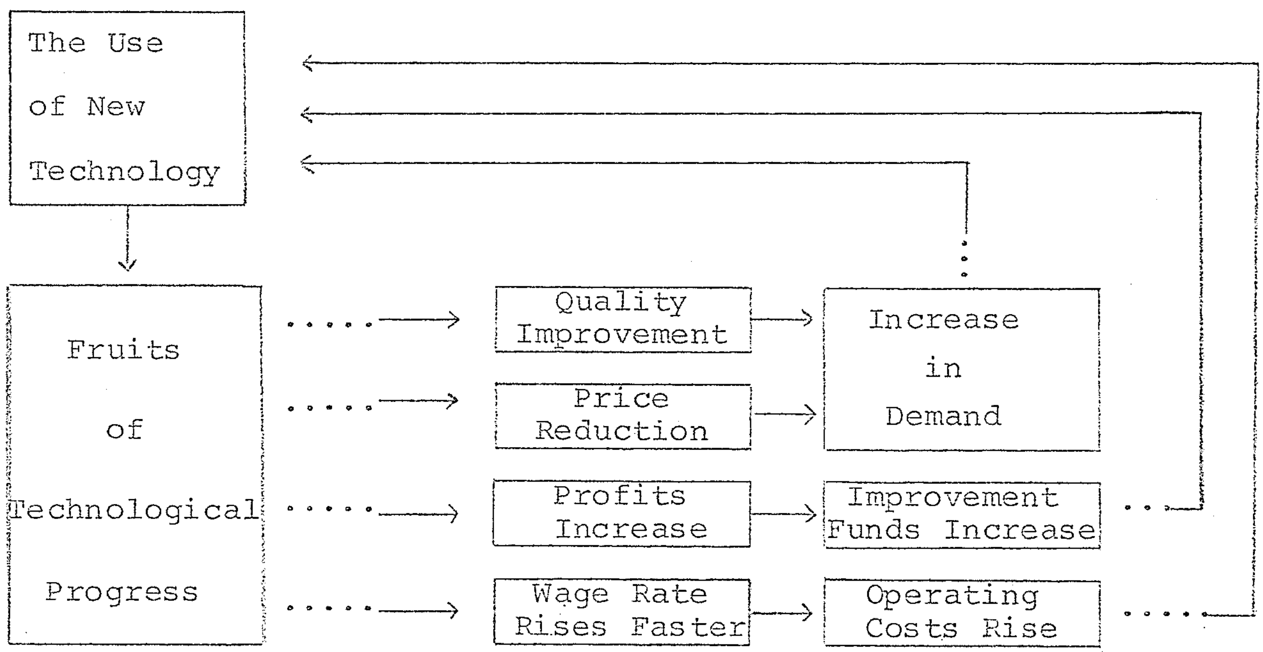


Once we have established that the greater the diffusion ratio of new technology, the greater the growth in net output has been, the role of factors in speeding up the diffusion rate becomes critical. We discussed at length the identification of these factors in Chapter IV and indicated that the growth rate of the wage rate, the competition structure of the market in Canada, the growth of this market and the profit rate of the major firms were major factors affecting the diffusion of the new technologies in the steel industry. If this conclusion is valid, can the same principle be also applied to other industries in general?

The effect of technological change are mainly two, namely, the improvement of the quality of product and the reduction of the unit costs. The former can induce the substitution of the product in question for other products and so increase the demand for it. In other words, it can induce the growth of the market. The reduction of the unit costs will either increase the profits of the producer if the price remains unchanged or reduce the selling price if price change is forced by competition. On the other hand, the reduction in unit costs by using cost-saving technology is partially offset by the growth of the wage rate. Thus, the fruit of technological change will be divided between the worker, the producer and the buyer, or any combination of the three. All these changes, namely, the wage rise, the increase in demand due to product quality improvement and price reduction, and the increase in profits, produce favourable effects on the speeding-up of the process of diffusion. Thus, the use of new technology affects the changes in factor incomes and demand, and after a time lag, the cumulated changes affect the diffusion of new technology. The relationship can be illustrated by the following chart.

