Canadian Productivity Growth
An Alternative (Input-Output) Analysis

H. H. Postner L. Wesa

A study prepared for the Economic Council of Canada

Canadian Productivity Growth

The Authors

Harry H. Postner

Is a research economist on the staff of the Economic Council of Canada. His doctorate is from the University of Minnesota. He has authored previous studies on productivity, international trade, and unemployment. He is an active member of the International Association for Research in Income and Wealth, and has presented papers on input-output analysis and national economic accounting at meetings in Austria, France, and Luxembourg.

Lesle Wesa

Is an economist on the staff of the Economic Council of Canada. She has studied at Carleton University, McArthur College of Education, Queen's University, and Lakehead University.

HARRY H. POSTNER
LESLE WESA

Canadian Productivity Growth

An Alternative (Input-Output) Analysis

Available in Canada through

Authorized Bookstore Agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada, K1A 0S9

Catalogue No. EC 22-115/1983E — Canada: $6.95
ISBN 0-660-11384-8 — Other countries: $8.35

Price subject to change without notice

Cette étude est également disponible en français sous le titre : «La croissance de la productivité : Une analyse interindustrielle».

Contents

Preface

This study has benefited from comments received from various sources. Special thanks are due to Neil Swan, Director of the Economic Council's Technological Change, Productivity and Growth Project, for stimulating questions and comments. Three anonymous reviewers also contributed valuable advice. A meeting with Professor Ed Wolff at New York University was helpful in clarifying some technical issues relating to productivity growth decomposition. We are particularly indebted to the Structural Analysis Division of Statistics Canada for supplying most of the statistical data.

The text and Appendix A of the study were written by the senior author. Appendix B and all calculations reported in Chapters 2, 3, and 4 were prepared by the second author. Pierre Mercier, who came into this study at a relatively late stage, performed the computer calculations reported in Chapters 5 and 6. Bob Lyle did a fine job of editing the study and bringing the manuscript to publication.

The study is essentially based on statistical data that were available by September 1982. All errors or inadequacies are the responsibility of the authors.

1 Introduction

The main purpose of this study is to present an alternative (and relatively new) approach to Canadian productivity growth analysis. The approach is based on utilization of Canadian input-output tables. It is assumed throughout the text that the reader has good familiarity with the economics of productivity growth analysis. On the other hand, it is not necessary to be acquainted with input-output analysis in order to understand the text, but some familiarity with this technique would be helpful.

General Background

One way to introduce the subject is to compare the alternative approach with the traditional simple measure of labour productivity. The latter approach is industry-oriented: productivity is defined in terms of gross domestic product (GDP) originating in each industry (i.e., value-added) per person employed. The value-added estimate of an industry's real output subtracts all purchased intermediate inputs (raw materials, energy, and contracted-out services) from the industry's gross output revenue, yielding a net measure of industry output. In effect, each industry is a separate entity, and industrial interdependence is overlooked. This industry productivity measure is easy to apply and, in fact, has two distinct advantages: 1/ the measure yields productivity levels at each point in time (as well as productivity growth rates), and 2/ the measure is straightforward to aggregate, as the total of all industries' net output divided by the total of all industries' employment yields the commonly accepted estimate of a nation's aggregate productivity level – namely, GDP per person employed. This level, calculated at various points in time, can then be transformed into the nation's aggregate productivity growth rates during various time periods.

Economic statisticians have, nevertheless, complained that the above simple measure of (labour) productivity is not satisfactory, particularly for individual industries. It is argued that there are other primary (own-industry) factors of production besides labour – namely, physical capital inputs. Moreover, merely subtracting out all intermediate inputs, as above, is often arbitrary, and has the effect of truncating the true industrial process picture. Therefore, other (multi-factor) measures of industrial productivity have been advocated, and these do account for physical capital and purchased intermediate inputs. These more general measures are well-illustrated and used in the *Seventeenth Annual Review* of the Economic Council of Canada (1980). It can, however, be shown that the more general measures do not possess the two distinct advantages of the simple measure mentioned above and are, therefore, sometimes difficult to interpret. There are also inherent problems relating to the incorporated treatment of intermediate imports and changes in the international terms of trade, which are important for a nation such as Canada. Finally, the more general measures of productivity growth, even though purchased intermediate inputs are accounted for, still remain essentially own-industry-oriented; industrial interdependence and its impacts on productivity growth dispersion (explained later in this study) are neglected. Hence the search for an alternative approach to Canadian productivity level and corresponding growth analyses.

This search has led to a productivity analysis based on input-output (I-O) techniques that is final demand-oriented (or consumption-oriented), rather than industry-oriented (or production-oriented). Productivity is now defined by the reciprocal of total labour required in the economy to produce and deliver one unit of each industry's output for final consumption. It will be seen that this alternative approach retains the two distinct advantages of the simple traditional (labour) productivity measure, but yet also possesses the generality of more sophisticated measures mentioned in the preceding paragraph. The input-output approach to productivity permits a natural incorporation of international trade effects and, of course, certainly accounts for industrial interdependence. The final demand orientation of the alternative approach embodies a more direct economic welfare interpretation of productivity trends and industrial policies designed to stimulate productivity growth.

Briefly, it will be found that the approach of this study provides the policy maker with a feasible and flexible framework for raising national economic welfare through productivity growth. In the traditional approach, to increase productivity of a particular industry's production over the medium term, one must stimulate technological advance within that industry. In the alternative approach of the present study, the focus is on final consumption. To raise productivity with respect to final consumption of a particular industry's commodities, there is considerable room for manoeuvre, because all industries to some extent contribute (however indirectly) to a particular industry's final consumption through the industrial interdependence of a modern economy. Some industries, of course, contribute more than others, and a main effort of this study is expended towards quantifying these interindustry productivity relationships. Indeed, we find that the policy maker may even concentrate stimulation for technological advances on a small number of key industries that are known to be "ripe" for such stimulation, and which have strong forward linkages to important industrial commodity components of final consumption. In other words, to raise productivity over the whole range of industrial commodity items comprising final consumption does not require stimulating technological advance within each and every industry associated with each final stage of production. The task can be accomplished by careful choice of a few key industries, and our evidence shows that such an (implicit) strategy has already played an important role in historical Canadian productivity growth. But why should the policy maker aim for the suggested balanced productivity growth path with respect to the range of final commodity consumption? The answer to this question brings us into the realm of applied theoretical welfare economics: the balanced productivity growth path with respect to final consumption is the safest course for assuring a well-defined and unambiguous rise in national economic welfare. This is precisely the reason why the present productivity study claims to have an economic welfare dimension; see discussion in Chapter 6 and a survey of the economic welfare basis of real national income comparisons in Sen (1979).

Canadian Input-Output Statistics

At this stage, it seems relevant to ask: Why are productivity levels and growth rates, according to the alternative measure, not used more often in productivity research? First, these measures call for I-O tables that are comparable over time and expressed in constant prices. There are very few national I-O systems that presently satisfy these needs; indeed, Canada is an exception! A related point is that I-O tables are typically not available for reasonably up-to-date analysis; again Canadian I-O is a fortunate exception. Second, the alternative approach requires not only I-O tables, but also the incorporation of an appropriate fixed capital replacement coefficient matrix in the productivity analysis. Though this latter matrix is not presently available from official sources, it is possible to construct the required matrix from available Canadian raw data that are consistent with the I-O classification system (this is further discussed in Appendix B). Third, an I-O analysis of productivity growth is subject to ambiguity in the presence of substantive international trade in intermediate goods. Indeed, the Canadian I-O tables embody very important elements of intermediate imports, particularly when augmented by a capital replacement coefficient matrix. This factor can certainly discourage use of the alternative approach to productivity for Canada. Our solution to this problem is to introduce an International trade "industry" into the analysis. In effect, the output of the industry is Canadian imports; the input of the industry is Canadian exports. Again, all the required data to carry out this calculation are available in a consistent form.

Thus we see that, while many other nations – even those with advanced statistical systems – may not be able to benefit from the I-O approach to productivity analysis, such is not the case for Canada. There is, nevertheless, one other reason for discouraging the use of I-O productivity growth research. It is stated in the preceding section that the alternative approach is final demand-oriented rather than industry-oriented. This raises the question of how the two sets of productivity measures are related. Unless this question is raised and at least partly answered, there remain doubts concerning the applicability of the "new" approach, particularly since the "old" traditional approach is so well-established. In this study, we introduce in Chapter 3 a decomposition procedure that attempts to clarify the basic issues.

Scope of the Study

Throughout the study, we use the terms "alternative approach" and "new approach" interchangeably. Though this approach to productivity analysis is relatively new (i.e., relative to traditional measures), the approach is not entirely new. Other investigations in both Canada and other countries have applied the I-O approach to productivity research; see, for example, Armstrong (1974), Carter (1970), and Sharpe (1981). We believe, however, that the present investigation is more extensive than other similar research and, at the same time, it introduces some novel aspects of analysis and interpretation. One may wish to regard these novel aspects as "experimental."

The present study is essentially empirical. The I-O approach to productivity analysis is performed on 40 Canadian industries, including the International trade "industry" mentioned above. These industries encompass the complete business sector of the Canadian economy, and the analysis covers the time period 1961 to 1978. Some of the most interesting results come from aggregation of the industrially disaggregated analysis. Thus, the study possesses features of both microeconomics and macroeconomics in a consistent framework. In addition to showing new sets of productivity levels and productivity growth rates, the study illustrates the estimates with practical applications. Each of the following empirical chapters contains exercises that, we hope, will clarify the nature of the alternative approach to productivity analysis. Also, in many cases, the I-O sets of productivity estimates are compared with estimates of the traditional type on an industry-by-industry basis and in aggregate. Some of the empirical chapters contain policy implications, but most such implications can be found in Chapter 6, which also contains our conclusions and a rather complete overview of the study's highlights. Readers mainly interested in policy implications are advised to proceed directly to Chapter 6 before turning to Chapter 2. The policy implications lead naturally to a series of future research directions in the closing section of Chapter 6.

A glance at the Contents page should give the reader a good idea of the study's organization. An effort is made to keep the main text free of mathematics. In the few places in the text where nontrivial mathematics is used, the relevant paragraphs can be omitted without serious loss of continuity; we also attempt to translate these operations into words. Thus the text is essentially nonmathematical, but not necessarily nontechnical. The most important tabular empirical results and discussion is to be found in the main text. Nevertheless, the I-O approach to productivity analysis is, fundamentally, a particular set of mathematical operations. Therefore, for a full understanding of the procedures, it is really necessary for the reader to consult Appendix A. This appendix is based on the mathematics of input-output and related analysis. Some advanced aspects of the analysis are illustrated by special tables in this appendix. Finally, Appendix B provides details of data sources and manipulations required to perform the analysis. In both the text and the appendixes, the exposition is kept relatively concise. Similarly, the tabular estimates shown in the study are the ones judged to be the most important in terms of clarifying the methodology and providing substance for analysis and interpretation. All references to the work of other authors can be found in the Bibliography.

2 Basic Productivity Growth Analysis, 1961-76

This chapter contains the basic analysis of the alternative approach to productivity measurement. This type of analysis has been performed by other investigators, generally using data that are not ideally appropriate for I-O purposes. The Canadian data deployed in this chapter are appropriate and, in fact, permit some extensions of the analysis. Considerable attention is given in this chapter to explaining each step in the analysis and to comparing the alternative approach estimates with the "corresponding" traditional productivity measures. The correspondence between the two sets of measures is, of course, incomplete, since the two sets possess different "orientations." The advantages and disadvantages of the final consumption orientation property of the I-O perspective are highlighted in this chapter and the next. In a later chapter (Chapter 5), the results are updated to the year 1978.

Statistical Background

We first provide some brief statistical background to this chapter and the next (further details are available in Appendix B). The basic productivity analysis is performed in terms of 40 Canadian industries classified according to Aggregation M in the Statistics Canada (1982*a*) input-output industrial system. It should be noted that Aggregation M actually contains 43 industries; three of these industries are special I-O dummy industries, which we have integrated (not eliminated) with conventional industries using a standard technique (the advantages of doing this are apparent in Appendix B). One industry – Owner occupied dwellings – was eliminated from this study's business sector and, in effect, added to final demand. This particular industry cannot play a useful role in our study for two reasons: 1/ Owner occupied dwellings has no direct labour input, and 2/ the industry does not produce intermediate output. Therefore, we are left with 39 conventional I-O industries (after modification to integrate the three dummy industries), to which is added an International trade industry explained below. The study, then, accounts for virtually the whole Canadian business sector, that is, industrial establishment aggregations that produce for the market at a price normally designed to cover costs and possibly earn a profit. Government enterprises paralleling privately owned (profit-seeking) firms are included in the business sector.[1]

All statistical data deployed in this study involving market (price) valuations are expressed in constant 1971 prices. This, for example, permits analysis in terms of real industrial output and real final demand consumption, even though our main interest is in time-series analysis. The availability of such data in the Canadian context is a key factor for successful application of the alternative approach to productivity growth research. Labour input in this chapter and the next is measured by the total number of "man-years employed." Most of the productivity calculations in the study are also estimated using a "man-hours worked" measure of labour input, and these additional results (where not shown) are available on request (see further discussion in Appendix B). It should also be noted that, in this study, labour is treated as homogeneous, so no direct account is taken of different "qualities" of labour input. If such an account is taken, then, in the spirit of input-output analysis, a human capital input approach is really required with a human capital-producing "industry" and human capital replacement and maintenance "expenditures." Such an approach would take us far from our immediate objective and, in any event, the basic, required statistical data are not available for an industry-disaggregated analysis. This is certainly a subject for further research.

There is one other statistical consideration that should be clarified. All productivity growth analyses in the study are performed using multiple-year time intervals of at least five years' duration. The reason here is that input-output tables and closely related data are not sufficiently accurate to permit economically meaningful time-series analysis for intervals of much less than five years' duration. Even though Statistics Canada has constructed an annual and comparable time-series of input-output tables covering the complete period 1961-78, there is good reason to believe that relatively short-term changes are typically not significant (see Postner, 1982, for related discussion). Therefore, our analysis using the alternative approach is limited to medium-term investigation.

Basic Input-Output Calculation

The basic calculation required to estimate a productivity level using the input-output approach can be characterized as follows. Consider a piece of domestically produced transportation equipment, such as an automobile, delivered to satisfy domestic consumer (final) demand.[2] Suppose we wish to know the economy-wide total labour required to produce this unit of transportation equipment. To perform the calculation, we certainly count the labour directly required at the final stage of the automobile production, that is, the labour embodied in the value-added of the automobile (or transportation equipment) industry. But this industry purchases a wide variety of intermediate inputs (energy, steel, rubber, plastics, electrical products, and business and financial services) from other industries, each of which also employ labour in their respective value-added operations. Thus, we must also add in the indirect labour of the other industries to the extent that the original automobile industry purchases their produced intermediate goods and services. And each of these industries in turn use intermediate commodities purchased from still other industries (including each other), so there is a very indirect labour content of the original automobile to be further counted in. And so on for the "still other industries" and their intermediate input purchases, with further labour content.

Although these calculations may look cumbersome, if not impossible, it turns out that the calculations are trivial when performed on the modern electronic computer using the standard estimation technique of I-O analysis. The basic idea of I-O productivity analysis is actually very simple, and can also be expressed equivalently with some mathematical notation. Let X represent the industrial gross output (column) vector, Y represent the final demand vector, A represent the input-output current account coefficient matrix, ℓ' represent the direct labour coefficient (row) vector, and I represent the standard identity matrix. Then, from the fundamental input-output accounting equation, we know that:

$$(2.1) \quad X = AX + Y$$

$$(2.2) \quad X = (I - A)^{-1}Y$$

and total labour employed in the industrial economy equals:[3]

$$(2.3) \quad \ell'X = \ell'(I - A)^{-1}Y$$

Now suppose that final demand for each of the industrial products is, each in turn, increased by one unit. It is then straightforward to see that each unit added to final demand is responsible for raising total labour requirements according to the corresponding elements of the row vector $\ell'(I - A)^{-1}$. The result of this procedure is a measure of the inputs required by an economy to produce each unit of industrial output delivered to final demand, expressed in terms of total (direct and indirect) labour requirements. The reciprocal of this measure (each element of the row vector) is the economy-wide total labour productivity of each industry's output delivered to final demand. Clearly these measures can be made at various points in time, yielding total labour productivity growth rates for each and every industry.

To illustrate, we estimate that the (economy-wide) total labour requirements needed to produce and deliver a typical bundle of Canadian agricultural products worth one million dollars (in 1971 prices) to final demand was 274 man-years employed in the year 1961. The same bundle, or unit, of agricultural products to satisfy final demand in the year 1976 required a total of only 138 man-years employed. One may call these estimates the "direct plus indirect labour coefficients" for Agriculture (industry no. 1) in the years 1961 and 1976, respectively. Table 2-1 shows these coefficients for all 40 industries, including International trade (explained below), for the two terminal years 1961 and 1976.

Intuitively we should feel, at least for Agriculture, that there has been a remarkable increase in Canadian productivity over the 1961-76 time period, and this is precisely what the alternative approach to productivity analysis indicates. The productivity level of Canadian Agriculture in any year (actually, Canadian agricultural products as delivered to final demand) is simply the reciprocal of the estimated total labour requirements per unit (one million dollars) estimated – namely, ($1,000,000 ÷ 274) in the year 1961 and ($1,000,000 ÷ 138) in 1976 – which equals $3,647 and $7,235, respectively. Again, in the year 1961, $3,647 of Canadian agricultural products, measured in constant 1971 prices, were produced and delivered to final demand per man-year of labour employed. By the year 1976, the corresponding estimate, also in 1971 prices, was $7,235. This yields an average annual productivity growth rate, using the

Table 2-1

Total Labour Requirements (Direct and Indirect) in Man-Years per One Million Dollars* of Output, 40 Industries, 1961 and 1976

	1961	1976
1 Agriculture	274.2	138.2
2 Forestry	128.3	87.2
3 Fishing and hunting	143.0	145.1
4 Metal mines	80.2	67.2
5 Mineral fuels	66.9	53.7
6 Nonmetal mines	108.2	67.7
7 Services to mining	97.2	71.6
8 Food and beverages	175.3	98.3
9 Tobacco products	144.8	79.1
10 Rubber and plastics	134.7	78.0
11 Leather products	174.9	106.5
12 Textiles	160.0	84.0
13 Knitting mills	187.2	90.2
14 Clothing	168.0	104.8
15 Wood products	140.0	91.6
16 Furniture and fixtures	146.5	99.5
17 Paper and allied products	112.3	83.0
18 Printing and publishing	113.3	80.3
19 Primary metals	103.4	77.0
20 Metal fabricating	121.3	78.6
21 Machinery	112.6	75.7
22 Transportation equipment	124.2	68.7
23 Electrical products	128.3	75.5
24 Nonmetallic mineral products	113.0	71.7
25 Petroleum and coal products	96.8	65.1
26 Chemicals	117.1	72.6
27 Miscellaneous manufacturing	133.0	83.3
28 Construction	109.0	76.2
29 Transportation and storage	132.3	74.7
30 Communications	147.3	75.9
31 Electric power and gas	78.7	55.4
32 Wholesale trade	116.0	76.4
33 Retail trade	175.0	125.8
34 Finance, insurance, and real estate	59.5	56.4
35 Education and health	71.5	60.5
36 Amusement and recreation	122.2	103.8
37 Services to business	95.3	87.0
38 Accommodation and food	127.7	127.4
39 Other personal services	144.6	185.0
40 International trade	128.4	71.8

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

alternate approach, equal to 4.7 per cent. These are precisely the productivity results shown in Table 2-2 for all 40 industries of the Canadian business sector. The alternative approach estimates are also called the I-O total labour productivity levels and the respective average annual percentage growth rates.

Before discussing Table 2-2, a number of points should be clarified. The alternative approach to productivity implicitly accounts for all primary and secondary (purchased intermediate inputs) factors of production. Indeed, physical capital inputs are incorporated by including the capital depreciation and replacement elements in each industry's production requirements. In effect, this is performed by adding an appropriate fixed capital replacement coefficient matrix to the conventional I-O current account coefficient matrix (using a rather cumbersome procedure outlined in Appendix B). What about intermediate imports? Many Canadian industries satisfy their production requirements for raw materials and capital equipment through imports – produced by labour, not domestically, but in other countries. Thus, one cannot measure the labour content of imported intermediate and capital replacement inputs by the conventional I-O technique described above. Our solution to this rather technical problem is to introduce an International trade "industry" into the analysis. The output of this industry is Canadian imports; the input of the industry is Canadian exports. One might say that the labour content of Canadian intermediate imports is ultimately derived from the total labour embodied in domestically producted exports. International trade is an "exchange" industry rather than a production industry and, therefore, has no direct labour content. The labour embodied in Canadian exports is always indirect (further interpretation of the International trade "exchange industry" is given below).[4] So, the alternative approach to productivity measurement permits all inputs to be reduced to a common denominator – namely, labour – even though there are many other types of input besides labour. We may unambiguously refer to total labour productivity growth and levels over time. This property is what still maintains the "two distinct advantages" of the simple traditional productivity measure mentioned in Chapter 1 (see also discussion to follow). It really means that all productivity changes ultimately become labour-saving devices (productivity advances), or labour-dissaving devices (productivity regresses) in our particular framework.

Tabular Analysis of Productivity Estimates

One way to analyse the I-O productivity estimates of Table 2-2 is to compare the results with the "corresponding" productivity measures using the simple traditional approach. These measures are shown in Table 2-3 for 39 individual industries during 1961-76 (excluding International trade, which has no counterpart in the traditional context). The specific measure used in Table 2-3 is simple: each industry's productivity level is defined in terms of gross domestic product originating in the industry (i.e., value-added) per person employed. As we know, this measure has the advantage of yielding productivity levels as well as productivity growth rates (more sophisticated multi-factor productivity measures

Table 2-2

(Input-Output) Total Labour Productivity Level and Average Annual Growth Rate, 40 Industries, 1961-1976

	Level		Average growth rate 1961-76
	1961	1976	
	(Dollars*)		(Per cent)
1 Agriculture	3,647	7,235	4.7
2 Forestry	7,794	11,465	2.6
3 Fishing and hunting	6,992	6,892	-0.1
4 Metal mines	12,463	14,887	1.2
5 Mineral fuels	14,942	18,616	1.5
6 Nonmetal mines	9,243	14,776	3.2
7 Services to mining	10,291	13,968	2.1
8 Food and beverages	5,706	10,168	3.9
9 Tobacco products	6,906	12,648	4.1
10 Rubber and plastics	7,425	12,821	3.7
11 Leather products	5,717	9,391	3.4
12 Textiles	6,255	11,901	4.4
13 Knitting mills	5,342	11,082	5.0
14 Clothing	5,952	9,537	3.2
15 Wood products	7,141	10,920	2.9
16 Furniture and fixtures	6,824	10,055	2.6
17 Paper and allied products	8,905	12,050	2.0
18 Printing and publishing	8,829	12,451	2.3
19 Primary metals	9,671	12,980	2.0
20 Metal fabricating	8,242	12,717	2.9
21 Machinery	8,877	13,213	2.7
22 Transportation equipment	8,050	14,557	4.0
23 Electrical products	7,791	13,252	3.6
24 Nonmetallic mineral products	8,846	13,938	3.1
25 Petroleum and coal products	10,331	15,354	2.7
26 Chemicals	8,541	13,769	3.2
27 Miscellaneous manufacturing	7,516	11,998	3.2
28 Construction	9,174	13,117	2.4
29 Transportation and storage	7,556	13,381	3.9
30 Communications	6,791	13,178	4.5
31 Electric power and gas	12,703	18,040	2.4
32 Wholesale trade	8,630	13,091	2.8
33 Retail trade	5,713	7,951	2.2
34 Finance, insurance, and real estate	16,818	17,744	0.4
35 Education and health	13,984	16,537	1.1
36 Amusement and recreation	8,184	9,637	1.1
37 Services to business	10,498	11,494	0.6
38 Accommodation and food	7,833	7,849	0.0
39 Other personal services	6,915	5,408	-1.6
40 International trade	7,788	13,928	3.9

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

cannot yield economically meaningful productivity levels). Now, by comparing Table 2-2 with Table 2-3, we can make the following observations.