Diagram VIII-2

THE LAGGED LOOP



In the above chart, the dots represent the existence of time lags. Thus, the circular reasoning process is avoided. Note that the distribution of the fruits of technological progress among the several items shown in the chart depends on the market structure of the industry. If for instance, the forces of competition were weak, the product price might fall less than it should or it might not fall at all. Institutional factors such as the bargaining power of the labour union and labour legislations also produce effects on the distribution. Again, the transmission of the effects of the rapid rise in the wage rate, the profit rate and the increase in demand, i.e., the growth in market to the adoption of new technology depends on the market structure of the industry. If the competition was inadequate in the product market, quasi-rents of the old capital equipment could be retained for a longer period because product price would not fall and so the pace of technological diffusion could be slower.

The degrees of influence from the increases in the wage rate, profits and demand on technological diffusion are not the same. They largely depend on the nature of the industry. For instance, the effect of a rising wage rate depends on the proportion of labour in the input combination, and the effect of profit increase on the size of investment required and the taxation regulations concerned. Therefore, it is difficult to attach weights to them separately. Nevertheless, it seems plausible to suggest that the compulsion to adopt cost-saving new technology[1] resulting from a rise in labour costs is more effective than the inducement through a high profit rate. Since the transmission effects of factors differ in importance and

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[1]The new technology is not necessary labour-saving since the purpose is to minimize the total costs of a given quantity of output but not the labour costs alone.

the distribution of the benefit of technological progress depends on market structure and other institutional arrangements, which can be modified by policy-makers, there are some alternatives to be chosen in decision-making. For instance, for the purpose of speeding the pace of technological innovation, would a wage policy of, say, 6 per cent annual increase be appropriate ? Or, should there be a policy granting the annual increase in the wage rate equal to its increase in labour productivity ? The precise answer to these questions again rests on the nature of the industry. From the experience of the Canadian steel industry, what we can say is that if a restrained wage policy was effectively pushed through, the compulsion to adopt new technology would have been less.

The adequate competition in the product market and the growth of the market are the most essential determinants in the technological diffusion process of the Canadian steel industry. As the prompt adoption of new technology is the main source of net output growth, policy actions by government should be aimed at increasing the pace of technological diffusion. The factors which are likely to speed up the diffusion rate have been discussed and the actual course of action rests upon the nature of the industry under review.

A P P E N D I X

Table A-1

RAW MATERIAL REQUIREMENTS IN PRODUCING A NET TON OF COKE

Year	Bituminous Coal, ton (1)	Absorbing and Wash Oil, Imp. Gal. (2)	Caustic Soda, lb. (3)	Sulphuric Acid 100% ton (4)
1960	1.3509	.0888	.7757	.0053
1961	1.3728	.0834	.7302	.0063
1962	1.3661	.1091	.6881	.0058
1963	1.2818	.1024	.6457	.0055
1964	1.3386	.0623	.4919	.0047
1965	1.3694	.0901	.6229	.0053
1966	1.3485	.0583	.5593	.0041
1967	1.3504	--	.4762	.0044
1968	1.1775	--	.2809	.0036
% of change between 1960&1968	-12.8	-34.3*	-63.8	-32.1%

*Between 1960 and 1966.

Source: Statistics Canada, Catalogue no. 41-203 (various issues). The coefficients are obtained by dividing raw materials by the corresponding annual productions of coke.