There are considerable similarities and differences between the two sets of labour productivity measurements. The similarities arise when an individual industry is "almost" vertically integrated, that is, intermediate and physical capital replacement commodity inputs are of little importance. This, for example, is the case with Amusement and recreation (industry no. 36) and Wholesale trade (no. 32). The big differences arise in opposite circumstances; see, for example, Mineral fuels (no. 5), Paper and allied products (no. 17), Petroleum and coal products (no. 25), and Accommodation and food (no. 38). In all industries, the basic determinants of the traditional productivity measure do implicitly obtain considerable "weight" in the construction of the alternative measure, at least in terms of direct labour content. But the indirect labour content element and its reciprocal, as expressed in productivity, are completely absent from the traditional measure. Since the indirect labour content factor reflects the impact of

Table 2-3

Traditional Labour Productivity Level and Average Annual Growth Rate, 39 Industries, 1961-76

	Level		Average growth rate 1961-76
	1961	1976	
	(Dollars*)		(Per cent)
1 Agriculture	2,965	6,226	5.1
2 Forestry	7,207	10,946	2.8
3 Fishing and hunting	8,351	6,301	-1.9
4 Metal mines	18,416	20,634	0.8
5 Mineral fuels	24,651	42,989	3.8
6 Nonmetal mines	10,649	19,724	4.2
7 Services to mining	15,822	16,786	0.4
8 Food and beverages	7,425	12,832	3.7
9 Tobacco products	13,168	24,004	4.1
10 Rubber and plastics	6,956	12,971	4.2
11 Leather products	4,584	7,299	3.1
12 Textiles	5,226	11,376	5.3
13 Knitting mills	3,835	9,950	6.6
14 Clothing	5,027	7,144	2.4
15 Wood products	6,615	9,962	2.8
16 Furniture and fixtures	5,797	7,860	2.1
17 Paper and allied products	11,342	13,041	0.9
18 Printing and publishing	9,105	12,647	2.2
19 Primary metals	10,568	13,235	1.5
20 Metal fabricating	7,951	12,686	3.2
21 Machinery	9,266	13,184	2.4
22 Transportation equipment	7,995	18,370	5.7
23 Electrical products	7,074	13,682	4.5
24 Nonmetallic mineral products	9,640	15,931	3.4
25 Petroleum and coal products	20,618	23,382	0.8
26 Chemicals	9,363	16,698	3.9
27 Miscellaneous manufacturing	6,659	11,009	3.4
28 Construction	9,416	12,371	1.8
29 Transportation and storage	7,774	14,748	4.4
30 Communications	8,818	17,930	4.8
31 Electric power and gas	25,191	37,211	2.6
32 Wholesale trade	8,579	13,283	3.0
33 Retail trade	4,939	6,821	2.2
34 Finance, insurance, and real estate	18,487	17,271	-0.5
35 Education and health	18,006	19,665	0.6
36 Amusement and recreation	7,120	8,479	1.2
37 Services to business	11,190	11,776	0.3
38 Accommodation and food	8,682	6,347	-2.1
39 Other personal services	6,321	4,217	-2.7

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

economy-wide influences on productivity levels and changes (further clarified in the next chapter), we should expect the various I-O industry productivity levels and growth rates to be more similar to each other than is the case with the traditional industry productivity levels and their own productivity growth rates. This is indeed so. If the two sets of estimates are correspondingly compared in terms of coefficients of variation, these variations are much lower among the I-O productivity calculations than among the traditional type of calculations, particularly when comparing productivity levels at the two points in time, 1961 and 1976.

A further analysis of Tables 2-2 and 2-3 can be made. For some industries, the I-O productivity levels are considerably lower than the corresponding traditional productivity levels (e.g., Metal mines and Mineral fuels). These are highly capital intensive industries using the simple traditional measure based on value-added. However, when the indirect labour content of the industries' intermediate input and capital replacement input are accounted for, productivity levels become much lower (which may, or may not, affect the respective productivity growth rates). On the other hand, there are industries where the I-O productivity levels are higher than the traditional calculations; see, for example, Leather products (no. 11) and Knitting mills (no. 13). These are highly labour intensive industries based on value-added measures. Their indirect labour content (based on intermediate inputs) is relatively less labour intensive than the own industries' value-added, so that I-O productivity level calculations turn out to be higher. In any event, the dispersion of the indirect labour contents is always smaller than the dispersion of direct labour contents, particularly when it is realized that all intermediate and capital replacement inputs that are imported are transformed into labour embodied in Canada's export industries (see model in Appendix A).

It is also revealing to show the two sets of productivity results for the subperiods 1961-66, 1966-71, and 1971-76. This is given in Tables 2-4 and 2-5, where we restrict our attention to the various productivity growth rates. The generalizations made in the preceding paragraphs continue to hold true for each of the subperiods. Note that these subperiods highlight the development and beginning of a

Table 2-4

(Input-Output) Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1961-66, 1966-71, and 1971-76

	1961-66 average	1966-71 average	1971-76 average
		(Per cent)	
1 Agriculture	7.8	3.5	2.7
2 Forestry	2.5	3.9	1.4
3 Fishing and hunting	-1.3	0.9	0.2
4 Metal mines	1.7	0.6	1.3
5 Mineral fuels	2.8	2.3	-0.6
6 Nonmetal mines	5.2	2.5	1.8
7 Services to mining	2.7	1.0	2.4
8 Food and beverages	5.4	4.1	2.3
9 Tobacco products	5.4	3.8	3.2
10 Rubber and plastics	5.2	3.8	2.2
11 Leather products	3.3	3.7	3.0
12 Textiles	4.3	5.2	3.6
13 Knitting mills	5.7	4.9	4.3
14 Clothing	3.0	3.0	3.6
15 Wood products	3.6	2.9	2.1
16 Furniture and fixtures	3.9	2.5	1.4
17 Paper and allied products	2.8	2.1	1.2
18 Printing and publishing	2.3	1.8	2.9
19 Primary metals	2.8	2.4	0.7
20 Metal fabricating	4.2	2.9	1.8
21 Machinery	4.0	1.5	2.6
22 Transportation equipment	4.0	4.5	3.7
23 Electrical products	4.1	3.1	3.7
24 Nonmetallic mineral products	4.0	2.9	2.3
25 Petroleum and coal products	4.7	1.0	2.4
26 Chemicals	4.4	2.9	2.4
27 Miscellaneous manufacturing	3.2	3.6	2.7
28 Construction	2.9	2.7	1.6
29 Transportation and storage	5.6	3.5	2.5
30 Communications	4.2	4.4	5.0
31 Electric power and gas	5.1	-0.3	2.3
32 Wholesale trade	3.3	3.0	2.2
33 Retail trade	2.7	2.0	1.9
34 Finance, insurance, and real estate	0.7	1.1	-0.7
35 Education and health	2.2	1.9	-0.7
36 Amusement and recreation	-1.2	1.1	3.5
37 Services to business	-0.5	0.6	1.7
38 Accommodation and food	-0.5	0.6	-0.1
39 Other personal services	-1.8	-1.8	-1.3
40 International trade	4.6	3.0	4.3
Aggregate	3.3	2.8	2.0

SOURCE Based on data from Statistics Canada.

Table 2-5

Traditional Labour Productivity Average Annual Growth Rates, 39 Industries, 1961-66, 1966-71, and 1971-76

	1961-66 average	1966-71 average	1971-76 average
		(Per cent)	
1 Agriculture	12.2	0.9	2.5
2 Forestry	1.6	5.8	0.9
3 Fishing and hunting	-3.7	1.2	-3.0
4 Metal mines	1.8	0.9	-0.4
5 Mineral fuels	6.1	8.7	-3.4
6 Nonmetal mines	7.9	3.9	0.8
7 Services to mining	-0.1	-0.1	1.5
8 Food and beverages	2.7	7.0	1.3
9 Tobacco products	2.4	5.1	4.8
10 Rubber and plastics	6.4	4.8	1.2
11 Leather products	2.2	4.0	3.2
12 Textiles	4.2	7.7	3.9
13 Knitting mills	7.7	6.0	5.8
14 Clothing	1.5	2.3	2.8
15 Wood products	3.3	2.5	2.1
16 Furniture and fixtures	4.1	1.8	-0.5
17 Paper and allied products	1.3	1.7	-0.3
18 Printing and publishing	1.6	1.5	3.2
19 Primary metals	2.2	4.0	-1.7
20 Metal fabricating	4.6	3.2	1.1
21 Machinery	4.6	0.3	1.8
22 Transportation equipment	3.7	8.8	4.3
23 Electrical products	4.5	3.9	4.8
24 Nonmetallic mineral products	4.1	3.7	1.8
25 Petroleum and coal products	6.1	-6.9	3.8
26 Chemicals	5.3	3.8	2.5
27 Miscellaneous manufacturing	2.8	4.5	2.2
28 Construction	2.0	2.8	0.6
29 Transportation and storage	6.4	4.0	2.7
30 Communications	4.4	5.1	5.0
31 Electric power and gas	6.7	-1.1	2.5
32 Wholesale trade	3.5	3.3	2.0
33 Retail trade	2.0	2.4	2.1
34 Finance, insurance, and real estate	0.4	0.5	-2.2
35 Education and health	1.7	1.7	-1.4
36 Amusement and recreation	-3.0	1.4	4.8
37 Services to business	-1.3	-0.6	3.0
38 Accommodation and food	-3.9	-0.9	-1.3
39 Other personal services	-3.7	-2.6	-1.7
Aggregate	3.3	2.8	1.4

SOURCE Based on data from Statistics Canada.

Canadian productivity slowdown. Because of the particular properties exhibited by the I-O measures (reflecting economy-wide influences), the impact of the slowdown is more uniformly evident among the I-O set of industry productivity growth rates than among the corresponding traditional set of average annual growth rates. This will become more evident in Chapter 5, where we analyse the most recent time period observed, 1973-78. The productivity slowdown can also be highlighted in an aggregate analysis exercise, to which we now turn.

Two Applications of Productivity Estimates

What happens if the industrially disaggregated I-O productivity levels are aggregated? And what is the appropriate method for such aggregation? We proceed mathematically, but we also translate the operations into words. Using the notation already introduced above and letting i' represent a row vector of unities, then total labour employed in the business sector per unit of total commodity final demand is simply:

$$(2.4)\quad (\ell'X)(i'Y)^{-1} = \ell'(I - A)^{-1}Y(i'Y)^{-1} \equiv \lambda'Y(i'Y)^{-1}$$

which is a weighted average of the elements composing the total labour requirements per unit of industrially disaggregated output delivered to final demand (the elements of the row vector $\lambda' \equiv \ell'(I - A)^{-1}$). Suppose we define the aggregate (business sector) productivity level as simply $(i'Y)(\ell'X)^{-1}$. Now the reciprocal of each element of the row vector λ' represents the industrially disaggregated total labour productivity level (our alternative I-O approach productivity measure), and can be written as $i'(\hat{\lambda})^{-1}$ where the hat $(\hat{\ })$ operation transforms the vector λ into a diagonal matrix. Then we see that:

$$(2.5)\quad (i'Y)(\ell'X)^{-1} = (i'Y)(\lambda'Y)^{-1} = i'(\hat{\lambda})^{-1}(\hat{\lambda}Y)(i'\hat{\lambda}Y)^{-1}$$

This means that the aggregate productivity level is, indeed, a weighted average of the industrially disaggregated labour productivity levels. Moreover the respective weights have a very natural interpretation. Each individual productivity level, say, the jth element of $i'(\hat{\lambda})^{-1}$ – namely λ_j^{-1} – is weighted by $\lambda_j Y_j$, which represents the total labour embodied in the jth commodity of final demand. (The weights are normalized by their simple summation.) In effect, then, each industrially disaggregated productivity level is weighted by its relative importance in terms of the corresponding labour embodied in the various commodity components of final demand. In particular, the aggregation procedure weights the International trade "industry" according to the relative importance of labour (indirectly) embodied in the total imports of final demand. This procedure is quite analogous to the trivial aggregation of the individually disaggregated traditional productivity levels, where, for example, we let V_j represent value-added of the jth industry and L_j represent labour employed in the jth industry, so that simple aggregation becomes:

$$(2.6)\quad (\Sigma V_j)(\Sigma L_j)^{-1} = \Sigma(V_j/L_j)(L_j/\Sigma L_j)$$

Again, each individual productivity level is weighted by the relative importance of labour employed in the respective industries. While the two sets of weights are analogous, the two sets are also different, because I-O productivity levels are final demand-oriented, while the traditional productivity levels are industry-oriented.

Further analysis shows (see Appendix A) that the aggregation of I-O productivity levels, as compared with the aggregation of traditional productivity levels, should yield identical productivity growth rates, except for two principal factors. The first factor is that the traditional method is stated in terms of gross domestic product originating in each industry, and therefore includes physical capital depreciation and replacement expenditures in value-added. The I-O method considers capital depreciation and replacement as an (intermediate) cost of production (transformed into embodied labour). If the traditional method were stated in terms of net domestic product originating in each industry, then this particular factor would be absent.[5] The factor affects the comparisons of the two sets of aggregate productivity growth rates to the extent that the ratio of business-sector total measured physical capital depreciation to business-sector total gross domestic product changes over time. The second factor concerns the presence of the International trade exchange industry in the I-O productivity methodology. The presence of this "industry" *per se* does not affect the comparison of aggregate productivity growth rates unless the Canadian economy experiences changes in the international terms of trade over time. This phenomenon enters the underlying I-O productivity model through the related balance-of-trade equation, which is more naturally represented in current prices rather than in constant (1971) prices. As a result, the export pattern, which "produces" imports, must be proportionally adjusted by a scalar translating an otherwise constant price relation into a current price relation. This adjustment scalar differs from unity only to the extent that the international terms of trade have improved or deteriorated over a particular time period. Let us now see precisely how the two factors described in this paragraph enter the aggregate productivity growth rate calculations shown in the bottom lines of Tables 2-4 and 2-5.

For both subperiods 1961-66 and 1966-71, the aggregate I-O productivity growth rate is virtually the same[6] as the corresponding aggregate traditional productivity growth calculation. During 1961-66, both the measured physical capital depreciation ratio and the international terms of trade remained essentially unchanged. During 1966-71, there was a small (4 per cent) deterioration in the Canadian terms of trade, but this factor was balanced by a fall in the physical capital depreciation (and replacement) ratio. For the subperiod 1971-76, the situation is more interesting.

First, the capital depreciation ratio increased. This factor alone would lower the traditional aggregate productivity growth rate from 1.4 per cent (shown in Table 2-5) to 1.1 per cent, if the traditional productivity growth were measured in terms of net domestic product originating in each industry. Second, during 1971-76, there was a dramatic improvement (almost 9 per cent) in the Canadian international terms of trade. The incorporated adjustment adds 0.9 percentage points to Canada's aggregate productivity growth rate when measured according to the I-O method.[7] This yields an aggregate growth rate equal to 2.0 per cent (shown in Table 2-4). Most important, the alternative approach to productivity growth then provides a more comprehensive picture of Canadian productivity change, and significantly mitigates the impact of the traditionally measured aggregate productivity slowdown (at least in the initial stages). This completes our discussion of one application of the productivity estimates according to this new method.

The second of the two applications described in this section can be outlined much more briefly. It is often argued that a demand "shift" to services may be partly responsible for an observed aggregate productivity slowdown, since service industries are supposed to have both lower productivity levels and lower productivity growth rates than most other industries. Our alternative approach to Canadian productivity analysis permits a direct test of this hypothesis as an integral part of the analysis. The test procedure shows the advantage of having unambiguous disaggregated productivity levels as well as productivity growth rates to work with. Moreover, the procedure is straightforward to apply and interpret.[8] Earlier in this section, we show that the I-O aggregate productivity level at a point in time is an appropriate final demand-weighted average of the individual, industrially disaggregated productivity levels. The final demand weights and the individual productivity levels all come from the same point in time. It is then easy to recalculate "artificial" aggregate productivity levels based on final demand weights for one point in time and industrially disaggregated productivity levels for some other point in time. The "artificial" aggregate productivity levels can be compared to yield "artificial" aggregate productivity growth rates in such a way as to reveal the marginal impact of changes in final demand weights on aggregate productivity growth.

Table 2-6 shows what the (artificial) aggregate productivity growth rates would be for the three subperiods, if the final demand weights were held constant at either 1961, 1966, 1971, or 1976 proportions. The last column of the tabulation gives the corresponding aggregate productivity growth rates (from Table 2-4) that implicitly reflect correct changes in final demand weights over time.

Table 2-6

(Artificial) Aggregated Total Labour Productivity Annual Growth Rates Calculated from Constant and Variable Final Demand Weights, 1961-76

	Constant weights				Variable weights
	1961	1966	1971	1976	1961-76
	(Per cent)				
1961-66 average	3.2	3.4	3.3	3.2	3.3
1966-71 average	2.5	2.6	2.5	2.5	2.8
1971-76 average	1.8	2.0	1.9	1.9	2.0

SOURCE Table 2-4.

The aggregate productivity growth patterns are largely invariant to the various final demand weights, even though there are some important shifts in these weights over time. It is true that some service components of domestic final demand (actually, final demand for domestically produced commodities for domestic use), such as Finance, insurance, and real estate (no. 34) and Amusement and recreation (no. 36), have increased in relative importance over the time period 1961-76.[9] But even if these and all other final demand "shifts" are held constant, the impact on aggregate productivity growth and the observed productivity slowdown is very small. In reality, a large final demand "shift" is the growing role of direct imports in satisfying Canadian final demand (i.e., final demand for commodities "produced" by International trade (no. 40)). These imports comprised only about 6.3 per cent of total final demand in the year 1961; by 1976, imports made up an estimated 11.7 per cent of the total. Again, even when this "shift" is held constant, the revised aggregate productivity growth patterns remain essentially unchanged. Nevertheless, the growing importance of Canadian international trade is not to be overlooked.

To conclude this chapter, it should be stressed that some industries, usually regarded as large and important according to traditional productivity measures, can receive very little final demand weight when analysed according to the alternative approach. For example, Agriculture's final demand weight, even after labour transformation (see the mathematical analysis earlier in this section and also Table 6-3), equaled no more than 1.6 per cent of the total final demand weight in the year 1961, and has decreased since that time. This might lead one to believe that Agriculture can make very little "contribution" to aggregate productivity growth in the context of the alternative approach. This, however, is an illusion, since Agriculture indirectly affects productivity growth through deliveries to final demand by many other industries that do have large and growing final demand weights. In fact, one purpose of the next chapter is to clarify this and other related matters of industrial interdependence in a productivity growth framework.

3 Decomposition of Productivity Growth Analysis, 1961-76

This chapter presents the results of a decomposition procedure that attempts to clarify and extend the alternative approach to productivity analysis. The exposition will now be more concise than in the previous chapter, and the material becomes rather more technical. Though the decomposition methodology is fairly straightforward to express mathematically, the procedure is exceedingly cumbersome to translate into words. We do try to give the reader a good intuitive understanding of our technique, and the chapter contains many illustrations and empirical results. Nevertheless, for a complete understanding of the procedures and their suggested interpretation, it is essential for the reader to refer to Appendix A. This chapter, like the previous one, contains two important applications of the decomposed productivity analysis, and it includes suggestions pointing towards implications for industrial policy.

Rationale of Decomposition Procedure

Chapter 2 shows that the productivity estimates yielded by the alternative (I-O) approach are associated with each industry's output produced and delivered to final demand. Thus, the various productivity levels and growth rates, for each and every industry and its corresponding commodities, will be affected not only by the technological changes in each respective industry, which represents the final stage of production (e.g., the automobile industry as illustrated in Chapter 2), but also by the technological changes in all other industries (e.g., energy, steel, rubber, plastics, business, and financial services) to the extent that other industries indirectly contribute to production. It seems natural and economically meaningful, as we shall see, to disentangle the two productivity effects. We may wish to know what proportion of changes in total labour requirements for an industry's product (as delivered to final demand) is the responsibility of the primary producing industry itself. Then the remainder would be the contribution of all other industries. Clearly, such an exercise must involve an appropriate and well-defined decomposition procedure.

The particular procedure used for decomposition productivity analysis in this study is given mathematically in Appendix A.[1] There it is shown that the procedure possesses desirable properties, and some sensitivity tests are mentioned. Though the procedure that we use is well-defined, it is not unique, because other reasonable decomposition techniques may be available. The sensitivity tests, however, indicate that any "reasonable" changes in the procedure used have very little bearing on the empirical productivity results obtained. For present purposes, it seems best to describe the decomposition technique and corresponding extensions in the context of our actual results.

Table 3-1 presents the decomposition of the change in total labour requirements (the direct plus indirect labour coefficients) during 1961-76 for each of the 40 industries, including International trade. We know, for example, from Table 2-1, that total labour requirements per unit (one million dollars) of Canadian agricultural products delivered to final demand in the year 1961 equaled 274 man-years while the corresponding figure in 1976 was 138 man-years, so the change in total labour requirements per unit of output (final demand) is −136 man-years, as shown for Agriculture in the first column of Table 3-1. This change is now decomposed into that part for which Agriculture is responsible, the own effects, equal to −109 man-years (shown in column 2), and the remainder for which all other industries are responsible, the input effects, equal to −27 man-years (shown in column 3). The own effects account for those changes in total labour requirements (per unit of output) that can be traced expressly to Agriculture, for example, and therefore these effects include changes to Agriculture's direct labour requirements, as well as changes in Agriculture's direct intermediate and physical capital replacement inputs, with the latter elements transformed into their immediate labour content. The input effects then account for the remainder of the changes in total labour requirements after the own effects have been subtracted out. In essence, the input effects reflect changes in the direct labour coefficients and changes in the intermediate and physical capital replacement inputs of all other industries to the extent that these other industries indirectly or ultimately contribute to the production of Agriculture, for example. The terminology "input effects" is appropriate here, since any particular industry's deliveries to final demand, with reference to total labour requirements, experiences input effects only if the particular industry consumes intermediate and capital replacement inputs. Loosely speaking, the input effects of total labour requirement change are induced through the process of backward linkages with intermediate inputs.

Table 3-1

Change in Total Labour Requirements Attributed to Own Effects or Input Effects, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Total change	Change due to own effects	Change due to input effects	Input effects as a share of total change
				(Per cent)
1 Agriculture	-136	-109	-27	20
2 Forestry	-41	-28	-13	31
3 Fishing and hunting	2	10	-9	-420†
4 Metal mines	-13	-7	-6	45
5 Mineral fuels	-13	-7	-6	46
6 Nonmetal mines	-41	-23	-17	43
7 Services to mining	-26	2	-27	107
8 Food and beverages	-77	-18	-59	77
9 Tobacco products	-66	-16	-50	76
10 Rubber and plastics	-57	-30	-27	47
11 Leather products	-68	-39	-30	43
12 Textiles	-76	-43	-33	43
13 Knitting mills	-97	-59	-38	39
14 Clothing	-63	-35	-28	44
15 Wood products	-49	-23	-25	52
16 Furniture and fixtures	-47	-24	-23	49
17 Paper and allied products	-29	-9	-20	68
18 Printing and publishing	-33	-21	-12	37
19 Primary metals	-26	-6	-20	77
20 Metal fabricating	-43	-22	-20	48
21 Machinery	-37	-22	-15	40
22 Transportation equipment	-56	-32	-23	42
23 Electrical products	-53	-29	-23	44
24 Nonmetallic mineral products	-41	-21	-20	50
25 Petroleum and coal products	-32	-0	-31	99
26 Chemicals	-45	-20	-25	56
27 Miscellaneous manufacturing	-50	-30	-20	41
28 Construction	-33	-11	-22	66
29 Transportation and storage	-58	-39	-18	32
30 Communications	-71	-47	-25	35
31 Electric power and gas	-23	-11	-12	51
32 Wholesale trade	-40	-25	-15	38
33 Retail trade	-49	-31	-18	37
34 Finance, insurance, and real estate	-3	3	-6	180
35 Education and health	-11	-4	-7	63
36 Amusement and recreation	-18	-10	-8	45
37 Services to business	-8	-4	-5	54
38 Accommodation and food	-0	18	-18	6,715
39 Other personal services	40	49	-9	-21†
40 International trade	-57	-7	-50	88

*Constant 1971 dollars.
†These percentages should be interpreted with care, as the input effect is negative, while the total change is positive.
SOURCE Based on data from Statistics Canada and from Table 2-1.

With this background, we can now examine the last column in Table 3-1, which shows input effects as a percentage of the total change in labour requirements for each of the 40 industries. (Clearly these percentages must be interpreted with care in the very few cases where the input effects do not have the same arithmetic sign as the change in total labour requirements.) It appears that, in many cases, input effects are far more important than the corresponding own effects in accounting for changes in labour requirements (or, reciprocally, in accounting for changes in total labour productivity levels associated with each industry's deliveries to final demand). Thus, the Canadian business sector economy is characterized by a high degree of industrial interdependence. It is not obvious, without doing the calculations, to what extent industrial interdependence contributes to each industry's total labour requirement changes over the time period 1961-76. Further analysis of this issue can be found in the next section of this chapter.

Now, since total labour requirements of a particular industry's output delivered to final demand can benefit (i.e., decrease) or deteriorate (i.e., increase) as a result of technological changes in all other industries, we may also ask another related question. To what extent does an industry indirectly contribute to changes in the total labour requirements of all other industries for their deliveries to final demand? We have already examined how a particular industry may be responsible for changes in its own labour requirements through the own effects. This new question simply poses the "other side of the coin," where we now focus on each industry's forward linkages with all industries of the business sector economy. Since these linkages ultimately occur through an industry's intermediate output, we refer to them as output effects. A particular industry's output effects is actually the total of all input effects derived from that particular industry. Indeed, the mechanics of our decomposition procedure are such that the summation of all input effects (i.e., changes in total labour requirements due to input effects and summed over all industries) is identically equal to the summation of all output effects (i.e., changes in total labour requirements associated with output effects and totaled over all industries). This is illustrated in the next table.

Table 3-2 is largely self-explanatory. The first column gives the estimated output effects for each and every industry. It is seen that output effects, which serve to lower total labour requirements throughout the business economy (and, therefore, raise total labour productivity levels), are largely dominated by the output effects transmitted from two key industries, Agriculture (no. 1) and Transportation and storage (no. 29). (See further analysis in the next section.) Services to business (no. 37) is an industry-associated source of output effects that tends to have the opposite impact, at least over the time period 1961-76. Column 2 is simply the corresponding (by industry) summations of column 1 and the previous column 2 of Table 3-1. We call this summation of each industry's own effects and output effects the total associated effects; the terminology is appropriate in view of the meaning of each "effect." It is also possible and instructive to compare each industry's input effects (from column 3, Table 3-1) with the corresponding output effects, and this is implicitly done in the third column of Table 3-2. Note that the summation of this column is identically zero. Column 4 then shows output effects as a percentage of the total associated effects. This provides yet another picture of the critical importance of Canadian industrial interdependence. In many cases, an industry's output effects is far more important than its own effects.

The reader may now realize that all the industry input effects and output effects ultimately come from a 40 x 40 matrix of disaggregated labour requirement changes during 1961-76, which simultaneously reveals all the intermediate linkages between industries. Such a matrix is shown (and further explained) in Table A-4. The summation of each column of the matrix yields the various industry input effects; the summation of each row yields the various industry output effects. Indeed, each element of the 40 x 40 matrix is an input effect of the industry named in the column heading and simultaneously an output effect of the industry named in the row. Thus the "total" input effects received by a particular industry's output delivered to final demand, with reference to the industry's unit labour requirements, can be traced back to the various individual industries from which the changes in labour requirements are transmitted in terms of output effects. Some important examples of this procedure are given later in the study.

Analysis of Decomposed Productivity Growth Rates

The procedures described in the previous section provide a decomposition of the changes in labour requirements per unit of each industry's output delivered to final demand. Implicitly, by using a reciprocal operation, the procedures also indicate a decomposition of the changes in the levels of total labour productivity. All the new concepts (own effects, input effects, and output effects) are with respect to changes, and do not yield a new set of productivity levels for economically meaningful

Table 3-2

Change in Total Labour Requirements Transmitted to Other Industries as a Result of Industry Output Effects and Total Associated Effects, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Change due to output effects	Change due to total associated effects	Output effects minus input effects	Output effects as a share of total associated effects
				(Per cent)
1 Agriculture	-264	-372	-236	71
2 Forestry	-56	-84	-43	66
3 Fishing and hunting	-2	8	6	-29†
4 Metal mines	-30	-38	-24	81
5 Mineral fuels	-10	-18	-4	59
6 Nonmetal mines	-7	-30	11	22
7 Services to mining	5	6	32	71
8 Food and beverages	-24	-41	36	57
9 Tobacco products	-1	-17	49	7
10 Rubber and plastics	-4	-34	23	11
11 Leather products	-5	-44	25	11
12 Textiles	-35	-78	-2	45
13 Knitting mills	-3	-63	34	5
14 Clothing	-2	-38	25	7
15 Wood products	-28	-52	-3	55
16 Furniture and fixtures	-3	-27	21	10
17 Paper and allied products	-36	-45	-16	79
18 Printing and publishing	-22	-43	-10	51
19 Primary metals	-30	-37	-10	84
20 Metal fabricating	-20	-43	0	48
21 Machinery	-17	-39	-2	43
22 Transportation equipment	6	-27	29	-20†
23 Electrical products	-22	-51	2	42
24 Nonmetallic mineral products	-9	-30	11	31
25 Petroleum and coal products	-3	-3	29	90
26 Chemicals	-21	-41	4	52
27 Miscellaneous manufacturing	-9	-38	11	23
28 Construction	-50	-61	-28	82
29 Transportation and storage	-108	-147	-90	73
30 Communications	-25	-71	-0	35
31 Electric power and gas	-6	-17	6	35
32 Wholesale trade	-34	-58	-19	58
33 Retail trade	-22	-53	-4	41
34 Finance, insurance, and real estate	2	4	7	42
35 Education and health	0	-4	7	-2†
36 Amusement and recreation	-2	-12	6	19
37 Services to business	23	19	28	120
38 Accommodation and food	1	18	19	4
39 Other personal services	15	64	23	23
40 International trade	0	-7	50	0

*Constant 1971 dollars.
†These percentages should be interpreted with care, as the output effect and the total associated effect do not have the same sign.
SOURCE Based on data from Statistics Canada and from Table 3-1.

analysis. It certainly is possible, however, to transform the decomposition results of Tables 3-1 and 3-2 into new sets of productivity growth rates. In this section, we will show and explain this new type of productivity growth rates for the individual subperiods 1961-66, 1966-71, and 1971-76. Reference is now made to Tables 3-3, 3-4, and 3-5. Consider first Table 3-3 with respect to the time period 1961-66.

The first column of Table 3-3 merely repeats the total labour productivity growth rates (using the I-O approach) for each industry, as already shown in Table 2-4. The second column now indicates what the total labour productivity growth rates would be if technological change (changes in direct labour and intermediate input coefficients) occurred only in the single industry responsible for the final stage of

Table 3-3

Decomposition of Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1961-66

	Total, 1961-66 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	7.8	5.7	1.5	19.4	42.9
2 Forestry	2.5	0.9	1.5	3.7	4.9
3 Fishing and hunting	-1.3	-1.7	0.4	-0.1	-1.8
4 Metal mines	1.7	1.1	0.6	4.9	6.4
5 Mineral fuels	2.8	1.6	1.1	1.8	3.5
6 Nonmetal mines	5.2	3.1	1.8	0.7	3.9
7 Services to mining	2.7	-0.4	3.3	-0.3	-0.8
8 Food and beverages	5.4	0.7	4.5	1.3	2.0
9 Tobacco products	5.4	0.6	4.5	0.1	0.7
10 Rubber and plastics	5.2	2.5	2.3	0.3	2.8
11 Leather products	3.3	1.5	1.6	0.2	1.8
12 Textiles	4.3	2.2	1.9	1.5	4.0
13 Knitting mills	5.7	3.4	1.8	0.1	3.6
14 Clothing	3.0	1.5	1.4	0.0	1.5
15 Wood products	3.6	1.5	1.9	2.9	4.7
16 Furniture and fixtures	3.9	2.0	1.7	0.2	2.1
17 Paper and allied products	2.8	0.9	1.8	3.4	4.5
18 Printing and publishing	2.3	1.2	1.0	1.9	3.2
19 Primary metals	2.8	0.7	2.0	2.8	3.7
20 Metal fabricating	4.2	2.0	1.9	1.0	3.2
21 Machinery	4.0	2.5	1.3	2.4	5.3
22 Transportation equipment	4.0	2.3	1.4	-0.9	1.3
23 Electrical products	4.1	2.2	1.6	1.2	3.6
24 Nonmetallic mineral products	4.0	1.9	1.9	0.8	2.8
25 Petroleum and coal products	4.7	0.2	4.4	0.5	0.7
26 Chemicals	4.4	1.8	2.3	1.7	3.7
27 Miscellaneous manufacturing	3.2	1.7	1.4	0.4	2.1
28 Construction	2.9	0.7	2.2	5.0	5.9
29 Transportation and storage	5.6	3.5	1.7	11.2	18.4
30 Communications	4.2	2.3	1.6	1.5	4.0
31 Electric power and gas	5.1	3.1	1.7	1.9	5.4
32 Wholesale trade	3.3	2.0	1.1	3.1	5.6
33 Retail trade	2.7	1.6	1.0	1.0	2.8
34 Finance, insurance, and real estate	0.7	0.1	0.7	2.0	2.0
35 Education and health	2.2	1.1	1.1	0.0	1.1
36 Amusement and recreation	-1.2	-1.7	0.5	-0.1	-1.8
37 Services to business	-0.5	-1.0	0.6	-2.5	-3.4
38 Accommodation and food	-0.5	-2.2	2.0	-0.8	-2.9
39 Other personal services	-1.8	-2.2	0.5	-0.8	-2.9
40 International trade	4.6	0.1	4.4	0.0	0.1
Aggregate	3.3	1.0	2.1	2.0	3.2

SOURCE Based on data from Statistics Canada and from Table 2-4.

production (i.e., technological change is permitted in the automobile industry, for example, but nowhere else). This calculation is performed by first beginning with the total labour requirements per unit of output in the year 1961 and then adding the respective own effects observed in computations analogous to those used in Table 3-1. Since most industries' own effects over the period 1961-66 were negative, these effects resulted in lowering total labour requirements by the year 1966 or, reciprocally, in raising total labour productivity levels. These new (partially) raised labour productivity levels in 1966, as compared with the original total labour productivity levels observed in the year 1961, furnish the basis for calculating the industry's productivity growth rates due to own effects during 1961-66, which is given in column 2 of Table 3-3. One might call these growth rates the own effects component of the total labour productivity growth rates. Column 3 then shows industry total labour productivity growth stemming from all technological changes in the business economy except the individual industry responsible for final production or preparation of the commodities corresponding to each listed industry. This is called the productivity growth rate due to input effects for 1961-66 or, simply, the input effects component of total labour productivity growth. This component is calculated in a manner (using input effects such as those in Table 3-1) completely analogous to the own effects component. It is now straightforward to show that the summation of the own effects productivity growth rate, the input effects productivity growth rate, and their interaction effects equals the original total labour productivity growth rate of column 1 (for each and every industry). It might be added that the interaction effects are typically very small, particularly when both of the productivity growth rates contributed by own effects and input effects are small (the reader could easily calculate interaction effects as a residual).

It is clear from Table 3-3 that, for some industries, the portion of the growth rate due to own effects dominates that due to input effects, especially in Agriculture (no. 1), Fishing and hunting (no. 3), Knitting mills (no. 13), and Other personal services (no. 39). In these cases, total labour productivity changes, whether positive or negative, derive mainly from the final stage of production or preparation. Deliveries of other individual industries to final demand benefit mostly from general technological advances in the industries supplying either directly or indirectly to them, as reflected in their input effects, rather than within their own industry. Important examples where input effects dominate the changes in total labour productivity growth are in Food and beverages (no. 8), Primary metals (no. 19), Petroleum and coal products (no. 25), Construction (no. 28), and Accommodation and food (no. 38). In the latter industry, the input effects serve to raise the total productivity level, while the corresponding own effects of the industry depress the total labour productivity level and growth rate.

We can now consider the last two columns of Table 3-3. The industry productivity growth rates due to output effects, given in column 4, are based on the previous decomposition analysis (in Table 3-2), which yields output effects for each industry. Each output effect over the period 1961-66 is simply added to the original total labour requirements per unit of output in the year 1961. When, for example, output effects are negative, they serve to lower the industry's total labour requirements, and they thus raise total labour productivity levels. To focus on one industry, consider Agriculture. The productivity growth rate for Agriculture attributed to output effects (column 4, row 1) shows what the total labour productivity growth rate for Agriculture would be, if Agriculture's output effects (which indirectly raise productivity levels for all other industries) were "somehow" captured by Agriculture itself. It is of critical importance to note that the operation described in the preceding sentence is based upon a fictitious notion, in the sense that the operation has no real world counterpart (i.e., Agriculture can in no way "capture" its output effects, but Agriculture does "capture" its input effects, properly defined). Nevertheless, the idea of the contribution of the output effects to the productivity growth rate of an industry, as described, does have the advantage of tracing the origin of input effects to the output associated with some other industry (see discussion in previous section) and expressing their relative importance in terms of a carefully defined (but fictitious) productivity growth rate. The final column of Table 3-3 shows the productivity growth rates attributed to total associated effects, and these figures are simply the summation, for each industry, of the contributions to the growth rate of own effects (column 2), the output effects (column 4), and their interaction effects. The latter effect, which could be calculated as a residual, is large in the cases of Agriculture (no. 1) and Transportation and storage (no. 29). Indeed, these two industries require some further discussion.

It is evident from Tables 3-2 and 3-3 (the former dealing with the overall period 1961-76) that output effects, whether measured in terms of industry changes in labour requirements (as in Table 3-2) or in terms of the contribution of output effects to productivity growth rates in an industry, are particularly large in absolute value for Agriculture and Transportation and storage. Though it is easy to trace the magnitude of these calculations back to the original mathematics of the decomposition procedure, we now try to provide a more intuitive explanation. Each industry is a very important direct or indirect supplier of intermediate goods or services to all other (and to each other) Canadian industries of the business sector. Indeed, the two industries' outputs are largely destined for intermediate use rather than for final demand consumption (recall that International trade is an endogenous "industry" in our context). Both industries have incurred significant technological advances during the relevant time periods, especially in terms of reductions in their respective direct labour coefficients (this is partly indicated by their respective productivity growth rates due to own effects). At the same time, we know, from further analysis, that agricultural commodities and transportation services are generally being consumed as intermediate inputs at least as efficiently in the later years of the time period as during the first year, 1961. This unique set of economic circumstances then implies that deliveries of many Canadian industries to final demands, with respect to total labour requirements per unit of output, are subject to relatively large indirect reductions, that is, input effects, that ultimately can be traced back and associated with either Agriculture or Transportation and storage, or both. Thus, the output effects, as defined, of these two industries are remarkably large. So are the two industries' total associated effects, but these latter effects require no new explanation, since total associated effects are simply based on the measured output effects and own effects (and their interaction effects) of each industry. Later in this study, we will comment on the more recent trend patterns of output effects, especially during 1971-76 (Table 3-5).

The International trade industry of Tables 3-3, 3-4, and 3-5 also calls for explanatory remarks. The decomposition procedure reveals that total labour productivity growth for this "artificial" exchange industry is almost entirely due to indirectly induced input effects. These reflect economy-wide technological advances that are captured by Canada's export industries, according to the relative importance of the

Table 3-4

Decomposition of Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1966-71

	Total, 1966-71 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	3.5	3.0	0.4	8.5	13.7
2 Forestry	3.9	3.4	0.4	4.4	8.9
3 Fishing and hunting	0.9	0.8	0.1	0.4	1.1
4 Metal mines	0.6	0.5	0.1	2.0	2.5
5 Mineral fuels	2.3	1.7	0.5	1.2	3.0
6 Nonmetal mines	2.5	1.3	1.2	0.2	1.5
7 Services to mining	1.0	-0.6	1.7	-0.9	-1.5
8 Food and beverages	4.1	1.2	2.6	1.1	2.4
9 Tobacco products	3.8	1.2	2.4	0.0	1.3
10 Rubber and plastics	3.8	2.3	1.3	0.3	2.7
11 Leather products	3.7	2.3	1.3	0.2	2.5
12 Textiles	5.2	3.3	1.6	2.5	6.4
13 Knitting mills	4.9	3.0	1.6	0.1	3.2
14 Clothing	3.0	1.5	1.4	-0.0	1.5
15 Wood products	2.9	1.4	1.4	0.9	2.4
16 Furniture and fixtures	2.5	1.3	1.1	0.1	1.4
17 Paper and allied products	2.1	0.6	1.4	2.3	3.0
18 Printing and publishing	1.8	1.1	0.7	1.1	2.3
19 Primary metals	2.4	1.0	1.4	2.3	3.4
20 Metal fabricating	2.9	1.6	1.2	1.5	3.2
21 Machinery	1.5	0.6	0.9	0.2	0.9
22 Transportation equipment	4.5	2.6	1.6	-1.5	0.9
23 Electrical products	3.1	1.5	1.5	0.6	2.1
24 Nonmetallic mineral products	2.9	1.5	1.3	0.4	2.0
25 Petroleum and coal products	1.0	-0.0	1.0	-0.1	-0.1
26 Chemicals	2.9	1.1	1.7	1.2	2.4
27 Miscellaneous manufacturing	3.6	2.3	1.1	0.5	2.9
28 Construction	2.7	1.5	1.1	5.4	7.5
29 Transportation and storage	3.5	2.6	0.7	6.1	10.0
30 Communications	4.4	3.0	1.2	1.5	4.8
31 Electric power and gas	-0.3	-0.6	0.4	-0.6	-1.2
32 Wholesale trade	3.0	1.8	1.0	0.9	2.9
33 Retail trade	2.0	1.1	0.9	0.4	1.4
34 Finance, insurance, and real estate	1.1	0.2	0.8	-0.6	-0.4
35 Education and health	1.9	1.1	0.8	-0.0	1.1
36 Amusement and recreation	1.1	0.8	0.3	0.2	1.0
37 Services to business	0.6	1.0	-0.4	-0.4	0.6
38 Accommodation and food	0.6	0.2	0.4	0.6	0.7
39 Other personal services	-1.8	2.0	0.3	-0.7	-2.6
40 International trade	3.0	0.4	2.5	0.0	0.4
Aggregate	2.8	1.4	1.5	1.7	3.0

SOURCE Based on data from Statistics Canada and from Table 2-4.

various commodity exports. The own effects component of total labour productivity growth is small because International trade has no direct labour content and, therefore, cannot by definition benefit from changes in this factor. There is, nevertheless, a nonzero own effects component, and this mainly embodies the changes in Canadian international terms of trade, as explained in Chapter 2. As seen in the International trade (no. 40) row of the three tables, the own effects component during the most recent subperiod 1971-76 is significantly larger than in the earlier subperiods. It should be noted, however, that the measured own effects of International trade also contain a minor impact due to changes in the Canadian export composition pattern. Finally, it will be noticed that the output effects of International trade are always zero; this stems from the absence of a direct labour coefficient in this industry (according to the methodology used in this chapter).

The three Tables 3-3, 3-4, and 3-5 also exhibit aggregate productivity growth rates (in their bottom

Table 3-5

Decomposition of Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1971-76

	Total, 1971-76 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	2.7	2.1	0.5	6.2	9.3
2 Forestry	1.4	1.2	0.2	2.9	4.3
3 Fishing and hunting	0.2	-0.5	0.6	0.0	-0.4
4 Metal mines	1.3	0.3	0.9	1.8	2.2
5 Mineral fuels	-0.6	-0.9	0.3	0.6	-0.3
6 Nonmetal mines	1.8	0.8	1.0	0.6	1.4
7 Services to mining	2.4	0.8	1.6	0.3	1.0
8 Food and beverages	2.3	0.6	1.6	1.0	1.7
9 Tobacco products	3.2	0.9	2.1	0.1	1.1
10 Rubber and plastics	2.2	0.7	1.5	0.1	0.8
11 Leather products	3.0	1.8	1.2	0.2	1.9
12 Textiles	3.6	1.5	1.9	2.0	3.7
13 Knitting mills	4.3	1.8	2.3	0.3	2.1
14 Clothing	3.6	2.2	1.2	0.4	2.7
15 Wood products	2.1	1.0	1.0	0.9	2.0
16 Furniture and fixtures	1.4	0.5	0.9	0.2	0.8
17 Paper and allied products	1.2	0.3	0.9	2.0	2.3
18 Printing and publishing	2.9	2.0	0.8	1.3	3.5
19 Primary metals	0.7	-0.3	1.1	2.0	1.7
20 Metal fabricating	1.8	0.8	0.9	2.0	2.9
21 Machinery	2.6	1.4	1.1	1.0	2.5
22 Transportation equipment	3.7	1.5	2.0	2.2	3.9
23 Electrical products	3.7	2.1	1.4	2.7	5.2
24 Nonmetallic mineral products	2.3	1.1	1.2	0.8	1.9
25 Petroleum and coal products	2.4	-0.2	2.6	0.2	-0.0
25 Chemicals	2.4	1.2	1.2	1.7	3.0
27 Miscellaneous manufacturing	2.7	1.3	1.2	0.8	2.2
28 Construction	1.6	0.1	1.4	0.9	1.1
29 Transportation and storage	2.5	1.6	0.9	8.3	10.9
30 Communications	5.0	3.1	1.6	1.1	4.4
31 Electric power and gas	2.3	0.8	1.4	0.2	1.0
32 Wholesale trade	2.2	1.2	0.9	3.4	4.8
33 Retail trade	1.9	1.4	0.5	1.5	3.1
34 Finance, insurance, and real estate	-0.7	-1.2	0.5	-1.9	-3.0
35 Education and health	-0.7	-1.0	0.2	-0.0	-1.0
36 Amusement and recreation	3.5	2.9	0.5	0.2	3.2
37 Services to business	1.7	0.9	0.8	-1.6	-0.8
38 Accommodation and food	-0.1	-0.5	0.5	0.1	-0.5
39 Other personal services	-1.3	-1.6	0.3	-0.4	1.9
40 International trade	4.3	0.8	3.4	0.0	1.8
Aggregate	2.0	0.7	1.3	1.0	1.7

SOURCE Based on data from Statistics Canada and from Table 2-4.

row). The technique used to aggregate the productivity growth rates of individual industries for the various types of productivity growth rates is entirely analogous to the aggregation procedure explained in Chapter 2. Again, we utilize appropriate (variable) final demand weights with the total labour productivity levels observed in the initial period and the partial labour productivity levels (partial, say, with respect to own effects only) observed in the terminal period. This procedure then results in a decomposition of aggregate total labour productivity growth into the components due to aggregate own effects and aggregate input effects (plus a small amount to approximate the interaction effect). It is instructive to observe the changing pattern of this aggregate productivity decomposition over the various subperiods. It will be seen that the Canadian aggregate productivity slowdown in its initial stages is mainly reflected in the own effects component rather than in the input effects component. Similarly, we construct an aggregate total associated effects productivity growth rate from a combination of own effects and output effects. It should again be noted, however, that this particular constructed growth rate is for comparative purposes and has no real-world counterpart. In any event, we have shown that the alternative approach to productivity analysis yields a total labour productivity growth rate that is subject to economically meaningful decomposition both by industry and in aggregate. One component of this growth rate – namely, the own effects component of productivity growth – is a counterpart of the traditional type of productivity growth rates, since this component reflects only technological changes within the industry itself. But the alternative (I-O) approach also reveals other components, with a potential for deeper productivity analysis.

Two Applications with Further Interpretations

This section contains two major applications of the decomposition of productivity changes using our I-O approach to productivity analysis. Though the following results are of some inherent interest, the main purpose is to further clarify the nature of the alternative approach and to furnish a basis for more advanced interpretations.