Table A-2

MATERIAL REQUIREMENTS IN PRODUCING A NET TON OF PIG IRON

Year	Iron Ore (1)	Mill Cinder,[3] Scale, etc. (2)	Iron & Steel Scrap (3)	Coke (4)	Limestone (5)	Dolomite (6)	(Unit= net tons)
1946	1.7963	.1150	.0164	.9391	.4430	.0149	
1947	1.8725	.0788	.0203	.9704	.3979	.0507	
1948	1.8396	.1288	.0209	.9763	.4174	.0543	
1949	1.7851	.1386	.0270	.9337	.3841	.0566	
1950	1.8012	.1239	.0183	.9234	.3735	.0642	
1951	1.8195	.1353	.0256	.9315	.3739	.0673	
1952	1.8206	.1195	.0398	.9300	.3660	.0791	
1953	1.7381	.2237	.0285	.9312	.3585	.0983	
1954	1.6956	.2612	.0373	.8908	.3520	.1169	
1955	1.6519	.2196	.0391	.8761	.3321	.0891	
1956	1.8280[1]	.0763[2]	.0487	.8553	.3058	.0849	
1957	1.8097	.0539	.0483	.8495	.2971	.0800	
1958	1.7831	.0525	.0413	.8074	.2486	.0728	
1959	1.7124	.0325	.0243	.7480	.1949	.0545	
1960	1.6341	.0634	.0259	.7179	.1851	.0589	
1961	1.5949	.0482	.0240	.7254	.1557	.0607	
1962	1.6130	.0411	.0178	.6404	.1364	.0756	
1963	1.4345	.0365	.0158	.5696	.1213	.0672	
1964	1.4285	.0282	.0119	.5464	.1163	.0653	
1965	1.3935	.0345	.0115	.5280	.1051	.0679	
1966	1.4399	.0479	.0148	.5470	.1051	.0755	
67	1.4215	.0432	.0249	.5796	.0834	.0772	
68	1.1064	.0389	.0248	.4595	.0790	.0325	
% Change Between 1946 & 1968	-38.4	-66.2	+51.2	-51.1	-82.2	+118.1	

[1]Since 1956, "iron ore" includes some ore in processed form previously reported under heading of "mill cinder, scale, etc.".

[2]Since 1956, "mill cinder, scale, etc." includes these products in not sintered form only.

[3]"Roll scale consists of oxides that form on the surface of steel during heating for rolling and is usually a source of relatively pure iron oxide." See U.S. Steel, *The Making, Shaping and Treating of Steel*, p. 387.

Source: Statistics Canada, Catalogue no. 41-203, 1955, 1959 and 1968 issues.

Table A-3

RAW MATERIAL REQUIREMENTS IN PRODUCING A NET TON OF STEEL

Year	Pig iron (1)	Scrap iron and steel (2)	Iron ore (3)	Limestone (4)	Dolomite (5)	Fluorspar (6)
1946	.4450	.6222	.0544	.0744	.0287	.0057
1947	.4984	.5403	.0503	.0750	.0309	.0061
1948	.5030	.5437	.0506	.0724	.0352	.0061
1949	.5189	.5290	.0548	.0759	.0360	.0063
1950	.4637	.5548	.0680	.0739	.0380	.0061
1951	.4837	.5544	.0801	.0678	.0398	.0062
1952	.4963	.5378	.0704	.0700	.0378	.0057
1953	.5336	.5080	.0637	.0695	.0396	.0052
1954	.5277	.4867	.0606	.0546	.0406	.0048
1955	.5352	.4957	.0850	.0459	.0383	.0039
1956	.5232	.5165	.0852	.0418	.0365	.0034
1957	.5415	.4945	.0794	.0376	.0358	.0032
1958	.5723	.4630	.0818	.0272	.0334	.0032
1959	.5667	.4764	.0678	.0227	.0304	.0032
1960	.5784	.4757	.0647	.0269	.0270	.0035
1961	.5995	.4704	.0600	.0203	.0287	.0036
1962	.6060	.4677	.0501	.0242	.0271	.0045
1963	.6015	.4718	.0480	.0232	.0274	.0046
1964	.5869	.4785	.0361	.0264	.0264	.0043
1965	.5707	.4835	.0271	.0299	.0232	.0035
1966	.5794	.4619	.0268	.0277	.0214	.0031
1967	.5860	.4746	.0208	.0274	.0213	.0027
1968	.6208	.4161	.0286	.0287	.0222	.0025
% Change Between 1946 & 1968	+39.5	-33.1	-47.4	-61.4	-22.6	-56.1

Source: Statistics Canada, Catalogue no. 41-203 (various issues). The quantity of each item is divided by total production of steel ingots and castings, including alloy-steel ingots and castings.