It is well-known that the official real output measures of certain service industries, even commercial service industries, are not well-defined and are subject to considerable improvement. We have been able to obtain an experimental measure of output for the Canadian Finance, insurance, and real estate (FIRE) industry (no. 34).[2] This measure appears to be superior in important respects to the official estimates used so far in this study. It turns out that the real gross output growth rates for the two measures were very similar during the 1961-66 and 1966-71 subperiods but, for the 1971-76 subperiod, the experimental measure indicates a considerably larger rate of growth (the real output level in the year 1976 using the experimental measure was about 22 per cent higher, compared with the official measure for that year). In effect, the experimental measure of real output embodies an alternative price deflator indicating that the price deflator officially used for FIRE is probably biased upward. It must be stressed, however, that FIRE is not only an important Canadian industry (contributing to at least 10 per cent of gross domestic product in terms of value-added), but also the single most important producer of intermediate commodities covered in this study. Therefore, both real gross output of FIRE and real intermediate input of FIRE services consumed by all industries, including itself, must be adjusted upward when using the experimental measure. It is possible to perform these adjustments in the context of the I-O approach to productivity analysis. What, then, would be the impact of introducing the experimental measure into the analysis of Canadian productivity growth for 1971-76, as originally shown in Table 3-5? The answer can be found by comparing the new Table 3-6 (using the experimental measure) with the original "official" Table 3-5.

It is a remarkable property of the I-O approach that all of the total labour productivity growth rates for individual industries (column 1 in both tables) are completely unaffected by the change to the experimental measure – all, that is, except the FIRE industry (no. 34). In Table 3-5, the total labour productivity growth rate for this industry during 1971-76 is -0.7 per cent; it is not surprising that the corresponding revised growth rate in Table 3-6 is much higher – equal to 3.3 per cent. What may be surprising is that all other total labour productivity growth rates are invariant to the revision. But this result should not be too surprising when it is realized that the revision involves not only an upward adjustment of FIRE real output, but also similar adjustments for the intermediate consumption of FIRE services by all other industries. This is further clarified by observing the decomposition of total labour productivity growth rates for each industry into their own effects and input effects components. Indeed, by comparing the second columns of Tables 3-5 and 3-6, we see that the contribution of own effects to growth rates for all industries becomes marginally smaller with the revision, reflecting increased intermediate usage of FIRE services (technological "regression," since conditions are *ceteris paribus*). Again, this is true for all industries except FIRE, which now experiences a contribution of own effects to the productivity growth rate equal to 2.0 per cent, compared with the previous estimate of −1.2 per cent shown in Table 3-5. This change reflects the large reduction in the direct labour coefficient of FIRE when the real output of the industry is adjusted upward. Now, since the total labour productivity growth rates for all industries except FIRE remain the same while their own effects components of growth rates marginally decrease, we should expect the input effects components of growth rates to marginally increase, and this is precisely the situation, as observed in the third columns of both tables. In fact, analysis of the fourth columns of the two tables shows that the marginal increase in the input effects for all industries are derived from and associated with a substantial increase in FIRE's output effects. These latter effects, equal to −1.9 per cent in terms of productivity growth rates in Table 3-5, become 0.9 per cent in the revised

Table 3-6

Decomposition of Total Labour Productivity Average Annual Growth Rate Revised with Respect to the Finance, Insurance, and Real Estate Industry, 40 Industries, 1971-76

	Total, 1971-76 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	2.7	2.1	0.6	6.2	9.3
2 Forestry	1.4	1.1	0.3	2.9	4.2
3 Fishing and hunting	0.2	-0.5	0.7	0.0	-0.4
4 Metal mines	1.3	0.3	1.0	1.8	2.1
5 Mineral fuels	-0.6	-1.3	0.8	0.6	-0.7
6 Nonmental mines	1.8	0.7	1.0	0.6	1.3
7 Services to mining	2.4	0.7	1.7	0.3	1.0
8 Food and beverages	2.3	0.6	1.6	1.0	1.7
9 Tobacco products	3.2	0.9	2.1	0.1	1.0
10 Rubber and plastics	2.2	0.7	1.5	0.1	0.7
11 Leather products	3.0	1.7	1.2	0.2	1.9
12 Textiles	3.6	1.5	1.9	2.0	3.6
13 Knitting mills	4.3	1.8	2.3	0.3	2.1
14 Clothing	3.6	2.2	1.2	0.4	2.7
15 Wood products	2.1	1.0	1.0	0.9	2.0
16 Furniture and fixtures	1.4	0.5	0.9	0.2	0.7
17 Paper and allied products	1.2	0.3	0.9	2.0	2.3
18 Printing and publishing	2.9	1.9	0.8	1.3	3.5
19 Primary metals	0.7	-0.3	1.1	2.0	1.7
20 Metal fabricating	1.8	0.8	1.0	2.0	2.9
21 Machinery	2.6	1.4	1.1	1.0	2.5
22 Transportation equipment	3.7	1.5	2.0	2.2	3.9
23 Electrical products	3.7	2.1	1.4	2.7	5.1
24 Nonmetallic mineral products	2.3	1.0	1.2	0.8	1.9
25 Petroleum and coal products	2.4	-0.2	2.6	0.2	-0.0
26 Chemicals	2.4	1.1	1.2	1.7	2.9
27 Miscellaneous manufacturing	2.7	1.3	1.3	0.8	2.1
28 Construction	1.6	0.1	1.4	1.0	1.1
29 Transportation and storage	2.5	1.5	0.9	8.4	10.9
30 Communications	5.0	3.1	1.6	1.1	4.4
31 Electric power and gas	2.3	0.8	1.4	0.2	1.0
32 Wholesale trade	2.2	1.1	1.0	3.4	4.7
33 Retail trade	1.9	1.3	0.6	1.6	3.0
34 Finance, insurance, and real estate	3.3	2.0	1.2	0.9	3.0
35 Education and health	-0.7	-1.1	0.3	-0.0	-1.1
36 Amusement and recreation	3.5	2.8	0.6	0.2	3.1
37 Services to business	1.7	0.8	0.9	-1.5	-0.8
38 Accommodation and food	-0.1	-0.6	0.5	0.1	-0.5
39 Other personal services	-1.3	-1.6	0.4	-0.4	-1.9
40 International trade	4.3	0.8	3.4	0.0	0.8
Aggregate	2.5	-	-	-	-

SOURCE Based on data from Statistics Canada and from Table 3-5.

Table 3-6. The substantive increase in FIRE's output effects is mainly transmitted through the reduction in the industry's direct labour coefficient, magnified by a higher level of direct and indirect intermediate consumption of FIRE services throughout the economy. The last line of Table 3-6 gives a new revised set of aggregate productivity growth rates.[3] It is interesting to note that the experimental measure of FIRE's real output results in an aggregate total labour productivity growth rate equal to 2.5 per cent for the 1971-76 period, compared with the previous estimate of 2.0 per cent. The Canadian aggregate productivity slowdown, at least in its initial stage, is now much less apparent.

One key point stemming from the above application must be re-emphasized. The I-O approach to productivity growth estimation, as we have seen, possesses a highly desirable property. The total labour productivity growth rate for each individual industry is invariant with respect to real output measurement errors occurring in any other individual industry or group of industries. This property holds in any economic state of industrial interdependence. Needless to say, the traditional type of measures of productivity growth do not possess this property.

We now turn to a second application of productivity decompositon analysis. Beginning with the observed 1976 productivity data base, we perform the following projection exercise. Five Canadian industries, among the given list of 40, are chosen to absorb a particular kind of technological stimulus. The five industries are Transportation and storage (no. 29), Communications (no. 30), Wholesale trade (no. 32), Finance, insurance, and real estate (no. 34), and Services to business (no. 37). Each of these industries is relatively large, in terms of real gross output, and each industry delivers at least 40 per cent of its total gross output to intermediate demand. The particular technological stimulus applied to each of these industries is very simple: each industry's direct labour coefficient and set of intermediate input (including capital replacement input) coefficients are cut by 25 per cent on the basis of their observed magnitudes for 1976. One may think of this exercise as a kind of 1976-81 projection of an assumed sort. The problem, then, is to prepare a complete productivity growth anatomy table similar to those already shown in this chapter. This table will represent our projected 1976-81 assumptions, the particular advantage being that we know precisely the industrial sources of all technological changes. Since these assumed technological changes are simple and concentrated, the exercise helps clarify the nature of I-O productivity analysis.

Table 3-7 contains all the required results. Note that the initial technological stimulus enters only through the own effects component of the total labour productivity growth rates. That is, all the contributions of an industry's own effects to productivity growth rates (column 2 of Table 3-7) are zero except for the five designated industries. (The own effects growth rates of these five industries are not "exactly" the same, even though they all receive identical stimuli, mainly because their total labour productivity levels for the base year 1976 are not "exactly" the same.) Since the five industries, as a whole, deliver most of their output to other industries (including each other), the original technological stimulus is eventually dispersed far and wide to all industries of the Canadian business sector, not excluding International trade. This is shown in the first column, in terms of the total labour productivity growth rates of the individual industries. The positive productivity growth rates for all industries not directly stimulated simply reflect the contribution of their input effects to productivity growth rates, as shown in column 3. These industries are not uniformly affected; the relative magnitudes of input effects depend mostly on the relative strengths of these industries' backward linkages with the five industries stimulated originally. The magnitudes of total labour productivity growths (equal to the input effects components of productivity growths) for Mineral fuels (no. 5), Petroleum and coal products (no. 25), and International trade (no. 40) are particularly noteworthy.

Clearly, we should expect the five stimulated industries to provide the major source of growth rates associated with output effects. This is evident from column 4 of Table 3-7. Again, the magnitudes of such associations are not uniform among the five industries; the relative magnitudes depend mainly on the relative strengths of these industries' forward linkages with all industries of the business economy. But note that now almost all industries exhibit some positive output effects. This phenomenon essentially derives from the fact that the technological stimulus applied to the five original industries involves not only a reduction in their direct labour coefficients, but also a reduction of the same proportion in all their intermediate input coefficients. This means that many other industries' gross outputs, delivered as intermediate inputs directly and indirectly throughout the economy, are now ("projected" to 1981) utilized more efficiently. This gain in economic efficiency is reflected in our decomposition methodology by association with the respective industry output effects. These positive output effects are all relatively small and would, indeed, equal zero, if the initial technological stimulus were restricted to a reduction

Table 3-7

Decomposition of Total Labour Productivity Average Annual Growth Rate, Artificial Projection Exercise with 1976 Base, 40 Industries

	Total projected average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	0.8	0.0	0.8	0.5	0.5
2 Forestry	1.7	0.0	1.7	0.2	0.2
3 Fishing and hunting	0.8	0.0	0.8	0.0	0.0
4 Metal mines	1.5	0.0	1.5	0.3	0.3
5 Mineral fuels	2.8	0.0	2.8	0.2	0.2
6 Nonmetal mines	1.4	0.0	1.4	0.1	0.1
7 Services to mining	1.1	0.0	1.1	0.1	0.1
8 Food and beverages	1.2	0.0	1.2	0.2	0.2
9 Tobacco products	1.2	0.0	1.2	0.0	0.0
10 Rubber and plastics	1.3	0.0	1.3	0.3	0.3
11 Leather products	0.9	0.0	0.9	0.0	0.0
12 Textiles	1.2	0.0	1.2	0.1	0.1
13 Knitting mills	0.9	0.0	0.9	0.0	0.0
14 Clothing	0.9	0.0	0.9	0.0	0.0
15 Wood products	1.3	0.0	1.3	0.4	0.4
16 Furniture and fixtures	1.0	0.0	1.0	0.1	0.1
17 Paper and allied products	1.5	0.0	1.5	0.5	0.5
18 Printing and publishing	1.1	0.0	1.1	0.5	0.5
19 Primary metals	1.6	0.0	1.6	0.5	0.5
20 Metal fabricating	1.2	0.0	1.2	0.6	0.6
21 Machinery	1.3	0.0	1.3	0.4	0.4
22 Transportation equipment	1.8	0.0	1.8	0.8	0.8
23 Electrical products	1.2	0.0	1.2	0.7	0.7
24 Nonmetallic mineral products	1.4	0.0	1.4	0.2	0.2
25 Petroleum and coal products	2.6	0.0	2.6	0.1	0.1
26 Chemicals	1.8	0.0	1.8	0.3	0.3
27 Miscellaneous manufacturing	1.2	0.0	1.2	0.2	0.2
28 Construction	1.4	0.0	1.4	2.1	2.1
29 Transportation and storage	7.6	4.4	2.4	16.9	30.7
30 Communications	6.9	4.6	1.8	5.1	11.6
31 Electric power and gas	1.3	0.0	1.3	0.3	0.3
32 Wholesale trade	7.1	5.0	1.6	14.0	26.8
33 Retail trade	0.6	0.0	0.6	0.9	0.9
34 Finance, insurance, and real estate	7.6	4.9	1.9	15.5	29.6
35 Education and health	1.2	0.0	1.2	0.0	0.0
36 Amusement and recreation	1.0	0.0	1.0	0.1	0.1
37 Services to business	6.9	5.2	1.2	10.7	21.6
38 Accommodation and food	0.7	0.0	0.7	0.4	0.4
39 Other personal services	0.4	0.0	0.4	0.5	0.5
40 International trade	2.1	0.0	2.1	0.0	0.0
Aggregate	2.1	0.8	1.3	2.4	3.3

Source Based on data from Statistics Canada.

in direct labour coefficents only. The magnitudes of the industry output effects shown in column 4 for the nonstimulated industries depend on the outputs of these industries delivered as intermediate and capital replacement inputs to the five directly stimulated industries.

Two final remarks can now be made concerning this exercise. The aggregate results[4] (last row of Table 3-7) show that, even though the original technological stimulus enters only through the own effects component of the productivity growth rates of the original five industries, the aggregate own effects component of productivity growth accounts for less than 40 per cent (0.8 ÷ 2.1) of aggregate total labour productivity growth. Since this exercise does not embody any change in international terms of trade, we should expect the aggregate productivity growth rate of column 1 to approximate the traditional type of aggregate productivity growth rate (corrected for a small change in the aggregate physical capital consumption ratio). The second remark means simply that the exercise shows the potential for generating a wide dispersion of industry total labour productivity growths stemming from technological advances in a limited number of "key" industries. This remark certainly requires further discussion, and this will be found in the context of industrial policy implications discussed in Chapter 6 (see especially the section on Canadian industrial policy).

There is one other application that conceivably could be tested with the available data base, which so far has not been done. We have emphasized in this chapter that the output effects component of productivity growth rates attached to each industry are somewhat fictitious (although still revealing), since an industry does not in reality "capture" the output effects transmitted to all other industries. One way to avoid this ambiguity is to decompose each of the columns pertaining to input effects in Tables 3-3, 3-4, 3-5, and 3-7 into 40 columns showing the distinct constituent parts, each of which would represent the input effects component of productivity growth stemming from one particular industry in our universe, that is, the industrial distribution of each industry's output effects in turn. In this case, with the suggested decomposition, the aggregation procedure of using final demand weights is well-defined (in contrast to the utilization of these weights on the somewhat fictitious output effects, as illustrated in the various tables).[5] Indeed, the well-defined aggregation of each of the 40 columns showing the decomposed contribution of input effects to growth rates would then yield a forty-fold decomposition of the aggregate input effects components of productivity growth rates already shown in the tables. The basic data essentially required to perform such an analysis for the time period 1961-76 are given in Table A-4. This type of analysis is most useful for tracing the indirect "contribution" of each industry to aggregate total labour productivity growth in the context of the alternative approach, since any industry's output effects contribute most to such aggregate growth when these effects bear on industries with large final demand weights. It therefore seems best to view output effects from a perspective of decomposed input effects, where the final demand orientation is not distorted. Some informal exercises along these lines are reported later in this study.

4 The Connection between Research and Development and Productivity Growth, 1966-76

This chapter has two main purposes. First, we try to show that industry productivity growth in Canadian industry, using the alternative approach measurements, can be "explained" by appropriate utilization of related variables. Second, because the key set of variables used in this connection involves Canadian research and development (R & D) expenditures, the exercise serves to further clarify the nature and significance of the I-O procedures, as applied to productivity analysis. Indeed, there are some distinct similarities between the correct treatment of labour input and R & D input within an I-O context. Again, results using the new alternative approach are compared with those yielded by the traditional method. One important implication of this chapter concerns the need for improved and more complete Canadian R & D data. This statistical policy implication is spelled out in the closing section of the chapter.

Statistical Background

The basic idea of this chapter is to investigate and measure the relationship between productivity growth rates of Canadian manufacturing industries and their R & D input growth rates. This relationship has been investigated in various American studies – see, for example, the survey in Griliches (1979) – but there do not appear to be recent Canadian studies of substantive depth. General discussion of this issue leads one to believe that the relationship, for the Canadian case, is probably rather weak and indirect, since Canadian industries are not dependent on their "own" R & D and related expenditures (see McFetridge, 1977, pp. 73-74). Equally important is the fact that productivity growth can arise from operations other than R & D and, indeed, R & D itself is not primarily or necessarily directed towards raising industry productivity growth rates. Nevertheless, it is felt that the relationship, if any, in the Canadian case is worth investigating, particularly since we are now equipped with a new and alternative set of industry productivity growth rates.

The statistical results of the investigation, reported in the next section, pertain to 13 Canadian manufacturing industries (using the familiar numbering system of the listed industries): Food and beverages (no. 8), Rubber and plastics (no. 10), Textiles (no. 12), Wood products (no. 15), Paper and allied products (no. 17), Primary metals (no. 19), Metal fabricating (no. 20), Machinery (no. 21), Transportation equipment (no. 22), Electrical products (no. 23), Nonmetallic mineral products (no. 24), Petroleum and coal products (no. 25), and Chemicals (no. 26). These industries are directly responsible for about 75 per cent of the total R & D expenditures of the Canadian business sector. It is possible to develop reasonably "reliable" (see also the section on policy implications below) R & D input data for each of these industries. The investigation is mainly concerned with relating various productivity growth rates and R & D input growth rates for the 13 manufacturing industries over two medium-term subperiods – namely, 1966-71 and 1971-76. This yields a total of 26 observations; it is not possible to extend the investigation further back in time, because of statistical data limitations. Before continuing, it should be noted that all productivity growth rates used in this chapter are estimated on the basis of "man-hours worked" to measure labour input, rather than "man-years employed" (used in previous chapters). It is believed that the former measure is a more sensitive instrument for the particular purposes of this chapter, and reasonably reliable measures of it are available, since the investigation is essentially limited to manufacturing industries (see also Appendix B). All productivity data used in this chapter are given in Table 4-1, so it is possible to compare productivity growth rates based on the two different measures of labour input.

Two distinct[1] types of R & D are included in the analysis: intramural R & D and extramural R & D. All intramural R & D expenditure activities, whatever the source of financing, are carried on within the reporting companies of the various manufacturing industries. (Over 80 per cent of Canadian intramural R & D is financed by the Canadian business sector; the remainder comes mostly from the federal government, with minor contributions originating in provincial governments and outside Canada.) Extramural R & D refers to R & D activities performed outside the reporting company but paid for by the reporting company, that is, R & D services "contracted out." Total extramural R & D expenditures account for payments made both to other companies inside Canada and to companies outside Canada. For the 13 manufacturing industries, total intramural R & D is considerably (or, should we say, "officially") larger than total extramural R & D; the latter is worth about 25 per cent of the former over the relevant time period 1966-76. More is said about this comparison of the two types of R & D later in this chapter.

The investigation is certainly dependent on how observed industrial R & D expenditures are transformed into a measure of industrial R & D inputs. In this exercise, we follow a procedure recommended by Griliches (1979). In effect, R & D current price gross expenditures are transformed into a constant price R & D net stock variable by cumulating, with depreciation, past current expenditures on R & D for each industry covered. This involves the familiar perpetual inventory method (with depreciation), and all expenditures are deflated to constant 1971 prices to conform with the derived productivity measures. Viewing R & D input as a (net) stock is now the commonly accepted procedure in analogous investigations. Actually, the assumptions underlying our particular procedure are less restrictive than most, since we are only concerned with industrial R & D stock input growth rates defined over five-year intervals. Full details concerning statistical data sources and related manipulations required to construct the R & D net stock measures can be found in Appendix B. R & D net stock estimates are created for both intramural and extramural R & D.

There is one other point. The R & D input data utilized together with the new (I-O) approach to productivity growth rates actually embody R & D input estimates for all Canadian industries of the business sector, not just the 13 manufacturing industries (to be more accurate, only 27 of the 39 listed industries, excluding International trade, have direct R & D input, whether intramural or extramural). The reason for this is discussed in the next section, where the critical role of indirect R & D content is highlighted. Nevertheless, the statistical investigation (i.e., the multiple regression estimations of the next section) are restricted to the 13 manufacturing industries in order to minimize the impact of the poor quality of R & D data originating from (or, should we say, "allocated" to) the 14 (27 minus 13) non-manufacturing industries.

Empirical Regression Results

Our first set of empirical results is based on the conventional kind of investigation into the relation between productivity growth and R & D input growth. Productivity growth is measured by the traditional type of labour productivity growth rates, as described in Chapter 2 and given in Table 2-5. Once more, it should be noted that the present analysis is directly concerned only with the 13 manufacturing industries during the subperiods 1966-71 and 1971-76 and that labour input is now measured in terms of "man-hours worked." The traditional labour productivity growth rates actually used in this analysis are listed in Table 4-1. R & D input growth rates of both kinds are simply measured on the basis of the growth rates of total R & D net stock (input) for each of the 13 manufacturing industries during the two subperiods. We also introduce two other variables into the analysis: one representing the rate of growth of the ratio between gross physical capital stock and labour input (to account for changes in the "capital intensity" of production), and another variable indicating the possible presence of economies of scale with respect to labour and physical capital productive factors. The latter variable is indicated by using the growth rate of labour input itself (this is the correct indicator when the simple, traditional measure of labour productivity growth, based on value-added, is deployed). Mathematically, one may suppose a simple Cobb-Douglas production function (appropriately normalized):

$$(4.1) \quad V = L^{\alpha} K^{\beta} R_1^{\delta} R_2^{\gamma} e^{\lambda t}$$

where V represents real value-added, L is labour input, K is gross physical capital stock, R_1 represents net stock of intramural R & D input, R_2 is net stock of extramural R & D, and α, β, δ, γ, and λ represent production function parameters. This is equivalent to:

$$(4.2) \quad (V/L) = (K/L)^{\beta} L^{\alpha+\beta-1} R_1^{\delta} R_2^{\gamma} e^{\lambda t}$$

so that economies of scale prevail with respect to K and L if $\alpha + \beta > 1$. Taking logarithms on both sides of the latter equation and differentiating with respect to time t yields an expression:

$$(4.3) \quad (v/\ell) = \lambda + \delta r_1 + \gamma r_2 + \beta(k/\ell) + (\alpha + \beta - 1)(\ell)$$

where the new lower-case symbols now represent (or approximate) average annual growth rates (e.g., (v/ℓ) is the traditional labour productivity growth rate, r_1 is the growth rate of intramural R & D input, and (k/ℓ) is the "capital intensity" growth rate). This expression is used in a multiple regression analysis with (v/ℓ) as the dependent variable and with r_1, r_2, (k/ℓ), and ℓ as the four independent variables (there is also a pure constant representing "residual" technological change). In effect, we try to "explain" interindustry variations in medium-term labour productivity growth rates in terms of the four variables, with particular emphasis on the two R & D input variables.

The first set of empirical regression results is then:

$$(4.4) \quad (v/\ell) = \underset{(1.49)}{2.94} - \underset{(-1.37)}{0.20r_1} + \underset{(0.59)}{0.06r_2} + \underset{(0.91)}{0.36(k/\ell)} - \underset{(-0.29)}{0.29\ell} \qquad \bar{R}^2 = 0.16$$

where the numbers in parentheses below the coefficient estimates represent "t" ratios (coefficient estimates divided by standard errors). Clearly, based on the 26 observations, the regression results are weak and insignificant. The regression technique "explains" only about 16 per cent of productivity growth differentials, while the two R & D input variables lack statistical significance. We conclude, on the basis of this particular investigation, that there is no real evidence that those Canadian manufacturing industries experiencing higher-than-average labour productivity growth rates also tend to be the industries with above-average R & D input growth rates, and vice versa.[2] This result continues to hold true when labour input is measured by "man-years employed" and when the regression analysis is extended to all 27 Canadian industries that experience direct R & D inputs (i.e., with a total of 54 observations, although the R & D estimates of non-manufacturing industries are typically of poor quality).

The next set of empirical results is built upon the alternative approach to productivity measurements explained in previous chapters. To fix ideas, consider the construction of the total labour productivity levels for each industry. These productivity levels, or, reciprocally, the total labour requirements per unit of output, reflect not only the labour directly added by each industry concerned, but also the labour embodied indirectly through each industry's purchases of intermediate and physical capital replacement inputs (both domestically produced and imported). It should now be clear that similar industry calculations can be performed with respect to R & D, in which R & D input is treated in a manner somewhat analogous to labour input. This means that we can calculate, for each of the 13 Canadian manufacturing industries, the total (direct plus indirect) R & D input content embodied in each industry's unit product as delivered to final demand. (All we do is replace the direct labour

Table 4-1

Labour Productivity Growth Rates and Selected Components, 13 Manufacturing Industries, 1966-71 and 1971-76

	1966-71				1971-76			
	Traditional rate (v/l)	Own effects component (p_1)	Total rate (p_2)	Total associated effects (p_3)	Traditional rate (v/l)	Own effects component (p_1)	Total rate (p_2)	Total associated effects (p_3)
	(Per cent)							
8 Food and beverages	7.1	1.2	4.8	2.2	1.6	0.5	3.1	1.5
10 Rubber and plastics	5.6	2.3	4.5	2.8	2.2	0.8	3.0	1.1
12 Textiles	8.7	3.6	6.2	7.3	4.8	1.7	4.3	4.2
15 Wood products	2.9	1.5	3.7	2.7	2.9	1.1	2.7	2.3
17 Paper and allied products	2.6	0.8	3.0	3.9	0.6	0.5	2.0	3.1
19 Primary metals	4.5	1.0	3.2	3.7	-1.0	-0.2	1.5	2.3
20 Metal fabricating	3.7	1.5	3.4	3.4	1.8	0.9	2.3	3.2
21 Machinery	1.6	0.8	2.5	1.6	2.1	1.1	3.0	2.1
22 Transportation equipment	9.4	2.0	5.2	0.7	4.7	1.1	4.3	3.5
23 Electrical products	5.1	1.8	4.1	3.0	5.0	2.0	4.1	5.0
24 Nonmetallic mineral products	4.8	1.8	3.8	2.5	2.8	1.3	3.0	2.3
25 Petroleum and coal products	-3.2	-0.2	2.2	0.0	5.7	0.3	3.3	0.6
26 Chemicals	3.8	0.9	3.5	2.0	2.3	1.0	2.9	2.6

SOURCE Based on data from Statistics Canada.

coefficients in the basic transformation calculation of Chapter 2 with direct R & D coefficients – namely, the ratio of R & D net stock to total gross output for each industry.) Moreover, it is also possible to disentangle the direct R & D input content (per unit of output) from the indirect R & D content (per unit of output) for each industry concerned. Indeed, it turns out that this decomposition is simpler and better defined in the case of R & D input than in the previous case of labour input (where own effects and input effects are decomposed). The reasons why decomposition is simpler in the R & D case are rather technical, and are discussed at length in Appendix A.

Thus, for each manufacturing industry at each point in time, we estimate the direct R & D input content and, separately, the indirect R & D input content, and we do this for both intramural and extramural R & D. Note that the indirect R & D content (per unit of output) assigned to a particular manufacturing industry reflects R & D input originating not only in the other manufacturing industries, but also in all industries in the Canadian business sector having direct R & D content. So, in order to perform the above calculations, R & D input data are required and obtained for another 14 industries (27 minus 13), as mentioned in the previous section. The whole procedure, then, yields four distinct R & D input growth rates: 1/ direct intramural R & D input growth, 2/ indirect intramural R & D growth, 3/ direct extramural R & D growth, and 4/ indirect extramural R & D growth. These four growth rates are calculated for the subperiods 1966-71 and 1971-76, and are used in conjunction with the 13 manufacturing industries. All R & D content growth rates are now defined with respect to each industry's unit of output delivered to final demand. It should also be noted that the basic R & D expenditure data include the wages and salaries of R & D personnel. Thus, the various derived R & D input measures contain a potential element of "human capital" growth to the extent that R & D wages and salaries reflect "true" human capital.

Once more, it is possible to develop a multiple regression equation analogous to the one described earlier in this section. The basic equation attempts to explain productivity growth differentials between industries, as measured by the methodology of the alternative approach. We first experiment with the own effects component of the productivity growth rates derived through a decomposition procedure similar[3] to that outlined in Chapter 3 (again, labour input is measured in "man-hours worked"). It should be recalled that the contribution of own effects to productivity growth rates is a counterpart of the traditional measure of productivity in an industry, since both reflect technological changes within the given industry. Nevertheless, these technological changes may be ultimately affected through purchases of intermediate inputs. Thus, our first multiple regression equation becomes:

$$(4.5)\quad p_1 = \lambda + \delta_1 r_1 + \delta_2 r_2 + \delta_3 r_3 + \delta_4 r_4 + \beta_1 (k/g) + \beta_2 g$$

where p_1 represents the own effects component of the productivity growth rate; r_1, r_2, r_3, and r_4 are the four distinct R & D input growth rates given in the preceding paragraph; (k/g) is the growth rate of the ratio of net physical capital stock to gross output (the counterpart of "capital intensity" in the new context, which includes physical capital replacement and depreciation as an intermediate input);[4] and g is the growth rate of total gross output in an industry (the indicator of possible economies of scale in the new context). Now, based on 26 observations over the two medium-term subperiods, the first empirical regression result is:

$$(4.6)\quad p_1 = \underset{(0.37)}{0.63} - \underset{(-1.12)}{0.05 r_1} + \underset{(2.01)}{0.18 r_2} + \underset{(1.23)}{0.04 r_3} - \underset{(-3.58)}{0.26 r_4} + \underset{(0.58)}{0.05 (k/g)} + \underset{(1.80)}{0.18 g} \qquad \bar{R}^2 = 0.50$$

where, again, numbers in parentheses below coefficient estimates represent "t" ratios.

The above regression results show that, for both intramural and extramural R & D, the direct impacts (through r_1 and r_3) on productivity growth are small and statistically insignificant. There is no statistical evidence that an industry's own (direct) R & D input growth has a positive influence on the same industry's own effects component of its productivity growth rate (at least, on average for the 13 manufacturing industries). But the regression also shows that the indirect impacts of Canadian industrial R & D input growth are significant. With respect to intramural R & D input (variable r_2), there is statistical evidence that the indirect R & D content embodied in the outputs of particular manufacturing industries does raise the own effects component of the productivity growth rates of these industries. In other words, productivity growth is stimulated not by an industry's own direct R & D, but by the industry's purchases and consumption of intermediate and physical capital (replacement) inputs, which themselves embody, directly and indirectly, growing amounts of intramural R & D inputs. Specifically, from the above regression result, we see (on average) that, for each percentage point increase in an industry's growth rate of indirect intramural R & D content, there is a 0.18 percentage point increase in the own effects component of the productivity growth rate for the same industry. For extramural R & D, on the other hand, the statistical evidence indicates a negative relationship between productivity growth and the growth of indirect extramural R & D content (variable r_4). The precise explanation for this "perverse" result is a mystery at present, but we do know that our industry estimates for extramural R & D input are qualitatively inferior to those for intramural R & D (see Appendix B and the discussion in the next section). It should also be noted that the productivity impacts of indirect extramural R & D are, in an important sense, "twice removed" from their industrial origin; this type of R & D is not only indirect, but also contracted out! Further investigation of this matter is clearly called for.

The results concerning the productivity impact of indirect R & D input, at least with respect to intramural R & D, should not be surprising. After all, there is evidence that most industrial R & D is oriented towards creating new and improved equipment and products sold externally, rather than towards the development of new production processes used internally by the industry that conducts the R & D (see Economic Council, 1983, and Scherer, 1982*a*). Thus, indirect R & D input growth probably reflects interindustry technology flows to a large extent. So long as the pricing of new products and equipment is not perfectly monopolistic, at least some of the benefit from the new materials and products developed in one industry can be ultimately passed on to buyers in other industries, and then reflected in the productivity growth rates of the purchasing industries. To test for a systematic bias of industry productivity growth rates stemming from mismeasurement of the price deflators for new products, we could check impact results using total labour productivity growth rates, which are largely invariant to such measurement errors. A definitive analysis of the subject matter, however, really calls for an industry-by-industry examination rather than the "on-average" analysis of this chapter.

In conclusion, then, we find that, by utilizing an alternative and perhaps more advanced treatment of productivity growth and R & D input growth, it is possible to discover new and significant relations between the two sets of variables. Indeed, the regression analysis just outlined "explains" 50 per cent ($\bar{R}^2 = 0.50$) of the differentials between the own effects components of productivity growth among industries.[5] Also, from Table 4-1, it is seen that nine of the 13 manufacturing industries experience slower productivity growth rates in the second subperiod, 1971-76, compared with the first subperiod, 1966-71. Thus, our statistical methodology goes some way towards "explaining" the Canadian productivity slowdown (in its initial stages). The above regression result should be considered the most important one of this chapter. The six independent variables in the regression are oriented towards utilization with the dependent variable representing the own effects component of productivity growth.

The empirical regression results can be checked by considering other productivity growth rates calculated with the alternative (I-O) approach. We perform a second regression experiment using the same set of six independent variables, and now introduce the total labour productivity growth rates (p_2) as the dependent variable. These productivity growth rates are well-defined and also possess a remarkable invariance property, as explained in Chapter 3. On the basis of 26 observations, the result is:

$$(4.7)\quad p_2 = \underset{(4.67)}{2.60} - \underset{(-0.94)}{0.05r_1} + \underset{(2.37)}{0.25r_2} + \underset{(0.46)}{0.02r_3} - \underset{(-3.70)}{0.33r_4} - \underset{(-1.20)}{0.12(k/g)} + \underset{(1.98)}{0.24g} \qquad \bar{R}^2 = 0.56$$

Clearly, the conclusions derived from the first regression experiment are confirmed *a fortiori*. Again, from Table 4-1, it is seen that 10 of the 13 manufacturing industries experienced lower total labour productivity growth rates during 1971-76 compared with the rates during 1966-71. So a substantial proportion of the Canadian manufacturing productivity slowdown, at least in terms of interindustry productivity growth differentials, is "explained" here.

A third and final regression experiment is based on the total associated effects productivity growth rates (p_3). It should be recalled that these growth rates represent a summation of the own effects and output effects components of the productivity growth rates (plus a small interaction effect). When p_3 is regressed on the original set of six independent variables, the results are:

$$(4.8)\quad p_3 = \underset{(4.49)}{4.08} - \underset{(-1.68)}{0.14r_1} + \underset{(1.64)}{0.29r_2} + \underset{(1.14)}{0.07r_3} - \underset{(-2.08)}{0.30r_4} - \underset{(-1.89)}{0.31(k/g)} - \underset{(-1.37)}{0.27g} \qquad \bar{R}^2 = 0.42$$

Again the conclusions regarding the four R & D input growth variables are confirmed, though the variable r_1 (direct intramural R & D input) comes close to statistical significance with a negative impact on productivity growth (the r_1 variable is significant at the 10 per cent level). The latter regression is also performed with a more sophisticated set of R & D input variables, reflecting the forward linkages component (i.e., the output effects component) of the productivity growth measure. Two R & D input variables are replaced by r_1^* (the indirect "output" intramural R & D) and r_3^* (the indirect "output" extramural R & D), both of which are discussed in Appendix A.[6] The regression results then become:

$$(4.9)\quad p_3 = \underset{(4.39)}{3.88} - \underset{(-1.81)}{0.14r_1^*} + \underset{(1.67)}{0.31r_2} + \underset{(0.99)}{0.06r_3^*} - \underset{(-2.17)}{0.33r_4} - \underset{(-1.85)}{0.31(k/g)} - \underset{(-1.22)}{0.21g} \qquad \bar{R}^2 = 0.43$$

which are very similar to those reported with the original set of four R & D input growth variables.

Finally, it might be added that the application and statistical testing of indirect R & D input growth variables in an exercise to determine the connection between productivity growth and R & D has now been done (to our knowledge) for the first time. Note that our indirect R & D impacts include all higher-order impacts, not just the "first-round" impacts. The need for an exercise that embodies all higher-order impacts has been emphasized by Griliches (1979). The results of this section should, nevertheless, be regarded with appropriate caution, since the essential R & D database is inadequate, for reasons spelled out in the next section.

Statistical Policy Implications

Three statistical implications of the exercise regarding the connection between productivity growth and R & D should be mentioned, if only briefly. Two of the implications involve statistical policy issues.

First, there is probably a serious statistical aggregation problem in the exercise reported in this chapter. The problem essentially arises because the (intra-industry) distribution of R & D within the 13 manufacturing industries is sometimes radically different from the distribution of production within those same industries. This is illustrated by the case for Transportation equipment; most R & D within this industry comes from Aircraft and parts (or, more exactly, from Pratt & Whitney), but most of the production weight stems from Automobiles and parts. Similarly, we know that Electrical products is subject to a distribution problem; most R & D occurs in Communications equipment (actually, Bell Canada), but production is largely weighted elsewhere. Clearly, the "solution" to this particular problem is industrial disaggregation: it is better to examine the relation between R & D and productivity growth at a finer disaggregation level, with better "matching" of the two sets of data (see also Chapter 6 for further comments). But, unfortunately, simple disaggregation, even with available data, is not enough!

This leads to the second problem. Statistics Canada now publishes a wide array of industrial R & D expenditures data. These data, for the business sector, are all based on statistical reporting units at the company or enterprise level. Canadian business sector R & D is mainly concentrated within a relatively small number of large enterprises; in the year 1976, just 25 reporting firms accounted for over 50 per cent of total R & D expenditures. These firms tended to be large, multi-industry enterprises, and yet each of their R & D expenditures was completely assigned by Statistics Canada to one component industry (usually a three-digit manufacturing industry). For example, Bell Canada, the big "sugar daddy" of Canadian R & D, was assigned to Communications equipment manufacturers, even though much of Bell Canada operations occur in Communication services.[7] Similarly, Imperial Oil Ltd. has operations in extraction, refining, transportation, storage, wholesaling, retailing, and even real estate; yet all of Imperial Oil Ltd.'s R & D was officially assigned to Petroleum refining manufacturing. The situation is similar for other big Canadian R & D spenders such as Canadian General Electric, Shell Oil, Alcan, and CIL.

The problem here is that company-based R & D data are statistically incompatible with the establishment-based production and employment data that are typically utilized in productivity research studies. The I-O framework of this study is certainly establishment-based, and so the empirical results of this particular chapter become open to suspicion. This problem is also faced by similar studies in other nations, but perhaps the Canadian "problem" is more severe because of the peculiar, concentrated nature of Canadian R & D.[8] Active steps have been taken in other countries, most notably the United States, towards constructing R & D expenditure data that are compatible with establishment-based productivity estimates. One method is the required disclosure of segmented financial statistics, including R & D data, by major multi-industry corporations. In this case, a company's R & D expenditures are allocated to the company's various lines of business; these business lines approximate reporting by establishment. A major American study of productivity and R & D growth has recently benefited from newly compatible data; see Scherer (1982*a*) and also Clark and Griliches (1982). It is, therefore, recommended that Canadian statistical authorities take the necessary steps towards resolving this problem, so that more meaningful Canadian productivity studies can be performed.

The third statistical implication pertains to the extramural R & D data used in this chapter (see also the data sources in Appendix B). The official Canadian statistics show that extramural R & D is small relative to intramural R & D. There is, however, reason to believe that the official figures are only "the tip of the iceberg," particularly with respect to extramural R & D performed (or "contracted out") outside Canada. The reason for this is Statistics Canada's failure to officially classify (outside) payments for royalties, patents, industrial designs, and technological transfers as (extramural) R & D. Similarly, there are a multitude of service payments outside the reporting firm, such as management fees and charges for professional and consulting services, that may be closely related to R & D, but which are not officially so classified. Clearly, these problems are compounded by the relatively high degree of foreign ownership in Canadian manufacturing industries. Our guess is that the "true" level of total extramural R & D in the Canadian business sector is much higher than that recognized officially, and so the growth rates constructed for the net stock input of extramural R & D may be biased in some unknown direction (the statistical bias of growth rates is not necessarily downward). In any event, it would be beneficial if Statistics Canada could provide a breakdown by industry of the payments and charges mentioned above that are not included in extramural R & D. It would be necessary to develop a consistent time-series of this industrial disaggregation, so that a perpetual inventory methodology could be applied to construct a (net) stock measure from observed expenditure data. Note, once again, that the basic data, even if made available, are based on company reporting systems. These data must be transformed onto an establishment approximation to be made compatible with productivity estimations.

5 An Anatomy of Productivity Stagnation, 1973-78

This chapter contains a rather detailed analysis of productivity growth using the most recent statistics available – namely, those for the period 1973-78. It is of considerable interest to analyse this period with our alternative approach calculations, since this period is one of aggregate productivity stagnation (i.e., aggregate Canadian productivity growth is close to zero). Once again, it is important to compare the results with those obtained using the simple, traditional productivity analysis. It is also revealing to explicitly trace some key characteristics of the development of the Canadian productivity slowdown over the entire 1961-78 period, using the alternative approach calculus. This chapter features some more advanced aspects of the alternative approach with respect to decomposition analysis. It is, therefore, particularly essential for the reader to become acquainted with Appendix A in order to understand this chapter. These advanced aspects lead naturally to certain potential policy implications, which are discussed in further detail in the next chapter.

Some Statistical Considerations

This study was originally planned to cover the 1961-76 period, with appropriate subperiod analysis. However, during the final stages of the study, I-O statistical data for 1977 and 1978 became available, together with revised data for the earlier years back to 1971. Also at this time, there was, and still is, considerable interest in the Canadian (aggregate) productivity slowdown, which is only "captured" in its initial stages for the 1971-76 subperiod. In view of the limitations of I-O productivity analysis to time intervals of at least five years' duration (see the discussion in Chapter 2), it was therefore decided to add another chapter to this study covering the most recent five-year period, 1973-78. It should be noted that the present productivity analysis is based on revised I-O and labour data, and thus is not strictly comparable with the analysis of the earlier subperiod 1971-76, where unrevised data are deployed. Also, as stated in Chapter 2, most empirical productivity results of this study are obtained using both the "man-years employed" and the "man-hours worked" measures of labour input (even though most results are explicitly shown only for "man-years employed"). For the subperiod 1973-78, unfortunately, only the "man-years employed" measure is available for the productivity calculations. On the other hand, we are able to perform a somewhat deeper productivity analysis in this chapter compared with that in other chapters. A final statistical point is that relatively good research and development (R & D) data are now available up to the year 1978 and even beyond. It would be interesting to extend the R & D productivity growth analysis of Chapter 4 in order to encompass three subperiods – 1963-68, 1968-73, and 1973-78. This, again unfortunately, has not yet been done.

Productivity Stagnation Results Compared

Table 5-1 displays the total labour productivity levels for each of the 40 industries (including International trade), in 1973 and 1978, using the alternative approach I-O calculations. The total labour productivity levels in the two years, then, determine the total labour productivity growth rates during 1973-78, which are also shown. This table is similar to Table 2-2 (see also the text discussion in Chapter 2 for the method of computation of productivity) but, as noted above, the productivity level results for the year 1976 (Table 2-2) are not strictly comparable with those for 1973 and 1978 in Table 5-1. This table is best examined in conjunction with Table 5-2, which shows the simple, traditional labour productivity levels and growth rates during 1973-78, using gross domestic product arising from each industry (i.e., real value-added) as the measure of output. The latter table is, then, similar but not strictly comparable with Table 2-3.

For present purposes, we restrict our attention to the industrial productivity growth rates of the two tables; in the next chapter, we reconsider the total labour productivity levels for the year 1978 in terms of industrial policy implications. It is evident that a general productivity growth stagnation is at hand, judging from the relatively[1] large number of negative

Table 5-1

(Input-Output) Total Labour Productivity Level and Average Annual Growth Rate, 40 Industries, 1973-78

	Level		Average growth rate
	1973	1978	1973-78
	(Dollars*)		(Per cent)
1 Agriculture	6,991	6,981	-0.0
2 Forestry	11,720	11,675	-0.1
3 Fishing and hunting	6,057	6,790	2.3
4 Metal mines	17,451	14,882	-3.1
5 Mineral fuels	21,777	14,805	-7.4
6 Nonmetal mines	15,233	13,747	-2.0
7 Services to mining	11,908	12,907	1.6
8 Food and beverages	10,105	10,160	0.0
9 Tobacco products	11,845	12,133	0.5
10 Rubber and plastics	13,096	13,582	0.7
11 Leather products	8,691	10,222	3.3
12 Textiles	11,408	12,944	2.6
13 Knitting mills	10,178	12,897	4.8
14 Clothing	8,768	10,447	3.6
15 Wood products	10,391	10,919	1.0
16 Furniture and fixtures	10,612	10,703	0.2
17 Paper and allied products	12,742	12,806	0.1
18 Printing and publishing	12,086	13,369	2.0
19 Primary metals	14,609	13,334	-1.8
20 Metal fabricating	13,058	12,826	-0.4
21 Machinery	12,901	14,300	2.1
22 Transportation equipment	14,393	15,167	1.1
23 Electrical products	13,150	14,185	1.5
24 Nonmetallic mineral products	14,342	14,225	-0.2
25 Petroleum and coal products	15,685	14,058	-2.2
26 Chemicals	14,179	14,680	0.7
27 Miscellaneous manufacturing	11,609	12,394	1.3
28 Construction	12,969	12,638	-0.5
29 Transportation and storage	13,279	12,718	-0.9
30 Communications	11,077	15,169	6.5
31 Electric power and gas	18,902	17,790	-1.2
32 Wholesale trade	12,412	12,019	-0.6
33 Retail trade	7,664	7,691	0.1
34 Finance, insurance, and real estate	18,289	18,213	-0.1
35 Education and health	17,792	16,968	-0.9
36 Amusement and recreation	8,456	10,255	3.9
37 Services to business	11,075	10,371	-1.3
38 Accommodation and food	8,201	8,425	0.5
39 Other personal services	5,706	5,377	-1.2
40 International trade	13,813	13,711	-0.1
Aggregate	-	-	0.3

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

industrial productivity growth rates in both Tables 5-1 and 5-2. However, there are also a significant number of positive and relatively large productivity growth rates during the 1973-78 period, as witnessed in the cases of Leather products (no. 11), Knitting mills (no. 13), Communications (no. 30), and Amusement and recreation (no. 36). Thus, productivity growth stagnation is certainly not uniform among industries, but seems concentrated mainly in the Mining industries (nos. 4, 5, and 6), and in the Petroleum and coal products (no. 25), the important Construction (no. 28), and the Transportation and storage (no. 29) industries. It is again apparent (as in Chapter 2) that the set of I-O productivity growth rates provides a rather different picture of productivity change, compared with the set of traditional productivity growth rates. The industrial elements of the former set are more similar to each other than are the industrial elements of the latter set; indeed, the traditional productivity growth rates feature some wide extremes. One reason for this phenomenon has already been explained in Chapter 2 and will not be

Table 5-2

Traditional Labour Productivity Level and Average Annual Growth Rate, 39 Industries, 1973-78

	Level		Average growth rate
	1973	1978	1973-78
	(Dollars*)		(Per cent)
1 Agriculture	5,752	5,708	-0.2
2 Forestry	11,075	11,735	1.2
3 Fishing and hunting	6,296	7,145	2.6
4 Metal mines	29,432	21,757	-5.9
5 Mineral fuels	66,706	23,639	-18.7
6 Nonmetal mines	21,644	17,427	-4.2
7 Services to mining	13,615	15,778	3.0
8 Food and beverages	12,912	13,702	1.2
9 Tobacco products	18,918	21,800	2.9
10 Rubber and plastics	13,558	14,492	1.3
11 Leather products	6,288	8,478	6.2
12 Textiles	10,668	13,465	4.8
13 Knitting mills	8,444	13,154	9.3
14 Clothing	6,309	8,452	6.0
15 Wood products	8,702	9,923	2.7
16 Furniture and fixtures	8,967	8,944	-0.1
17 Paper and allied products	15,040	15,367	0.4
18 Printing and publishing	11,982	14,123	3.3
19 Primary metals	16,295	14,992	-1.7
20 Metal fabricating	12,784	12,784	-0.0
21 Machinery	12,525	15,955	5.0
22 Transportation equipment	17,328	21,048	4.0
23 Electrical products	13,241	15,532	3.2
24 Nonmetallic mineral products	16,377	16,695	0.4
25 Petroleum and coal products	23,389	20,640	-2.5
26 Chemicals	17,710	20,207	2.7
27 Miscellaneous manufacturing	10,279	11,621	2.5
28 Construction	12,136	11,342	-1.3
29 Transportation and storage	14,649	13,496	-1.6
30 Communications	14,713	22,714	9.1
31 Electric power and gas	40,004	36,978	-1.6
32 Wholesale trade	12,457	11,606	-1.4
33 Retail trade	6,499	6,438	-0.2
34 Finance, insurance, and real estate	18,480	18,596	0.1
35 Education and health	21,818	20,778	-1.0
46 Amusement and recreation	6,701	9,433	7.1
37 Services to business	10,981	10,272	-1.3
38 Accommodation and food	6,772	7,167	1.1
39 Other personal services	4,387	4,166	-1.0
Aggregate	-	-	0.3

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

repeated here (see the discussion of relative coefficients of variation in that chapter). However, we now also know that the total labour productivity growth rates of Table 5-1 possess a remarkable invariance property: each industrial productivity growth rate is independent of the errors in measurement of real output that might occur in any other industry or group of industries. The total labour productivity growth rate calculations are sensitive only to errors in measurement of output in their own industry, irrespective of the state of industrial interdependence (see the formal proof of this proposition in Appendix A). The simple, traditional labour productivity growth rates of Table 5-2, or indeed any of the traditional multi-factor productivity growth rates, do not possess this invariance property. This particular property is especially valuable during an inflationary period, such as 1973-78, when the possibilities of real output measurement errors are magnified, as discussed and illustrated in Clark (1982). The impact of inflation on industrial productivity growth is also considered in the next chapter.