Table A-4

LABOUR SHARES

	Value Added (Current $) (1)	Salaries & Wages (Current $) (2)	Salaries (Current $) (3)	Wages (Current &) (4)	Total Share (5)	Labour Share (Non-production)	Labour Share (Production worker)
1946	69,880,040	51,230,787	7,518,271	43,712,516	.7331	.1076	.6255
1947	90,008,355	61,348,624	8,843,217	52,505,407	.6816	.0982	.5834
1948	120,509,401	78,991,734	10,156,298	68,835,436	.6555	.0843	.5712
1949	129,999,141	84,999,629	11,755,215	73,244,414	.6538	.0904	.5634
1950	146,454,407	87,811,391	13,230,268	74,581,123	.5996	.0903	.5093
1951	197,014,126	111,989,978	17,272,743	94,717,235	.5684	.0877	.4807
1952	218,017,840	128,748,727	19,637,264	109,111,463	.5905	.0901	.5004
1953	200,956,312	134,709,683	21,017,629	113,692,054	.6703	.1046	.5657
1954	199,894,060	113,391,451	22,369,938	91,021,513	.5673	.1119	.4554
1955	256,290,711	143,110,040	24,160,817	118,949,223	.5584	.0943	.4641
1956	318,972,826	170,862,752	28,011,607	142,851,145	.5357	.0878	.4479
1957	309,313,061	179,744,673	32,271,752	147,472,921	.5811	.1043	.4768
1958	271,552,163	157,041,543	33,713,397	123,328,146	.5783	.1242	.4541
1959	348,959,145	194,906,598	37,148,961	157,757,637	.5585	.1064	.4521
1960	315,764,972	199,039,209	41,021,190	158,018,019	.6303	.1299	.5004
1961	350,199,072	204,499,821	43,476,481	161,023,340	.5840	.1242	.4598
1962	387,063,287	221,541,373	46,194,391	175,346,982	.5724	.1193	.4531
1963	429,930,467	242,501,102	50,853,432	191,647,670	.5640	.1183	.4457
1964	479,391,553	269,749,696	55,735,769	214,013,927	.5627	.1163	.4464
1965	546,457,236	296,383,486	59,778,074	236,605,412	.5424	.1094	.4330
1966	542,402,444	321,401,323	67,495,437	253,905,886	.5926	.1245	.4681
1967	511,115,009	328,621,867	73,635,840	254,986,027	.6430	.1441	.4989
1968	564,316,998	349,405,988	78,511,927	270,894,061	.6192	.1391	.4801
1969	579,585,637	362,071,267	88,300,051	273,771,216	.6247	.1524	.4723

Source: Statistics Canada, Catalogue no. 41-203, 1947, 1949, 1951, 1953, 1955, 1957, 1962, 1968 and 1969 preliminary issues.