Tables 5-1 and 5-2 both show aggregate productivity growth rates during 1973-78. As we know from Chapter 2, the aggregation of industrial productivity growths could yield different results according to the methodology used to measure the basic industrial productivity growths. It turns out that, for this particular time period, the aggregate productivity growths for the Canadian business sector are virtually identical (to the nearest decimal point) in the two tables – namely, an average annual growth rate equal to 0.3 per cent. Recalling the discussion in Chapter 2, during the period 1973-78, there was a small improvement in the Canadian international terms of trade (equal to about 2 per cent, based on the revised trade data); at the same time, the physical capital depreciation ratio also rose slightly. The two effects in this case are self-canceling in terms of aggregate productivity growth impact. However, it should be noted that the Canadian aggregate productivity slowdown has a somewhat different timing, when measured in terms of the alternative approach, compared with the traditional approach (Table 5-3). The two measures, though, do agree as to the magnitude of aggregate business sector productivity stagnation during the most recent time period.[2]

Table 5-3

Comparison of Two Measures of Average Annual Aggregate Labour Productivity Growth, 1966-71, 1971-76, and 1973-78

	Alternative measure	Traditional measure
	(Per cent)	
1966-71 average	2.8	2.8
1971-76 average	2.0	1.4
1973-78 average	0.3	0.3

SOURCE Tables 2-4, 2-5, 5-1, and 5-2.

Decomposition of Productivity Stagnation

One advantage of the total labour productivity growth rates shown in Table 5-1 is that these estimates permit a decomposition into the components of productivity growth rates, each of which has a natural economic interpretation (see Chapter 3). Reference is now made to Table 5-4; this table is identical in meaning and structure to the set of Tables 3-3, 3-4, and 3-5 (especially Table 3-5, which refers to the subperiod 1971-76). For the purposes of the present chapter, however, we have added a modification to the decomposition analysis not used in Chapter 3. The modification arises from the presence of the International trade industry and from the fact that this pure exchange industry does not directly employ labour input. This introduces a slight ambiguity into the decomposition analysis of the own effects component of productivity growth (the total labour productivity growth analysis is entirely unaffected). Appendix A devotes a whole section to this problem and the suggested solution, to which the reader is referred. Therefore, we have produced an additional Table 5-5, which incorporates the modification refinement. It is possible to observe the impact of the refinement by simply comparing all productivity growth rates in Table 5-4 with their counterparts in Table 5-5. In almost all cases, the impact is very small; indeed, the output effects component of productivity growth rates for all 39 production industries remain unchanged (only the own effects and input effects components are changed, in opposite directions). Nevertheless, Table 5-5 is the more accurate representation of productivity growth decomposition, and we mostly restrict our attention to this table.

First, it is interesting to check whether those industries experiencing large negative productivity growth in Table 5-1 (i.e., using total labour productivity growth rates) continue to experience relatively large negative growth when examined on the basis of their own effects component of productivity growth rates. Using the first and second columns of Table 5-5, the check is confirmed for such industries as Metal mines (no. 4), Mineral fuels (no. 5), Services to business (no. 37), but not for Petroleum and coal products (no. 25). Similarly, most industries experiencing the highest positive productivity growth rates using the total measure (column 1) are also those with relatively high growths using the own effects measure (column 2); this is confirmed for Knitting mills (no. 13), Communications (no. 30), and Amusement and recreation (no. 36). However, it is more important to try to gain an overall impression of the phenomenon of productivity growth stagnation during the period 1973-78. In other words, we wish to know what is the main distinguishing feature of the Canadian productivity stagnation period, compared with other time periods. One way to accomplish this task is to examine the industrial aggregation of the decomposed productivity growth rates in Table 5-4 (last line), in comparison with their counterparts from previous time periods, as shown in Table 5-6. Although the own effects component of the aggregate productivity growth rate has fallen over the whole period 1961-78, the decrease is much more apparent, both absolutely and relatively, with respect to the Canadian input effects component of aggregate productivity growth.

Table 5-4

Decomposition of Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1973-78

	Total, 1973-78 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	-0.0	0.5	-0.5	0.1	0.6
2 Forestry	-0.1	0.1	-0.2	0.8	0.9
3 Fishing and hunting	2.3	2.4	-0.0	0.1	2.5
4 Metal mines	-3.1	-1.9	-1.4	2.0	-0.1
5 Mineral fuels	-7.4	-5.1	-3.2	-2.1	-6.6
6 Nonmetal mines	-2.0	-1.4	-0.7	0.1	-1.3
7 Services to mining	1.6	1.6	0.0	-0.1	1.5
8 Food and beverages	0.0	0.2	-0.2	0.1	0.4
9 Tobacco products	0.5	0.3	0.1	0.1	0.5
10 Rubber and plastics	0.7	0.5	0.2	0.0	0.6
11 Leather products	3.3	2.8	0.4	0.1	3.0
12 Textiles	2.6	1.8	0.6	1.9	4.0
13 Knitting mills	4.8	3.1	1.4	0.5	3.7
14 Clothing	3.6	2.4	1.0	0.4	2.9
15 Wood products	1.0	1.0	0.0	0.0	1.0
16 Furniture and fixtures	0.2	-0.0	0.2	0.1	0.1
17 Paper and allied products	0.1	0.4	-0.3	1.1	1.5
18 Printing and publishing	2.0	1.9	0.1	0.8	2.8
19 Primary metals	-1.8	-0.6	-1.3	-0.0	-0.6
20 Metal fabricating	-0.4	-0.1	-0.3	0.2	0.1
21 Machinery	2.1	1.7	0.3	0.6	2.4
22 Transportation equipment	1.0	1.0	0.1	0.0	1.0
23 Electrical products	1.5	1.4	0.1	1.1	2.5
24 Nonmetallic mineral products	-0.2	0.4	-0.5	0.3	0.7
25 Petroleum and coal products	-2.2	-0.9	-1.3	-0.4	-1.3
26 Chemicals	0.7	1.0	-0.3	0.4	1.4
27 Miscellaneous manufacturing	1.3	1.3	0.0	0.6	1.9
28 Construction	-0.5	0.1	-0.6	1.0	1.1
29 Transportation and storage	-0.9	-0.8	-0.0	-1.8	-2.5
30 Communications	6.5	5.5	0.7	2.2	8.7
31 Electric power and gas	-1.2	-0.7	-0.5	-1.3	-2.0
32 Wholesale trade	-0.6	-0.6	-0.0	-1.9	-2.4
33 Retail trade	0.1	-0.0	0.1	0.1	0.1
34 Finance, insurance, and real estate	-0.1	0.0	-0.1	-2.1	-2.0
35 Education and health	-0.9	-0.7	-0.3	-0.0	-0.7
36 Amusement and recreation	3.9	3.9	0.0	0.3	4.3
37 Services to business	-1.3	-1.5	0.2	-6.6	-7.6
38 Accommodation and food	0.5	0.7	-0.1	-0.1	0.5
39 Other personal services	-1.2	-1.2	-0.0	-0.6	-1.8
40 International trade	-0.1	-0.1	-0.0	0.0	-0.1
Aggregate	0.3	0.4	-0.1	-0.1	0.2

SOURCE Based on data from Statistics Canada.

At this point, two factors should be recalled. First, the above two components of productivity growth represent a simple decomposition of total aggregate productivity growth, that is, the summation of the aggregate own effects components of productivity growth added to the aggregate input effects components approximates (allowing for a very small interaction effect component) the aggregate total labour productivity growth rate. The latter average annual growth rate equals 0.3 per cent for the period 1973-78. The second factor is that the input effects component of productivity growth, whether aggregate or industrially disaggregated, reflects economy-wide technological changes, which are sometimes difficult to identify and associate with particular industries. However, we do know that the simple total of "captured" input effects of all industries (before translation into productivity growth terms) equals the simple total of their "transmitted" output effects (also before translation into productivity growth language). Indeed, this has already been illustrated for the period 1961-76 in Table 3-2. (We do not specifically

Table 5-5

Modified Decomposition of Total Labour Productivity Average Annual Growth Rate, 40 Industries, 1973-78

	Total, 1973-78 average	Own effects component	Input effects component	Output effects component	Total associated effects
			(Per cent)		
1 Agriculture	-0.0	0.4	-0.4	0.1	0.5
2 Forestry	-0.1	0.0	-0.1	0.8	0.8
3 Fishing and hunting	2.3	2.3	0.0	0.1	2.4
4 Metal mines	-3.1	-2.0	-1.3	2.0	-0.2
5 Mineral fuels	-7.4	-5.3	-2.9	-2.1	-6.8
6 Nonmetal mines	-2.0	-1.5	-0.6	0.1	-1.4
7 Services to mining	1.6	1.6	0.0	-0.1	1.5
8 Food and beverages	0.0	0.2	-0.2	0.1	0.4
9 Tobacco products	0.5	0.3	0.1	0.1	0.5
10 Rubber and plastics	0.7	0.5	0.2	0.0	0.5
11 Leather products	3.3	2.7	0.5	0.1	2.9
12 Textiles	2.6	1.9	0.6	1.9	4.1
13 Knitting mills	4.8	3.3	1.3	0.5	3.9
14 Clothing	3.6	2.4	1.0	0.4	2.9
15 Wood products	1.0	0.9	0.1	0.0	0.9
16 Furniture and fixtures	0.2	-0.1	0.3	0.1	-0.0
17 Paper and allied products	0.1	0.3	-0.2	1.1	1.4
18 Printing and publishing	2.0	1.8	0.2	0.8	2.8
19 Primary metals	-1.8	-0.8	-1.1	-0.0	-0.8
20 Metal fabricating	-0.4	-0.1	-0.3	0.2	0.1
21 Machinery	2.1	1.6	0.4	0.6	2.3
22 Transportation equipment	1.0	0.9	0.2	0.0	0.9
23 Electrical products	1.5	1.3	0.2	1.1	2.4
24 Nonmetallic mineral products	-0.2	0.3	-0.5	0.3	0.6
25 Petroleum and coal products	-2.2	0.1	-2.2	-0.4	-0.3
26 Chemicals	0.7	0.9	-0.2	0.4	1.3
27 Miscellaneous manufacturing	1.3	1.1	0.2	0.6	1.7
28 Construction	-0.5	-0.0	-0.5	1.0	1.0
29 Transportation and storage	-0.9	-0.8	-0.0	-1.8	-2.5
30 Communications	6.5	5.5	0.7	2.2	8.7
31 Electric power and gas	-1.2	-0.8	-0.4	-1.3	-2.1
32 Wholesale trade	-0.6	-0.6	-0.0	-1.9	-2.4
33 Retail trade	0.1	-0.0	0.1	0.1	0.1
34 Finance, insurance, and real estate	-0.1	0.0	-0.1	-2.1	-2.0
35 Education and health	-0.9	-0.8	-0.2	-0.0	-0.8
36 Amusement and recreation	3.9	3.9	0.0	0.3	4.3
37 Services to business	-1.3	-1.5	0.2	-6.6	-7.6
38 Accommodation and food	0.5	0.6	-0.1	-0.1	0.5
39 Other personal services	-1.2	-1.2	-0.0	-0.6	-1.8
40 International trade	-0.1	-0.1	-0.0	1.7	1.6
Aggregate	0.3	0.3	-0.0	0.1	0.3

SOURCE Based on data from Statistics Canada.

illustrate this identity for the new period 1973-78, preferring to show all results in terms of productivity growth rates.) Now output effects, whether stated in terms of changes over time in labour requirements or transformed into output effects components of productivity growth rates, can be associated with particular industries. But such association requires special care, since output effects *per se* can be decomposed into two basic constituents, each of which has a different economic interpretation. The difficulties of analysing output effects and a suggested solution to this problem are explained at length in Appendix A. For present purposes, we proceed as follows.

We know that industrial and aggregate own effects components of productivity growth are largely dominated by reductions in the direct labour coefficients of industries. Generally speaking, such reductions continued to occur during 1973-78, but at a somewhat diminished rate. The major difference between this period and the others appears as a shift, for many industries, towards greater consumption of intermediate inputs per unit of output. Note that purchases of intermediate inputs include physical capital replacement inputs, all of which may be domestically produced or imported. Also note that our methodology is able to translate any changes in intermediate inputs into a common denominator – labour! We know that augmented interindustry intermediate purchases will retard productivity growth unless balanced by larger reductions in direct labour coefficients, that is, intermediate inputs substitute for direct labour employed. Again, generally speaking, this required condition for maintaining productivity growth is not satisfied in the period 1973-78. Our analysis, however, permits us to be more specific by examining the particular industries whose outputs became the subject of increased consumption as intermediate inputs during the relevant time period. And such examination can proceed along lines naturally related to considerations of productivity, since all units of change in our analysis have the ultimate common denominator of labour input. The method for achieving this goal is to reconsider the industry output effects component of changes in labour requirements (described in Chapter 3) and, particularly, the two principal constituents of this component.

Table 5-6

Comparison of Average Annual Aggregate Measures of Two Industry Productivity Effects, 1961-66, 1966-71, 1971-76, and 1973-78

	Own effects aggregate	Input effects aggregate
	(Per cent)	
1961-66 average	1.0	2.1
1966-71 average	1.4	1.5
1971-76 average	0.7	1.3
1973-78 average	0.4	-0.1

SOURCE Tables 3-3, 3-4, 3-5, and 5-4.

Table 5-5 already includes a list by industry of output effects components of productivity growth rates (column 4). Many of these growth rates are negative, reflecting the "other side of the coin" displayed by the industrial input effects component of productivity growth rates (column 3). It is more revealing, though, to now consider Table 5-7, which provides a further decomposition of the output effects component of productivity growth rates. The first constituent (column 2) is the pure output effects contribution to the productivity growth rate. This is an unambiguous term that reflects both the direct and indirect intermediate coefficient consumption level of all industries with respect to the particular industries' outputs, weighted by the change in the particular industries' direct labour coefficients over the period 1973-78. Since almost all industries experienced a reduction in labour coefficients during the period, once this term is transformed into a corresponding productivity growth rate by the usual procedure (described in Chapter 3), the growth rates become positive. Thus, pure output effects in most cases present a positive contribution to economy-wide productivity growth. The remaining constituent shown in Table 5-7 (column 3) is the substitution output effects contribution to the productivity growth rate. This term is somewhat controversial, as explained in Appendix A. Ultimately, the term accounts for the changes over time in the importance of the respective industries' outputs as indirect intermediate consumption throughout the business sector; these changes are now weighted by the *level* of the industries' direct labour coefficients. Hence, when an industry's output is increasingly utilized for intermediate consumption purposes, the impact of this term, expressed in productivity growth language, becomes negative. The term "substitution" seems appropriate, since an increased intermediate consumption of a particular input (per unit of output) usually, but not necessarily, indicates substitution for some other input, including labour input. Now it seems clear that the substitution output effects components of productivity growth for many industries were negative during the period 1973-78. The positive contribution of the first constituent (column 2) is often (partly) cancelled by the negative contribution of the second constituent (column 3) in the case of some important industries. Thus, examining only the total output effects component of productivity growth (column 1) may often conceal more than it reveals. Indeed, the industries displaying large (in absolute values) negative productivity growth rates in the third column, through substitution of intermediate inputs, expressed in the common denominator of labour units, are precisely those industries that we can now identify (through association) with the distinguishing feature of productivity stagnation, which characterizes the 1973-78 period.

To show all this more specifically, consider Table 5-8, which displays the substitution output effects constituent measured by associated changes in labour requirements (i.e., before transformation into productivity growth language). All the changes are positive (as indicated by the plus sign), implying

Table 5-7

Decomposition of Output Effects Component Average Annual Growth Rate, 40 Industries, 1973-78

	Total output effects	Pure output effects	Substitution output effects
		(Per cent)	
1 Agriculture	0.1	1.2	-1.0
2 Forestry	0.8	0.1	0.7
3 Fishing and hunting	0.1	0.2	-0.1
4 Metal mines	2.0	-0.8	3.0
5 Mineral fuels	-2.1	-3.0	1.1
6 Nonmetal mines	0.1	-0.2	0.3
7 Services to mining	-0.1	0.5	-0.6
8 Food and beverages	0.1	0.7	-0.5
9 Tobacco products	0.1	0.1	-0.1
10 Rubber and plastics	0.0	0.3	-0.3
11 Leather products	0.1	0.2	-0.0
12 Textiles	1.9	1.6	0.3
13 Knitting mills	0.5	0.4	-0.1
14 Clothing	0.4	0.3	0.1
15 Wood products	0.0	1.0	-0.9
16 Furniture and fixtures	0.1	0.0	0.1
17 Paper and allied products	1.1	0.8	0.3
18 Printing and publishing	0.8	1.2	-0.3
19 Primary metals	-0.0	-1.0	1.0
20 Metal fabricating	0.2	0.0	0.2
21 Machinery	0.6	1.7	-0.9
22 Transportation equipment	0.0	2.9	-2.5
23 Electrical products	1.1	1.2	-0.1
24 Nonmetallic mineral products	0.3	0.3	0.1
25 Petroleum and coal products	-0.4	-0.2	-0.1
26 Chemicals	0.4	1.4	-0.8
27 Miscellaneous manufacturing	0.6	0.6	0.1
28 Construction	1.0	1.1	-0.0
29 Transportation and storage	-1.8	-2.4	0.7
30 Communications	2.2	5.1	-2.2
31 Electric power and gas	-1.3	-0.6	-0.7
32 Wholesale trade	-1.9	-0.7	-1.2
33 Retail trade	0.1	0.0	0.1
34 Finance, insurance, and real estate	-2.1	1.2	-3.1
35 Education and health	-0.0	0.0	-0.0
36 Amusement and recreation	0.3	0.4	-0.0
37 Services to business	-6.6	-2.5	-4.6
38 Accommodation and food	-0.1	0.3	-0.3
39 Other personal services	-0.6	-0.4	-0.2
40 International trade	1.7	0.0	1.7
Aggregate	0.05	0.42	-0.33*

*The aggregate substitution output effect growth rate would equal -0.38 per cent, if the international trade modification were excluded.
SOURCE Based on data from Statistics Canada.

negative impacts on economy-wide productivity growth from this particular source. The data in the first column come directly from Table A-3, while those in the second column underlie the productivity estimates in Table 5-7, (column 3). Since the first column covers a 15-year time period, we should expect *ceteris paribus* the magnitude of the particular output effects in this column to be at least three times the magnitude of the corresponding output effects in the second column. Indeed, the magnitudes in the first column may be even larger than this expectation, since the underlying weights of direct labour coefficient have typically fallen over the whole period 1961-78. Nevertheless, the figures in the second column, 1973-78, are generally of the same order of magnitude as those in the first column with reference to the four important intermediate output industries. We regard this result as one of the key characteristics of the productivity stagnation period: there is a dramatically increased industrial consumption of intermediate services contracted out (such as the four listed service inputs), but this phenomenon is not balanced, generally speaking, by corresponding reductions in direct labour employed or by reduced consumption of other intermediate inputs.

Table 5-8

Associated Changes in Total Labour Requirements Contributed by Substitution Output Effects, in Man-Years per One Million Dollars* of Output, Four Industries, 1961-76 and 1973-78

	1961-76	1973-78
30 Communications	+11.6	+10.3
32 Wholesale trade	+12.4	+ 4.7
34 Finance, insurance, and real estate	+ 0.8	+ 9.1
37 Services to business	+30.3	+23.6

*Constant 1971 dollars.
SOURCE Tables 5-7 and A-3.

How shall we explain this distinguishing phenomenon? Clearly, we need further disaggregation of the four listed intermediate service industries in order to be more precise. This is discussed in the next chapter. For the present, though, we leave the reader with the following thoughts. Has accelerating industrial computerization resulted in productivity losses during the "learning period" rather than in productivity gains, at least in the medium term? Also, lurking behind the scenes is the all-pervasive influence of inflation on productivity growth. An economy experiencing relatively high rates of inflation is characterized by increased financial transactions and by increased consumption of business accounting and consulting services, much of which is now computer-based.

To conclude this chapter, it should be stressed that there are other features of the Canadian productivity stagnation period that also deserve emphasis. For example, it is clear that Agriculture and the mining industries have experienced technological and natural resources changes that have led to a sharp productivity slowdown and stagnation in these particular sectors over the whole 1961-78 period. Some of these features are mentioned in the next chapter, where the orientation is more forward-looking.

6 Conclusion

The text of this study concentrates mainly on explaining the nature and significance of the new (alternative) approach to Canadian productivity analysis. It comprises many statistical tables illustrating the productivity estimates for various time periods. It also includes some exercises that can further clarify the nature of the alternative approach. It should be evident for many readers that this approach requires a deliberate reorientation of thinking about the notion of productivity, particularly for those who have worked with traditional productivity concepts for many years. It therefore seems important to separate the explanation of the new productivity measurements from the discussion of potential policy implications. Indeed, in this way, the reader who has followed the development has the opportunity to form his or her own interpretations for economic policy from the material available. Nevertheless, it is still beneficial to include in this conclusion some fairly specific guidelines concerning Canadian industrial and productivity policy implications. Most of this chapter is therefore devoted to collecting and outlining such guidelines. It contains also a recapitulation of the key properties of productivity measurement characterizing our new approach, together with a final section on suggested future research directions.

Productivity Measurement Issues: A Recapitulation

The outstanding feature of the alternative approach is that all industrial productivity measurements are final demand-oriented, that is, productivity is measured with respect to deliveries to satisfy (final) consumption. This is in marked contrast to long-established, traditional productivity calculations, which are all industry-oriented, or simply production-oriented. Since, loosely speaking, total consumption in the economy equals total production in the economy, we should expect the two sets of productivity measures to coincide at the aggregate level. This condition is essentially satisfied, but the productivity measures disaggregated by industry can and do differ significantly.

The purpose of introducing an alternative approach, however, is not just to show that "different" measures are possible. Rather, it is argued in this study that the alternative approach yields productivity measures that possess highly desirable properties. On the other hand, there is no traditional productivity calculation that possesses all these properties. For example, one property, which we feel that a productivity measure should have, is an unambiguous definition of a productivity level at a point in time, as well as of productivity growth rates over time. Is this almost trivial property too much to ask for? We think not! Well-defined productivity levels are required to study interindustry shifts or changes in final demand composition. Disaggregated productivity levels are required to be consistent with well-known measures of a nation's standard of living. Yet the only traditional productivity measure capable of yielding unambiguous productivity levels among industries is the very simple one based on real value-added and labour employed. In this study, we show that the alternative approach creates a total labour productivity level for each and every industrial product delivered to satisfy final demand. This productivity measure accounts for physical capital replacement and all intermediate inputs, both domestically produced and imported, as well as labour; all nonlabour inputs are essentially transformed into their labour-embodied equivalents, so that all inputs have a common denominator – namely, labour. This is the feature that permits the calculation of well-defined productivity levels, as well as of productivity growth rates.

It is our impression that there also exists a certain uneasiness among economic statisticians regarding the meaning and validity of traditional multi-factor productivity growth rates. For example, does increased "capital intensity" of production necessarily raise productivity and, if so, in what particular sense? How can increased intermediate imports be brought into the traditional productivity calculus in a well-defined manner? Why do multi-factor productivity growth estimates for an industry simply aggregate all intermediate inputs or, perhaps, distinguish just two or three subaggregates? The answers to these questions are not clear to us. We do know, however, that these issues raise no problems for the alternative (I-O) approach to productivity analysis. The trick again is to transform all industrial inputs, both primary and secondary, into their labour equivalents. For example, if the construction industry, a major producer of physical capital, is undergoing a productivity decline within the industry, there is no reason to assume that increased industrial "capital intensity" will raise economy-wide productivity in any well-defined sense. The alternative approach will immediately recognize such a situation. Similarly, our methodology introduces an International trade industry; the labour equivalent of intermediate imports ultimately is derived from the labour embodied in a nation's export industries (subject to an appropriate adjustment to change in the international terms of trade). The explicit incorporation of International trade in a productivity analysis is essential for a nation such as Canada. We find that the integrated presence of International trade in the analysis has a significant impact on the productivity levels and growth rates of individual industries, though the economy-wide aggregated impact could be small.

Another feature of the alternative approach concerns the statistical issue of errors in measurement of real output. We know that real output in many industries, particularly in service industries, is difficult to measure and even define, because of the lack of meaningful output price deflators. Each industrial productivity growth rate of the traditional type is sensitive to such measurement errors occurring in any other industry as well as in its own industry. This means, for example, that even well-established manufacturing productivity growth rates are subject to some unknown measurement errors due to the industries' intermediate purchases of various service commodities; the latter real inputs are probably mismeasured over time. This could be a serious problem in statistical exercises designed to "explain" productivity growth or even simply to "observe" the industrial extent and intensity of a supposed aggregate productivity slowdown. The alternative approach methodology is not subject to this statistical measurement problem. Indeed, it is a most remarkable property of our total labour productivity growth rates[1] that the estimated growth rate of an individual industry is sensitive only to possible errors in measurement of its own real output; such measurement errors occurring anywhere else in the business sector do not affect the calculation of the individual industry's productivity growth, irrespective of industrial interdependence. This means, for example, that we have considerable confidence in the statistical accuracy of our estimated productivity growth rates for the manufacturing sector, which use the total labour productivity methodology (see applications in Chapters 3, 4, and 5). The methodology has a built-in self-correcting feature with respect to measurement error.

There is one other issue regarding productivity measurement that should now be mentioned. (The nontechnical reader may wish to skip this paragraph without loss of continuity.) It will be noted that the alternative approach is based almost entirely on statistical data derived from input-output tables and the closely related national accounts. This, by itself, is not peculiar, since traditionally measured productivity also utilizes and, in fact, simply aggregates (as intermediate inputs) the same collection of data for calculation purposes (at least, this is true for the Canadian statistical system). However, there are other, more sophisticated productivity measurements that also embody some theoretical assumptions, such as industrial profit maximization or industrial cost minimization. Utilization of such assumptions can lead to supposedly "sharper" and more profound productivity estimates. These assumptions play no role in our alternative approach, which is essentially accounting based and statistically based. It is our view that the validity of theoretical assumptions in applied statistical research must depend on the nature of the mechanism actually generating the available statistical data. In Canada, all industrial productivity research, particularly with economy-wide coverage of the business sector, is based on the same collection of highly processed and manipulated data, which in no meaningful way can claim to be generated by an economic mechanism satisfying either of the above-mentioned assumptions. Very briefly, there are two conflicting statistical problems. First, if the productivity levels of individual industries are measured at a crude industrial level (say, the two-digit level), then there exists a classical aggregation problem: nonlinear theoretical assumptions cannot match the simple, additive observed data for heterogenous aggregations of industries. Second, if the productivity levels of individual industries are measured at a fine industrial level (say, the four-digit level), then the units of observation may be sufficiently homogenous, but the units then largely represent "bits and pieces" of industrial firms (e.g., plants, establishments, ancillary units, headquarters, and so on). It would appear that the classical aggregation problem is now resolved. This is, however, an illusion, since the individual units in one industry are often linked by ties of firm ownership and control to individual units in other industries (the data are typically dominated by large multi-industry, multi-establishment firms or enterprises). While the firms may be profit maximizers or cost minimizers, there is no necessary reason to assume that the same assumptions hold for their observed individual component units (the problem of joint management and service costs, intrafirm transfer pricing arrangements, and so on). In any event, the basic available statistical data are subject to a series of adjustments and conventions carried out by the statistical authorities. Such processing and manipulation effectively preclude the validity of the suppositions used in economic theory.[2] Therefore, it is in a spirit free of theoretical assumptions that the present alternative approach to productivity analysis is performed.

Productivity Growth "Explanation"

Does the alternative approach to productivity measurement "explain" productivity growth? The answer to this question is no, and neither does any other productivity measurement! All we can really hope for is that the particular productivity measurement possesses reasonable and desirable properties (as mentioned earlier) and that the measurement technique conveys at least a potential for "explaining" the productivity growth process. At the same time, of course, a great deal depends on what precisely one means by the term "explanation." For example, traditional multi-factor industrial productivity studies often "explain" labour productivity growth by showing variables accounting for changes in capital intensity, energy intensity, intensity of other intermediate inputs, and so on. In the alternative approach of our study, all these variables have already been transformed into their labour-embodied equivalents. There is only one way in which true productivity can change, because all productivity changes ultimately become either labour-saving devices (productivity advances), or labour-dissaving devices (productivity regresses). We will show, however, later in this chapter, that this idea can be pushed even further; the particular technique used in this study for embodying the labour equivalents is not "sacred."

There is, nevertheless, a qualified sense in which Canadian productivity growth is "explained" in this study. This qualification arises in the productivity decomposition analysis of Chapters 3 and 5. Our basic calculation of industrial productivity growth is the total labour productivity growth rate, described at length in Chapter 2. This growth calculation involves changes in the total (direct and indirect) labour required by the Canadian economy to deliver one unit of a particular industry's product to satisfy final demand consumption. Since all industries in an economy are, to some extent, responsible for the total labour required, the measure by itself is not particularly revealing until we can trace the productivity change back to technological changes in the individual industries. Before continuing, two points should be made. When we say "not particularly revealing," this phrase is strictly with respect to so-called productivity growth "explanation." It will be shown later in this chapter that productivity growth "explanation" is not the only game in town! The second point is to clearly distinguish between productivity change and technological change. As used in this study, productivity change is a derived concept; there are various methods for measuring productivity change, and a good deal depends on their orientation. We favour a final demand orientation with labour as the ultimate sole primary factor (this is also discussed later). On the other hand, technological change is a primitive concept: it refers to any change in an industry's direct labour coefficient or set of intermediate input (including physical capital) coefficients, whether domestically produced or imported.

To return, therefore, to the main issue, this study does offer an "explanation" of productivity growth in an industry in the following sense: each industry's total labour productivity growth rate, over a particular time period, is decomposed into an (industry) own effects component and an (intermediate) input effects component of the productivity growth rate. The two components of the growth rate have distinct meanings and a natural economic interpretation in our context (see Chapter 3). Each component of the growth rate can itself be decomposed into at least two subcomponents, and each subcomponent is easy to identify with particular types of technological changes in each industry and in all industries. Indeed, one may go even further and examine the composition of the input effects component of the productivity growth rate "captured" by a particular industry's total labour productivity growth disaggregated by industry. Such examination involves consideration of the output effects associated with an industry, which themselves can be decomposed into various subterms, each with clear identifications regarding the technological change involved. A procedure of this nature is used in Chapter 5 in an attempt to identify some distinguishing characteristics of the Canadian aggregate productivity growth stagnation period, 1973-78. Whether or not this procedure can be called a productivity growth "explanation" is a philosophical point that we prefer not to debate.

The alternative approach to productivity growth analysis also creates an opportunity to "explain" productivity growth in a more conventional sense. This is illustrated at length in the research and development (R & D) exercise in Chapter 4. For many years, it has been the accepted wisdom that Canadian industrial R & D and Canadian industrial productivity growth are not directly related. This acceptance seems reasonable at the level of individual industries (see Economic Council, 1980, pp. 97-98). But in view of the importance attached to R & D in the economic literature describing technological change, it would seem advisable to probe more deeply for any significant relationship that may exist in the Canadian case. Indeed, the most recent active literature on the subject (see Scherer, 1982*a*, p. 226) stresses the critical distinction between the industrial origin of R & D and the industrial destination of R & D:

> Invention then flowed through a kind of input-output matrix from knowledge-rich originating industries to high-demand using industries.

Without repeating the content of Chapter 4, it is clear that the alternative (I-O) approach to industrial productivity growth and R & D change is a natural vehicle for tracing the impacts of direct and indirect technology flows between industries throughout the Canadian economy. Our empirical results concerning the connection between productivity growth and R & D growth are somewhat disappointing, probably as a result of the present poor quality of the Canadian R & D statistical data. But, for the first time, the results do show that Canadian intramural R & D expenditures can have a significant positive impact on Canadian industrial productivity growth (appropriately measured). The trick is to expose and capture all of the R & D technology flows that may, directly or indirectly, stimulate productivity growth. Since our measures of productivity growth are all-embracing in the sense that "all" inputs are accounted for in terms of their ultimate labour cost equivalents, it is a meaningful discovery to learn that R & D inputs still retain a significant impact over and above the "double counting" problem (see the discussion in Schankerman, 1981). In fact, our R & D experiments show the key importance of considering physical capital input as an intermediate commodity input. This result itself should not be surprising since, for many years, the theoretical literature has considered new physical capital investment as the prime embodiment of new technology and associated productivity advance. This "conjecture" is now confirmed by our empirical efforts using Canadian data. Our feeling, though, is that we have merely identified the tip of the iceberg and that improvements in both R & D statistical data and the basic methodology (see next sections) will reveal much more. In the meantime, for purposes of Canadian economic policy guidelines, it would seem beneficial to conclude that expenditures by Canadian industries for R & D can have a significant positive impact on productivity growth in Canadian industry; but the precise mechanism by which this occurs can be, and probably is, very indirect. In order to achieve significant results, any further work in this area in Canada must be especially sensitive to the full interindustry matrix portraying the flow of R & D technology.

Before turning to questions of Canadian industrial policy and related matters, there is one more point that should be clarified. It may surprise the reader to know that this point concerns an explicit limitation of the alternative approach to productivity calculus. The methodology of this study does not account for nor incorporate any estimation of what is known as "spillover effects." Although the term "spillover effects" can have various meanings, in the productivity context, the term refers to a situation whereby technological change within a particular industry has nonmarket external effects on technological change in another industry (see the discussion in Griliches, 1979). This phenomenon may well be important, but is very difficult to measure. A careful reading of the alternative approach to productivity measurement should reveal that all measurements are with respect to observed market (price) transactions or imputed market transactions (according to certain statistical conventions). More specifically, and with reference to the developments in Chapter 3, an industry's own effects component of the productivity growth rate, reflecting changes in its own set of technological coefficients, is not altered by technological changes occurring in any other industries by means of any nonmarket externalities. Thus, we prefer not to consider any of the interindustry impacts of R & D on productivity growth mentioned in the preceding paragraph as industrial spillover effects.

Canadian Industrial Policy and All That

Contrary to traditional presuppositions, "explaining" productivity growth is not the only productivity game in town. The alternative approach to productivity analysis opens up some new economic possibilities that traditional methods cannot handle. In this section, we discuss this new potential under the general heading of "industrial policy," for lack of a better word.

It is mentioned in Chapter 1 that the alternative approach defines an interpretation of productivity trends and analysis based more on economic welfare, compared with standard measures. The reason for this should now be clear: the basic productivity results are all with respect to industrial production and deliveries to satisfy final demand consumption. Raising industrial productivities with reference to final consumption should be the ultimate economic welfare objective of any Canadian industrial productivity policy (this point is further developed below). Now it is true that any technological changes that are ultimately reflected in productivity growth must originate within an industry. This, presumably, has been the prime motivation for the long-established tradition of industry-oriented productivity studies. But these studies, we shall see, are self-limiting in an important sense. For example, suppose we wish to increase total labour productivity growth with respect to final consumption of domestically produced food and beverages. Food consumption is an important component of final demand, and receives a correspondingly large weight in the consumer price index; consumer price inflation will be significantly affected by (all-embracing) total labour productivity change with respect to the final consumption of domestically produced food and beverages (this is also further developed later). The standard recommendation in this case, based on industry-oriented productivity analysis, would then be that technological changes and productivity advances should be stimulated in Canada's Food and beverage industry. The alternative approach, based on final demand-oriented productivity analysis, recognizes that this recommendation is only one possibility. We may equally well concentrate on technological changes and productivity improvements in Agriculture or in Transportation and storage. Why? Because we know, from an analysis of input-output effects, that both of these industries have a large potential for contributing favourably to total labour productivity growth with respect to final consumption of Food and beverage commodities. In fact, our 1961-76 productivity analysis shows that Agriculture alone was primarily responsible for the total labour productivity growth rate (3.9 per cent) experienced by Food and beverages during this period (see Table 3-1 and particularly Table A-4). Indeed, the subperiod analysis of Chapter 3 in Tables 3-3, 3-4, and 3-5 shows that this particular source of productivity gain has now largely dried up, and Canada must look elsewhere for such productivity advances in the future (see also the Tables 5-1 to 5-8 covering the most recently observed period, 1973-78).

Thus, the alternative economic welfare approach to productivity permits us to evaluate a range of possible options to attain a given productivity objective. We do not claim that this is the first study to show that technological advances in Agriculture can help keep down consumer prices for food and beverages! Our emphasis here is to spell out and quantify the precise nature of such industrial interdependence in a framework for productivity analysis. It is now possible to see why industries dealing in intermediate commodities (i.e., industries that deliver most of their output to intermediate demand) can have a special status in this study. Consider first an industry whose characteristic product is almost completely delivered to final demand (i.e., a final goods industry). This industry's technological change can only affect productivity levels with respect to its own particular product. On the other hand, an industry whose characteristic product is completely delivered to intermediate demand cannot change the productivity level of its own product as delivered to final demand, because such deliveries do not exist! In this case, technological advances within this intermediate goods industry show up, in our calculations, as indirectly raising productivity levels in final demand components that are characteristic of other industries (i.e., industries to which the intermediate good is directly or indirectly delivered as an industrial input). But does all this make intermediate goods industries "special" from an economic welfare viewpoint? We think it does, as the example in the preceding paragraph shows. More generally, the situation can be described as follows.

Suppose we are interested in raising economic welfare. In a productivity context, suppose further that this involves raising productivity levels with respect to each and every important final demand component (the important components in Canada are given below in Tables 6-2 and 6-3). In essence, we might call this a balanced productivity growth path with a final demand viewpoint.[3] Then the existence of intermediate goods industries presents us with a set of options for reaching this goal. For example, if all industries were completely integrated vertically, there would be no choice: to reach the stated goal, we must raise productivity levels within each and every important industry without exception. But we know that technological advances within any important intermediate goods industry can raise productivity over a wide range of industrial deliveries to final demand. In fact, this phenomenon of dispersion of productivity growth is demonstrated at length in Chapter 3 (see particularly Table 3-7). Thus, the existence of important intermediate goods industries and the possibility of stimulating technological advances within any of these industries create the opportunity to bypass technological change bottlenecks that may occur within important final goods industries. (This latter statement holds so long as the final goods industries are not vertically integrated, a condition that certainly holds for all business sector industries in this study.) The trick, again, is to always focus on industrial productivity growth with respect to final consumption – our economic welfare objective. Traditional analysis of productivity growth, aside from the measurement issues discussed in the first section of this chapter, makes the mistake of always focusing on the means (production-oriented analysis) rather than the ends (consumption-oriented analysis). In the process of making this distortion, the "means" become identified with the "ends," leaving us all in a veritable strait jacket! In this study, the alternative approach to productivity focuses directly on the "ends" (economic welfare objective as defined) with the result that the "means" become much more flexible.

With this background, we can now briefly outline some Canadian industrial policy guidelines that stem from the time-series analysis. It appears to us that the study reveals a rather special historical role for two Canadian industries – namely, Agriculture (no. 1) and Transportation and storage (no. 29). Both of these industries deliver most of their commodity output to intermediate demand, and both have experienced significant technological advances during the 1961-76 period (especially 1961-71). The result is that the intermediate output (productivity) effects associated with the two industries have been remarkably large and have dominated those of all other industries (see a more detailed account in Chapter 3 and the decomposition of industry output effects in Table A-3). Most important, the two industries have strong forward linkages with the major components of final demand (see Table 6-2 and also the complete matrix of input-output effects in Table A-4). For our economic welfare purposes, all this means that the two Canadian industries have succeeded in maintaining a reasonably balanced productivity growth with respect to important final demand components during the historical time period.[4] At least, this was the situation until the early 1970s. The productivity analysis of Chapter 5, for the most recent period observed, 1973-78, clearly shows that the honeymoon is over (see especially Tables 5-5 and 5-7). Whether or not technological advances in Agriculture and Transportation and storage can be revived at a pace similar to that during the historical period is a question that we are not prepared to answer. There is, however, concrete evidence that the two industries have become relatively less important in terms of the magnitude of their forward linkages to the key ultimate components of final consumption. Therefore, if Canada is interested in restoring a reasonably balanced productivity growth path with reference to final consumption, it seems advisable to look elsewhere. In effect, we are seeking an alternative to the standard recommendation: Canada must "learn" to increase productivity growth in (all or most) important industries, even though (some of) these industries may be characterized by technological bottlenecks.

Judging from the projection exercise in Chapter 3 (Table 3-7) and particularly the analysis in the last section of Chapter 5 (Table 5-7), it appears to us that there are three Canadian industries that have a potential in the future for playing a role in raising productivity, as did Agriculture and Transportation and storage during the historical period. One of these industries – namely, Communications (no. 30) – is already stimulating balanced productivity growth. All indications are that Communications is a rapidly growing intermediate service industry, having significant technological advances and contributing corresponding productivity growth to all important components of final consumption. For a more precise analysis, we really need a finer disaggregation of the industries within communications; this will be forthcoming in the new Canadian 1980 Standard Industrial Classification (SIC). The case for the other two industries – namely, Finance, insurance, and real estate (no. 34) and Services to business (no. 37) – is not as strong. In fact, at the present time, their net official contribution to Canadian aggregate productivity growth is actually negative. Nevertheless, the potential for stimulating balanced productivity growth with respect to final consumption certainly exists. Many important Canadian industries (of all types) are now contracting out their financial and other business services, which were formerly performed in-house. In an era of relatively high rates of inflation, there is also an additional (production) requirement for such intermediate services (discussed again in the next section). Since both the substitution and secular trends in this direction are already clear, the pay-off from technological advances in these two industries becomes exceptionally large in terms of the objective for balanced productivity growth. Once again, more precise guidelines really call for a finer disaggregation of industries, particularly with respect to such components of Services to business as Computer software services and Computer rental equipment services. One might then examine the hypothesis put forward by the Organisation for Economic Co-operation and Development (1981) that accelerated industrial computerization may, in its initial stages, lead to declines in aggregate productivity growth. The OECD report argues that this phenomenon, wherein computerization is at first more "addition" than "substitution," is found in Canada as well as in many other industrial nations. However, this characteristic initial stage may be over as of 1982, and associated productivity growth can be expected to be restored in the future.

There are other general guidelines for industrial policy that can be inferred from the analysis. Some of these are closely related to suggested directions for future research, and so are best discussed in the next section.

Future Research Directions

There are various directions towards which future productivity research, along the lines of the alternative approach, can proceed. In outlining some of these directions, it should be made clear that this study is not merely a prelude to further research. We believe our present results are sufficiently concrete and economically meaningful to stand on their own. It is true, nevertheless, that the empirical results can be improved and refined in various ways. The following outline of suggested refinements is kept deliberately brief.

The first direction concerns a point made earlier in this chapter, which stresses that our new approach to productivity is "all-embracing." All industrial inputs are transformed into a common denominator – their labour-embodied equivalents – so that we may unambiguously refer to positive productivity growth as ultimately the result of labour-saving technological change. This statement is certainly the goal of our approach, but the goal has not been reached by the productivity estimates given so far in this study. The main discrepancy arises in our treatment of physical capital input; only input involving physical capital replacement (depreciation) has been correctly accounted for. There remains the industries' net physical capital stocks in place and their associated capital services. (This is precisely why a variable for the growth rate of net physical capital stock is included in the R & D regression equations of Chapter 4.) It turns out, however, that the contribution of this input can also be translated into a labour-embodied equivalent, given the necessary statistical data. The trick is to regard the production contribution of gross physical capital stock as consisting of two elements: 1/ depreciation and replacement expenditures, and 2/ interest (debt capital) and dividend (equity capital) payments from the operating surplus on the production account. The two elements together would represent the gross rental (opportunity) cost of physical capital stock, if it were rented.[5] The first element has already been embodied in our productivity calculations. The second element can also be embodied (and, therefore, transformed into a labour cost equivalent) by using a technique similar, but not identical, to that used for the first element. This technique implicitly gives most of the weight in the second element to the construction component of physical capital, whereas it gives most of the (labour cost equivalent) weight in the first element to the machinery and equipment components. Our suggested methodology for handling this problem is given in the final section of Appendix A.

It should be noted that the idea of considering physical capital input as, ultimately, a produced intermediate commodity input, rather than as an "original" primary input, is often associated with the name of Sir Roy Harrod. In our view, this idea is of considerable importance in avoiding the confusion over neoclassical assumptions concerning productivity, whereby physical capital input is considered primary; see also the discussion in Peterson (1979) and Rymes (1982). In fact, an integrated approach to national accounting, which was suggested very recently, calls for a symmetrical treatment of physical capital rental and physical capital interest payments as intermediate purchases in business sector production accounts; see Ruggles and Ruggles (1982). This is similar in spirit to our extended methodology, although further adjustments will be required, in future research, to make our methodology consistent with national accounting constraints.