Table A-5

GROWTH RATES OF NET OUTPUT AND PRODUCTIVE FACTORS AND FACTOR SHARES

		1946-51 %	1952-57 %	1958-63 %	1964-69 %	1946-57 %	1958-69 %	1946-69 %
(1)	Net Output	12.55	6.41	7.31	5.01	9.20	6.16	7.61
	Increase in Total Inputs							
	Labour							
(2)	- Employment	5.36	1.70	1.95	2.34	3.37	2.15	2.73
(3)	- Labour Input Adjusted for Hours ($\frac{\dot{L}^*}{L^*}$)	5.57	2.22	2.20	2.45	3.74	2.33	3.00
(4)	- Labour Input Adjusted for Education	5.79	2.42	2.39	2.64	3.95	2.52	3.18
(5)	- Labour Input Unadjusted ($\frac{\dot{L}}{L}$)	5.89	1.70	2.00	1.46	3.60	1.73	2.63
	Capital Service							
(6)	Weighted and Underutilization corrected	15.88	10.93	11.72	5.09	13.18	8.41	10.69
(7) $\frac{\dot{K}^*}{K^*}$	Weighted but underutilization not corrected	8.48	11.25	9.27	6.78	9.99	8.03	8.97
(8) $\frac{\dot{K}}{K}$	Unweighted and underutilization not corrected	8.27	10.98	9.12	6.66	9.75	7.89	8.78
	Factor Shares							
(9)	Total Labour Share	64.87	58.39	58.13	59.74	61.63	58.93	60.28
(10)	Production Workers' Share	55.56	48.51	46.09	46.64	52.03	46.36	49.19
(11)	Nonproduction Workers' Share	9.31	9.88	12.04	13.10	9.60	12.57	11.09
(12)	Total Capital Share	35.13	41.61	41.87	40.26	38.37	41.07	39.72
(13)	Construction Share	8.94	9.93	8.75	7.62	9.44	8.18	8.81
(14)	Machinery-equipment Share	26.19	31.68	33.12	32.64	28.93	32.89	30.91

Sources: (1), (2) and (3) are calculated from Columns (5), (1) and (4) of Table II-3, respectively.

(4) is calculated from Column (3) of Table II-5.

(5) is calculated from a series which is a sum of production worker man-hours paid and nonproduction worker man-hours paid. The former is obtained by dividing "wages" (Column (4) of Table A-4) by hourly earning of production worker (Column (5) of Table A-1). The latter is obtained by multiplying average weekly hours by the number of nonproduction worker and 52 weeks. These data are available from Statistics Canada, Catalogue no. 72-204, *Earnings and Hours of Work in Manufacturing* (various issues). (6) and (7) are calculated from Columns (4) and (1) of Table II-8, respectively. (8) is calculated from Column (2) of Table A-1. (9), (10) and (11) are calculated from Columns (5) (6) and (7) of Table A-4. (12), (13) and (14) are calculated from Columns (1), (2) and (3) of Table II-7, respectively.

Appendix A-6. The Sources of productivity growth in blast furnace stage.

Higher hot blast temperature has been used lately to increase productivity but the flame temperature becomes unnecessarily high which causes the furnace to operate irregularly. Moisture in the form of steam can be used to control the flame temperature in order to obtain a smooth furnace operation. Automatic instruments are now used to measure the moisture content of hot blast temperature and to control the opening of a steam valve in order to set the blast moisture at a desired level. The use of higher blast temperatures and the accompanied moisture control increase blast furnace productivity. Second, fuels such as natural gas, coke-oven gas, fuel oil and so on can be injected into the blast furnace tuyeres. The injection can be controlled and hence the flame temperature is regulated. Also, fuel injection replaces some of the coke and so lowers the flame temperature since fuel produces less heat than coke does. Third, oxygen enrichment of the hot blast can increase the hot blast temperature and hence the productivity. However, the flame temperature will also be higher and so more fuels have to be injected and more moisture be used. Nevertheless, if oxygen is cheap enough then oxygen enrichment is still a promising source of productivity growth. Fourth, high pressure operation is designed to prevent the burden from descending by producing a lifting effect. Productivity would increase if the burden was not falling to the bottom of the furnace too fast. Fifth, the beneficiation of burden materials includes the washing of coal in making better coke and the agglomeration of fine ores by sintering or pelletizing. The latter shortens the time required for heating since fine ores take more time to heat. As a result, it saves not only fuels such as coke and fuel oil but also fixed capital input per unit of output.

BIBLIOGRAPHY

Books and Articles

ABRAMOVITZ, M. "Resources and Output Trends in the United States Since 1870." *American Economic Review*, Papers and Proceedings, 1956.

ADAMS, W. and DIRLAM, J. B. "Big Steel, Invention and Innovation." *Quarterly Journal of Economics*, May 1966.

ADAMS, W. and DIRLAM, J. B. "Steel Imports and Vertical Oligopopy Power." *American Economic Review*, September 1964.

ALLEN, R.G.D. *Mathematical Analysis for Economists* (London: Macmillan & Co. Ltd., 1962).

ARROW, K. J., CHENERY, H. B., MINHAS, B. S., and SOLOW, R. M. "Capital-Labour Substitution and Economic Efficiency." *Review of Economics and Statistics*, 1961.

ARROW, K. J. "The Economic Implications of Learning by Doing." *Review of Economic Studies*, 1962.

BAIN, J. *Industrial Organization*, 2nd edition (New York: Wiley, 1968).

BARTLETT, J. H. *The Manufacture, Consumption and Production of Iron, Steel and Coal in the Dominion of Canada* (Montreal: Dawson Brothers, 1885).

BERTRAM, G. W. *The Contribution of Education to Economic Growth.* Economic Council of Canada Staff Study No. 12 (Ottawa: Queen's Printer), June 1966.

BROWN, M. *On the Theory and Measurement of Technological Change* (Cambridge: Cambridge University Press, 1966).

CHRISTENSEN, L. R., and JORGENSON, D. W. "U.S. Real Product and Real Factor Input, 1929-1967." *Review of Income and Wealth*, 1970.

COBB, C. W., and DOUGLAS, P. H. "A Theory of Production." *American Economic Review*, 1928.

DALY, D. J., KEYS, B. A., and SPENCE, E. J. *Scale and Specialization in Canadian Manufacturing.* Economic Council of Canada Staff Study No. 21, March 1968.

DENISON, E. *The Sources of Economic Growth in the United States and the Alternatives Before Us* (New York: Committee for Economic Development, 1962).

DENISON, E. *Why Growth Rates Differ* (Washington, D.C.: The Brookings Institution, 1967).

DONALD, W.J.A. *The Canadian Iron and Steel Industry* (Boston: Houghton Mifflin Co., 1915).

ELVER, R. B. *Economic Character and Change in the Canadian Steel Industry Since 1945*, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa.

FELLNER, W. "Two Propositions in the Theory of Induced Innovations." *Economic Journal*, 1961.

GALE, W.K.V. *The British Iron and Steel Industry - A Technical History* (New York: Augustus M. Kelley, 1967).

GRILICHES, Z. "Research Expenditures, Education, and the Aggregate Agricultural Production Function." *American Economic Review*, 1964.

GRILICHES, Z. "Production Functions in Manufacturing: Some Preliminary Results", NB ER, vol. 31, and *The Theory and Empirical Analysis of Production* (ed. by M. Brown) (New York: Columbia University Press, 1960).

HAAVELMO, T. *A Study in the Theory of Investment* (Chicago: University of Chicago Press, 1960).

HAHN and MATTHEWS. "The Theory of Economic Growth: A Survey." *Survey of Economic Theory* (Britain: Royal Economic Society and American Economic Association, 1965).

HICKS, J. R. *The Theory of Wages* (London: Macmillan & Co. Ltd., 1963).

HOGAN, W. P. "Technical Progress and Production Function." *Review of Economics and Statistics*, 1958.

HONE, G. A., and SCHOENBROD, D. S. "Steel Import and Vertical Oligopoly Power: Comment." *American Economic Review*, March 1966.

JOHNSTON, J. *Econometric Methods* (New York: McGraw Hill Book Co., 1963).

JORGENSON, D. W., and GRILICHES, Z. "The Explanation of Productivity Change." *Review of Economic Studies*, July 1967, pp. 249-83.

KALDOR, N., and MIRRLEES, J. "A New Model of Economic Growth." *Review of Economic Studies*, 1962.

KENDRICK, J. W. *Productivity Trends in the United States* (Princeton: Princeton University Press, 1961).

KIRKALDY, J. S. *Aspects of Modern Ferrous Metallurgy* (Toronto: University of Toronto Press, 1964).

KLEIN, L. R. "Some Theoretical Issues in the Measurement of Capacity." *Econometrica*, 1960.

KLEIN, L. R., and PRESTON, R. S. "Some New Results in the Measurement of Capacity Utilization." *American Economic Review*, 1963.

KOTOWITZ, Y. "Technical Progress, Factor Substitution and Income Distribution in Canadian Manufacturing, 1926-39 and 1946-61." *Canadian Journal of Economics*, 1969.

KOTOWITZ, Y. "Capital Labour Substitution in Canadian Manufacturing, 1926-39 and 1946-61." *Canadian Journal of Economics*, 1968.

LITHWICK, N. H., POST, G., and RYMES, T. K. "Postwar Production Relationships in Canada." *The Theory and Empirical Analysis of Production* (New York: Columbia University Press, 1967).

LU, Y., and FLETCHER. " A Generalization of the CES Production Function." *Review of Economics and Statistics*, 1968.

MADDALA, G., and KNIGHT, P. "International Diffusion of Technical Change - A Case Study of the Oxygen Making Process." *Economic Journal*, September 1967.

MANSFIELD, E. *The Economics of Technological Change* (London: Longman's, Green Co., 1969).

MANSFIELD, E. *Industrial Research and Technological Innovation* (New York: W. W. Norton & Co., Inc., 1968).

MASSELL, B. F. "Capital Formation and Technological Change in U.S. Manufacturing." *Review of Economics and Statistics*, 1960.

MASSELL, B. F. "A Disaggregated View of Technical Change." *Journal of Political Economy*, 1961.

MORGAN, L. *The Canadian Primary Iron and Steel Industry*, Royal Commission Report, October 1956.

NELSON, R. R., PECK, M. J., and KALACHEK, E. D. *Technology, Economic Growth and Public Policy* (Washington, D.C.: The Brookings Institution, 1967).

NERLOVE, M. "Recent Empirical Studies of the CES and Related Production Function." *The Theory and Empirical Analysis of Production* (New York: Columbia University Press, 1967).

NORDHAUS, W. D. *Invention, Growth and Welfare* (Cambridge, Mass.: The M.I.T. Press, 1969).

OECD. *The Residual Factor and Economic Growth* (Paris: Organisation for Economic Co-Operation and Development, 1964).

RAO, P., and MILLER, R. L. *Applied Econometrics* (California: Wadsworth Publishing Co., 1971).

RETTY, J. A. "The Discovery of Iron Galore in New Quebec-Labrador." *Canadian Geographical Journal*, 1951.

ROBINSON, J. "The Classification of Inventions." *Review of Economic Studies*, 1938.

SALTER, W.E.G. *Productivity and Technical Change* (London: Cambridge University Press, 1966).

SCHMOOKLER, J. *Invention and Economic Growth* (Cambridge: Harvard University Press, 1966).

SINGER, Jacques. "The Structure and Performance of the Canadian Primary Iron and Steel Industry." *The Impact of Trade Liberalization: 2*, by J. Singer and J. M. Munro, Private Planning Association of Canada (Toronto: University of Toronto Press, 1969).

SOLOW, R. M. "Investment and Technical Progress." *Mathematical Methods in the Social Science* (Standford: Standford University, 1960).

SOLOW, R. M. "Capital, Labour, and Income in Manufacturing." *The Behaviour of Income Shares* (Princeton: Princeton University Press, 1964).

SOSKICE, D. "A Modification of the CES Production Function to Allow for Changing Returns to Scale over the Function." *Review of Economics and Statistics*, 1969.

U.S. STEEL. *The Making, Shaping and Treating of Steel*, 8th edition (ed. by H. E. McGammon), Pittsburgh, 1964.

WALTERS, A. A. *An Introduction to Econometrics* (London: MacMillan, 1968).

WANSBROUGH, V. G. "Implications of Canadian Iron Ore Production." *Canadian Journal of Economics and Political Science*, 1950.

ZELLNER, A., and REVANKAR, N. S. "Generalized Production Function." *Review of Economic Studies*, 1969.

Documents

I. Publications by Statistics Canada

Catalogue no. 41-203, *Iron and Steel Mills* (various issues).

Catalogue no. 61-506, *Indexes of Real Domestic Product by Industry* (1961 Base).

Catalogue no. 61-510, *Indexes of Real Domestic Product by Industry* (revised).

Catalogue no. 61-005, *Indexes of Real Domestic Product by Industry*.

Catalogue no. 72-202, *Review of Man-Hours and Hourly Earnings.*

Catalogue no. 72-204, *Earnings and Hours of Work in Manufacturing.*

Catalogue no. 14-503, *Productivity Trends in Industry Report No. 2: Iron and Steel Mills.*

Catalogue no. 13-522, *Fixed Capital Flows and Stocks: Manufacturing, 1926-1960.*

Catalogue no. 91-510, *Earnings and Education* (by J. R. Podoluk).

Catalogue no. 41-001, *Primary Iron and Steel* (various issues).

Catalogue no. 11-003, *Canadian Statistical Review*, 1971.

Catalogue no. 98-501, *Incomes of Individuals.*

Census of Canada, *Labour Force: Occupations and Industries*, vol. IV, 1951.

Census of Canada, *Occupations and Industries*, vol. VII, 1941.

Catalogue no. 61-206, *Private and Public Investment in Canada, Outlook, Mid-Year Review* (various issues).

II. Publications by Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa.

Canadian Mineral Yearbook (various issues).

ELVER, R. B. *Survey of the Canadian Iron Ore Industry During 1959*, Department of Mines and Technical Survey, Ottawa.

LAFLEUR, P. *Canadian Iron Ore Industry*, Department of Energy, Mines and Resources, Ottawa, 1968.

MILLER, Harry. "Canada's Historic First Iron Castings." Department of Energy, Mines and Resources, Ottawa, 1968.

Operators List 1, Part 1, *Primary Iron and Steel* (various issues).

SCHNEIDER, V. B. *Canadian Primary Iron and Steel Statistics to 1969.*

WITTUR, G. E. *Primary Iron and Steel in Canada*, 1968.

III. Other Publications

Prices and Incomes Commission, *Steel and Inflation*, February 1970.

Prices and Incomes Commission, *Steel Prices*, 1971.

Tariff Board, *Basic Iron and Steel Products*, Ref. 118.

Submission to the Standing Senate Committee on Banking, Trade and Commerce by Algoma Steel Corporation Ltd., Dominion Foundries and Steel, Ltd., and The Steel Company of Canada, Ltd., May 1970, *Appendix C.*

"Big Steel Gets Jump in Canadian Ore Race", *Business Week*, January 28, 1961.

Annual Company Reports, Algoma, Dofasco and Stelco (various issues).

IV. United States Publications

Committee on Finance, U.S. Senate, *Steel Imports* (chaired by R. B. Long), December 1967.

American Iron and Steel Institute, *Steel Imports - A National Concern*, Washington, July 1970.

Domestic Member Companies of American Iron and Steel Institute, *The Steel Industry Today: A Report to the Cabinet Committee on Economic Policy*, May 1971.

The Council of Economic Advisers, *Report to the President on Steel Prices*, April 1965.

Cabinet Committee on Economic Policy, *Report to the President on the Economic Position of the Steel Industry*, July 1971.

American Iron and Steel Institute, *Annual Statistical Reports*, 1970.

U.S. Department of Labour, *Statistical Abstract of the United States* (various issues).

Metallurgical Bulletin Monthly, February 1971.

V. Unpublished Materials

D. P. De Melto, *The Effect of Foreign Competition on the Canadian Primary Steel Industry: 1950-66*, McGill University, 1970.

H. G. Baumann, *The Diffusion of Technology and International Competitiveness: A Case Study of the Canadian Primary Iron and Steel Industry*, Queen's University, 1971.

Statistics Canada, 1961, unpublished table on school year and earnings (provided by Mrs. Kempster).

Statistics Canada, *Capital Stock of the Iron and Steel Mills Industry*.

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