Table 6-1 contains estimates of productivity levels and growth rates by industry for 1973-78, calculated using total labour productivity, but now with the additional feature explained in the preceding paragraph. The calculations in this table should be compared with those in Table 5-1. Clearly, all total labour productivity levels for each industry in the new table are lower than the corresponding levels in Table 5-1, since the new calculations embody an additional labour cost equivalent for each industry's deliveries to final demand. Two industries – Communications (no. 30) and Electric power and gas (no. 31) – are most affected; the impacts of the additional labour costs are not industrially uniform. The productivity growth rate estimates, however, are only slightly affected. The results in Table 6-1 should be regarded as experimental, since the statistical data base available at present for such calculations is incomplete (see statistical assumptions in Appendix A). Therefore, this is a first direction for future research. It is hoped that more complete data, including inventory stock matrix data, will soon be available to perform calculations of the type shown in Table 6-1 at regular intervals.[6]

A second direction concerns the relative magnitudes of final demand components among industries. The importance of this subject is evident from the defined economic welfare objective of the alternative approach. Moreover, as indicated and proved in Chapter 2, aggregate (business sector) productivity levels and growth rates are correctly formed by using the final demand component weights to aggregate the productivity levels disaggregated by industry. It may, therefore, be of some interest to explicitly show these weights, and this is done in Table 6-2 for the two comparable years, 1961 and 1976. At first glance, these final demand weights may look rather strange, if not peculiar. We must, however, recall what is actually included in this study's final demand:

Table 6-1

Extended Total Labour Productivity Level and Average Annual Growth Rate, 40 Industries, 1973-78

	Level		Average growth rate 1973-78
	1973	1978	
	(Dollars*)		(Per cent)
1 Agriculture	6,564	6,458	-0.3
2 Forestry	10,910	10,888	-0.0
3 Fishing and hunting	5,748	6,417	2.2
4 Metal mines	13,640	12,417	-1.9
5 Mineral fuels	18,252	12,894	-6.7
6 Nonmetal mines	13,507	12,403	-1.7
7 Services to mining	10,883	11,789	1.6
8 Food and beverages	9,275	9,244	-0.1
9 Tobacco products	10,612	10,820	0.4
10 Rubber and plastics	11,866	12,428	0.9
11 Leather products	8,209	9,574	3.1
12 Textiles	10,410	11,837	2.6
13 Knitting mills	9,385	11,886	4.8
14 Clothing	8,270	9,768	3.4
15 Wood products	9,444	9,977	1.1
16 Furniture and fixtures	9,817	9,997	0.4
17 Paper and allied products	11,210	11,286	0.1
18 Printing and publishing	10,825	11,952	2.0
19 Primary metals	12,304	11,520	-1.3
20 Metal fabricating	11,640	11,563	-0.1
21 Machinery	11,729	12,926	2.0
22 Transportation equipment	12,876	13,742	1.3
23 Electrical products	11,856	12,829	1.6
24 Nonmetallic mineral products	12,499	12,568	0.1
25 Petroleum and coal products	13,624	12,627	-1.5
26 Chemicals	12,530	12,993	0.7
27 Miscellaneous manufacturing	10,599	11,400	1.5
28 Construction	12,083	11,772	-0.5
29 Transportation and storage	11,871	11,555	-0.5
30 Communications	9,342	12,438	5.9
31 Electric power and gas	12,971	12,455	-0.8
32 Wholesale trade	11,432	11,224	-0.4
33 Retail trade	7,370	7,382	0.0
34 Finance, insurance, and real estate	16,304	15,821	-0.6
35 Education and health	16,918	16,103	-1.0
36 Amusement and recreation	7,902	9,277	3.3
37 Services to business	10,394	9,800	-1.2
38 Accommodation and food	7,786	7,955	0.4
39 Other personal services	5,538	5,225	-1.2
40 International trade	12,269	12,334	0.1

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada.

personal consumption expenditures,[7] business net physical capital formation, and total government net expenditures (there is also an international trade balance with an export pattern "weight," but this term is typically very small; see Appendix A).[8] Thus, Canadian exports and all intermediate imports are essentially endogenous and absent from final demand; so are business physical capital replacement expenditures. Note that government expenditures are net with respect to government revenue from commodity sales (this is discussed further). Most important, all final demand components of the 39 listed industries are with respect to domestic production. All Canadian imports that satisfy final demand are aggregated and shown as final demand for International trade (no. 40). It therefore makes a considerable difference whether final demand for, say, textiles is satisfied by domestic production of Textiles (no. 12) or by imports through International trade (no. 40). It should now be clear why intermediate goods industries, including Canadian export industries, receive so little direct weight in final demand. It should also be clear why International trade has become increasingly important in final demand – mainly because of the trend towards increasing import coefficients (the share of imports in total Canadian commodity demand for domestic use).

Table 6-2

Actual Distribution of Final Demand Weights, 40 Industries, 1961 and 1976

	1961 weight	1976 weight
	(Per cent)	
1 Agriculture	0.8	0.8
2 Forestry	0.2	0.0
3 Fishing and hunting	0.0	0.0
4 Metal mines	0.2	0.1
5 Mineral fuels	0.1	0.0
6 Nonmetal mines	0.1	0.0
7 Services to mining	0.3	0.0
8 Food and beverages	11.0	7.8
9 Tobacco products	0.8	0.5
10 Rubber and plastics	0.4	0.5
11 Leather products	0.7	0.4
12 Textiles	0.5	0.7
13 Knitting mills	0.5	0.4
14 Clothing	2.5	1.9
15 Wood products	0.0	0.0
16 Furniture and fixtures	0.9	0.8
17 Paper and allied products	0.3	0.1
18 Printing and publishing	1.1	1.1
19 Primary metals	0.0	0.0
20 Metal fabricating	0.8	0.9
21 Machinery	0.0	0.3
22 Transportation equipment	2.4	1.4
23 Electrical products	1.3	1.6
24 Nonmetallic mineral products	0.2	0.1
25 Petroleum and coal products	1.7	1.5
26 Chemicals	1.2	1.0
27 Miscellaneous manufacturing	0.8	0.9
28 Construction	20.8	18.5
29 Transportation and storage	3.2	3.5
30 Communications	1.4	2.7
31 Electric power and gas	1.6	2.3
32 Wholesale trade	3.0	3.7
33 Retail trade	12.2	11.7
34 Finance, insurance, and real estate	9.8	10.9
35 Education and health	3.0	3.2
36 Amusement and recreation	0.9	1.3
37 Services to business	1.2	2.0
38 Accommodation and food	5.8	5.3
39 Other personal services	1.5	0.9
40 International trade	6.4	11.7
Total	100.0	100.0

SOURCE Based on data from Statistics Canada.

From Table 6-2, we can observe that final demand, as defined, is largely concentrated in a few industrial components: Food and beverages (no. 8), Construction, including repair construction (no. 28), Retail trade (no. 33), Finance, insurance, and real estate (no. 34), Accommodation and food (no. 38), and International trade (no. 40). From this analysis, two comments follow from the viewpoint of future research.

First, the industrial classification disaggregation used in this study does not appear to be entirely appropriate. Indeed, the selected classification seems more production-oriented than consumption-oriented! Therefore further research, using the alternative approach to productivity, should attempt a finer disaggregation of the important final demand components. (It is particularly desirable to disaggregate Finance, insurance, and real estate.) This is certainly statistically feasible except, perhaps, for Retail trade (no. 33). Even International trade can be disaggregated using a procedure outline in Appendix A. For Canada, a suggested disaggregation might include: Canada-U.S. trade (excluding the autopact), the Canada-U.S. Automotive Agreement (the autopact), and Canada-Rest-of-the-world trade.

The second comment concerns total government net expenditures in final demand. The effect of netting government revenue from commodity sales, mentioned above, is to make some of the potentially important final demand service components smaller than "normal": this applies particularly to Education and health (no. 35) and Other personal services (no. 39). Therefore, in future research, it appears desirable to create a distinct government services industry with the pattern of government gross current and capital expenditures serving for the industry's intermediate commodity inputs. The outputs of government services are distributed to other industries (intermediate demand) and final demand, according to calculated government production coefficients (the ratio of government revenue production to total Canadian demand for domestic use and foreign use). Indeed, such treatment is somewhat analogous to our present treatment of International trade except that: 1/ government production is not fictitious and requires direct labour inputs, and 2/ only part of government gross expenditures become endogenized – only enough to "balance" government (production) revenue from commodity sales. This procedure is, again, entirely feasible, but some minor data pieces are still missing (which could be approximated). If this procedure were performed, the industrial productivity results of this study would be only slightly affected, since most government services are directed towards final demand. There would, however, be some changes in the estimated Canadian aggregate productivity growth rates. In any event, the weights for the final demand components would certainly look more "normal."[9]

Table 6-3

(Labour) Transformed Distribution of Final Demand Weights, 40 Industries, 1961 and 1976

	1961 weight	1976 weight
	(Per cent)	
1 Agriculture	1.6	1.3
2 Forestry	0.2	0.0
3 Fishing and hunting	0.0	0.0
4 Metal mines	0.1	0.0
5 Mineral fuels	0.0	0.0
6 Nonmetal mines	0.0	0.0
7 Services to mining	0.2	0.0
8 Food and beverages	15.1	9.0
9 Tobacco products	0.9	0.5
10 Rubber and plastics	0.5	0.4
11 Leather products	1.0	0.5
12 Textiles	0.7	0.7
13 Knitting mills	0.7	0.4
14 Clothing	3.3	2.3
15 Wood products	0.0	0.0
16 Furniture and fixtures	1.0	0.9
17 Paper and allied products	0.3	0.2
18 Printing and publishing	1.0	1.1
19 Primary metals	0.0	0.0
20 Metal fabricating	0.8	0.8
21 Machinery	0.0	0.3
22 Transportation equipment	2.4	1.1
23 Electrical products	1.3	1.5
24 Nonmetallic mineral products	0.2	0.1
25 Petroleum and coal products	1.3	1.2
26 Chemicals	1.1	0.9
27 Miscellaneous manufacturing	0.9	0.9
28 Construction	17.8	16.4
29 Transportation and storage	3.3	3.1
30 Communications	1.6	2.4
31 Electric power and gas	1.0	1.5
32 Wholesale trade	2.7	3.3
33 Retail trade	16.7	17.1
34 Finance, insurance, and real estate	4.6	7.2
35 Education and health	1.7	2.3
36 Amusement and recreation	0.9	1.6
37 Services to business	0.9	2.0
38 Accommodation and food	5.8	7.9
39 Other personal services	1.7	2.0
40 International trade	6.4	9.8
Total	100.0	100.0

SOURCE Based on data from Statistics Canada and from Tables 2-1 and 6-2, using methodology explained in Chapter 2.

By putting Tables 6-1 and 6-2 together,[10] it is easy to infer an additional industrial policy guideline. We know that changes in final demand composition could affect aggregate productivity levels and growth rates. In fact, an exercise along these lines, based on historical data, is performed in Chapter 3. Suppose the composition of incremental final demand can be influenced by government industrial policy. Then, if it is our objective to raise aggregate productivity levels, and therefore the aggregate growth rate, such policy should be slanted towards stimulating industrial final demand components with relatively high total labour productivity levels. Conversely, policy should be slanted away from stimulating final demand components with relatively low total labour productivity levels.[11] This almost trivial policy exercise shows the distinct advantage of having a productivity calculus that yields industrial productivity levels and growth rates that are economically meaningful and unambiguous. Table 6-1 for the year 1978 shows, somewhat surprisingly, that Education and health (no. 35) has the highest total labour productivity level, closely followed by Finance, insurance, and real estate (no. 34). The total labour productivity level of International trade (no. 40), which ultimately reflects total labour productivity levels in Canada's export industries, is above average. On the other hand, beware of stimulating final demand with relatively large retail trade margins, as evident from the low total labour productivity level of Retail trade (no. 33). Other personal services (no. 39) is the labour productivity growth "*persona non grata*."[12]

One topic that usually turns up when analysing productivity growth is the question of accounting for entirely new commodities and industries. Officially speaking, this is not a statistical problem in our context, since the Statistics Canada data classification base is completely comparable over the whole 1961-78 period. Therefore, one might argue that the solution to the "problems" of new commodities and changing quality commodities is merely disaggregation, even to the finest level! We do not accept this "solution," because we feel that the Statistics Canada system of complete comparability is, in part, a statistical illusion. Indeed, we hope that, once the new revised 1980 SIC is in force, the input-output classification and data base for the 1980s will not be comparable with those for the 1960s and 1970s. How, then, can productivity growth time-series analysis proceed? The correct solution to this substantive problem is a strong dose of the Leontief double inversion procedure, as given in Leontief (1967) and further expounded in Postner (1982, pp. 236-37). It is interesting to observe that the alternative approach to productivity analysis can make very natural use of this procedure. This means that real problems regarding dramatic technological changes and entirely new commodities and industries present no unsurmountable obstacles to the productivity methodology of this study. In fact, our methodology is entirely consistent with the solution to these problems. Needless to say, traditional measures of productivity do not possess this property.

Our final direction for future research concerns the complex and contemporary issue of the connection between inflation and productivity. There is growing evidence that aggregate price inflation and aggregate productivity growth interact in full-feedback mode (see Jarrett and Selody, 1982, and also P. Clark, 1982). This issue cannot be clarified and resolved until the analysis becomes more disaggregated. After all, the anecdotal and theoretical arguments supporting such a connection are "industrially" disaggregated in nature. There is, as yet, no quantitative analysis of the various specific economic mechanisms through which, for example, accelerated inflation or even sustained inflation is supposed to reduce productivity growth. In the final section of Chapter 5, we present some statistical evidence that could be interpreted as identifying a symptom of the "disease" attacking the connection between inflation and productivity during Canada's productivity stagnation period, 1973-78. This evidence is far from conclusive or even satisfactory. Put bluntly, the key problems run something like this. 1/ How does excessive attention to cash balances and debt management interact with observed productivity growth? 2/ What is the effect of shorter investment planning horizons and increased financial renegotiations on observed productivity levels? 3/ Can inventory and working capital holdings be brought into the productivity calculus? 4/ What is the relation between purely financial innovations and technological change that affects production? Clarifying problems of this nature requires moving out of the conventional frameworks of production and consumption accounts to incorporate transactions involving income and outlays and financial capital accounts. Such movement can only lead to new insights if the production and consumption sets of accounts are fully integrated with the financial set of accounts at a level suitably disaggregated by industry. There are some severe statistical problems in the way of full integration. But working with the alternative approach to productivity analysis is already a step in this direction, since the corresponding data base is a key ingredient of a full-fledged integrated analysis.

Appendixes

A Mathematics

The main purpose of this appendix is to provide the mathematical models and proofs underlying this study. It is essentially self-contained, so some readers may prefer to go directly to this appendix before reading the text. It is assumed, however, that readers are already acquainted with the Canadian input-output (I-O) statistical system; a good introduction is Statistics Canada (1969). The Canadian I-O system is actually very similar to the basic United Nations System of National Accounts (1968), and so is the most recent United States I-O statistical system, described in Ritz (1980). As well as giving proofs or more formal statements of propositions offered in the text, this appendix also presents a number of advanced aspects of productivity growth analysis that are not directly referred to in the main text (though some of these aspects underlie certain arguments in Chapter 6). It is also appropriate here to illustrate the advanced aspects of productivity analysis with special tables. Finally, the appendix considers briefly some possible future extensions of productivity growth analysis that naturally follow from our initial efforts.

Basic Input-Output Model

We first present the basic model underlying our new approach to productivity estimation. The model is stated in a relatively simple form to avoid "swamping" the reader with a multitude of symbols. Later, we show how the productivity model can be made more complete, if this is desired. The basic model consists of the following six equations:

$$(A.1)\quad g = Dq$$

$$(A.2)\quad q + m = Bg + Cg + e + x$$

$$(A.3)\quad n = Ng + f$$

$$(A.4)\quad m = \hat{\mu}(q + m - x)$$

$$(A.5)\quad x = a(i'x)$$

$$(A.6)\quad i'x = i'm + i^{*\prime}n + \beta$$

Equation (A.1) shows the transformation of domestic competitive commodity output vector q into the domestic industry gross output vector g by means of the rectangular output coefficient matrix D. Equation (A.2) states that total supply of competitive commodities (the summation of domestic commodity output q and competitive import vector m) equals total demand for these competitive commodities (summation of current intermediate input demand Bg using the rectangular input coefficient matrix B, fixed capital replacement input demand Cg using the capital replacement coefficient matrix C, net final demand for domestic use vector e, and the competitive commodity export vector x). Equation (A.3) deals with noncompetitive commodities all of which are imported; the total supply of noncompetitive import vector n equals[1] total demand for noncompetitive commodities (the summation of current intermediate input demand Ng using the input coefficient matrix N, and final demand for domestic use vector f). Equation (A.4) relates competitive imports m to total demand for domestic use vector $(q + m - x)$ by means of a diagonal matrix of competitive import coefficients $\hat{\mu}$. Equation (A.5) simply rewrites the commodity export vector x as the pattern coefficient vector a (with elements that sum to unity) multiplied by the total of all exports $i'x$. Equation (A.6) is a balance-of-trade relationship; total exports equal total competitive imports plus total noncompetitive imports plus a trade balance scalar β, where the different dimensions of the two import vectors m and n are distinguished by the summation notation row vectors i' and $i^{*\prime}$.

Although the basic model could be used in various ways, for the purposes of this study, we are interested in obtaining a solution for the domestic industry gross output vector g and total imports, $i'm + i^{*\prime}n$, in terms of the exogenous vectors e and f and the trade balance scalar β. The solution procedure is as follows. Using equations (A.2) and (A.4), we have:

$$\text{(A.7)} \quad m = \hat{\mu}(B + C)g + \hat{\mu}e$$

Substituting (A.7) in (A.2) and also using equation (A.5), we derive:

$$\text{(A.8)} \quad g = (I - \hat{\mu})(B + C)g + (I - \hat{\mu})e + a(i'x)$$

From equations (A.3) and (A.7), it follows that:

$$\text{(A.9)} \quad i'm + i^{*\prime}n = i'\hat{\mu}(B + C)g + i^{*\prime}Ng + i'\hat{\mu}e + i^{*\prime}f$$

Then using (A.1) and (A.6) in equation (A.8), we obtain:

$$\text{(A.10)} \quad g = D(I - \hat{\mu})(B + C)g + Da(i'm + i^{*\prime}n) + D(I - \hat{\mu})e + Da\beta$$

Thus, equations (A.9) and (A.10) represent two vector equations showing the relationship between the endogenous variables g and $i'm + i^{*\prime}n$, and the exogenous variables e, f, and β. All coefficients matrices and vectors are treated as constants. It is now convenient to rewrite the system (A.9) and (A.10) in terms of the notation introduced in Chapter 2 of this study. There we had:

$$\text{(2.1)} \quad X = AX + Y$$

or, equivalently, in partitioned form, we could write:

$$\text{(A.11)} \quad \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} + \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix}$$

Then, to relate the system (A.9) and (A.10) to (A.11), it is straightforward to see that:

$$X_1 = g$$

$$X_2 = i'm + i^{*\prime}n$$

$$Y_1 = D(I - \hat{\mu})e + Da\beta$$

$$Y_2 = i'\hat{\mu}e + i^{*\prime}f$$

and that:

$$A_{11} = D(I - \hat{\mu})(B + C)$$

$$A_{12} = Da$$

$$A_{21} = i'\hat{\mu}(B + C) + i^{*\prime}N$$

$$A_{22} = 0$$

Two comments are now in order. First, consider the grand summation of the final demand vector Y. We see that:

$$\text{(A.12)} \quad i'Y_1 + Y_2 = i'D(I - \hat{\mu})e + i'Da\beta + i'\hat{\mu}e + i^{*\prime}f$$

Then, since $i'D = i'$ and $i'a$ = unity, the summation becomes simply:

$$i'Y_1 + Y_2 = i'e + i^{*\prime}f + \beta$$

which is total net final demand for domestic use of competitive commodities ($i'e$) plus total final demand for noncompetitive commodities ($i^{*\prime}f$) plus the trade balance β. It is straightforward to see, from national accounting identities, that this grand summation also equals the total of all net domestic product originating in business sector industries valued at market prices (this follows from Statistics Canada, 1982*a*, pp. 10-13). Note that both final demand expenditures on competitive commodities ($i'e$) and industry domestic product are net of physical capital replacement and consumption allowances (see the term Cg in equation (A.2). Both final demand commodity expenditures and industry domestic product exclude primary inputs of final demand categories (Statistics Canada, 1982*a*).

The second comment relates to the balance-of-trade equation (A.6). The basic I-O model (A.1) to (A.6) is applied with all valuations expressed in constant 1971 prices. This assumption, however, must be relaxed for equation (A.6), which is more naturally represented in current prices rather than in constant prices. For applications with respect to the base year 1971, no changes are required. For all other years, the balance-of-trade equation (A.6), initially expressed in constant prices, is transformed into a balance-of-trade relation expressed in current prices by multiplying $i'x$ on the left-hand side of (A.6) by an adjustment scalar δ derived from:

$$(A.13)\quad \delta = \frac{(i'x)_c/(i'x)_o}{(i'm + i^{*\prime}n)_c/(i'm + i^{*\prime}n)_o}$$

where the subscript c denotes current prices and the subscript o denotes evaluation of the bracketed expression in constant (base year) prices. This is equivalent, in view of equation (A.5), to proportionally adjusting the export pattern coefficient vector a by the scalar δ. The adjustment affects both the A matrix through the submatrix $A_{12} = Da$ and the $Da\beta$ term in Y_1. In effect, the adjustment in (A.13) reflects changes in the international terms of trade between the base year 1971 and any other year. If $\delta > 1$, there is an improvement in the terms of trade between the base period and current period. The specific adjustment of the export pattern coefficient vector a is effected by setting $x = a^* (i'x)$ in equation (A.5) where $a^* = \delta^{-1}a$. Thus, $\delta > 1$ implies $i'a^* < 1$, and $\delta < 1$ (terms of trade deterioration) implies $i'a^* > 1$. The post-adjusted export pattern coefficient vector a^* is essentially, in the given model, the intermediate input coefficient vector column of the International trade industry after transformation by matrix D. (See also Leontief, 1946.)

The model described so far in this section is the one actually applied in the study. It is possible to extend the model in various directions. For example, the international trade relations embodied in equations (A.3), (A.4), (A.5), and (A.6) can be disaggregated according to bilateral trade rather than aggregated into total international trade. This may be of some relevance to Canada, where Canadian international trade divides naturally into Canada-U.S. trade and Canada-Rest-of-the-world trade. The extension of the basic model with each of the equations (A.3) to (A.6) replaced by two equations reflecting two bilateral trade relations is trivial to perform. Note that we will also need two distinct terms of trade adjustment scalars, δ_1 and δ_2, in this case. The model actually applied in this study implicitly assumes that Canadian international trade is multilateral rather than comprising a system of bilateral trades. Another possible extension concerns the treatment of re-exports. Our applied model simply ignores the distinction between domestic exports and re-exports in the total export vector x. A more refined treatment will feature an additional equation $x_m = \hat{\mu}_1 x$, where x_m represents re-exports and $\hat{\mu}_1$ is a diagonal matrix of re-export coefficients. Then equation (A.4) is replaced by:

$$(A.4a)\quad m - x_m = \hat{\mu}_0 (q + m - x)$$

following a suggestion of Statistics Canada (1969). If all operations are carried out, the four submatrices of matrix A now become:

$$A_{11} = D(I - \hat{\mu}_0)(B + C)$$

$$A_{12} = D(I - \hat{\mu}_1)a$$

$$A_{21} = i'\hat{\mu}_0 (B + C) + i^{*\prime}N$$

$$A_{22} = i'\hat{\mu}_1 a$$

Since the re-export coefficients μ_1 are all very small, a distinctive treatment of re-exports is indeed a refinement.[2]

In Chapter 2 of the text, it is shown that the vector system of equations:

$$(2.1)\quad X = AX + Y$$

is applied to yield a row vector of total (direct plus indirect) labour requirements per unit of output:

$$(A.14)\quad \lambda' = \ell' (I - A)^{-1}$$

where ℓ' is a row vector of direct labour coefficients. Each element of the vector ℓ' is simply the ratio of total labour employed to total gross output in each industry; the last element of the vector ℓ' is zero, since this element corresponds to the international trade exchange industry, which has no direct labour input. Indeed, from equation system (A.11), it is easily seen that the International trade industry "produces" imports $i'm + i^{*\prime}n$ by means of the transformed export pattern vector Da or Da^*. The estimation formula (A.14) is further developed in the next section. At this point, we can prove an assertion stated with respect to formula (A.14) in Chapter 3 – namely, the invariance property of the calculation. This property is best understood by considering the impact on calculation (A.14) of errors in measurement of the output price deflation in a subset of industries. This means that all base year data for 1971 are assumed correct, since all price deflators are identically equal to unity in that year. An error in the output price deflator for a particular industry affects the industry's direct labour coefficient and all intermediate input coefficients of that industry; all these coefficients are uniformly and proportionally affected in the same direction. But intermediate consumption of that industry's output by all other industries (and itself) are proportionally affected in the opposite direction, that is, the coefficients for the intermediate inputs of all industries with respect to consumption of the particular industry's output must also be adjusted to reflect the existence of errors in the measurement of the output price (deflator). All this can be expressed formally and, indeed, generalized.

Therefore, suppose that the set of business sector industries are divided into two subsets. The first set is initially free of measurement error; each industry in the second set is subject to price deflator measurement errors, and these errors can differ from industry to industry. Now suppose that all the required output price deflator adjustments are incorporated in order to yield real output measurements that are free of error. The problem, then, is to compare the results of two calculations for formula (A.14); the first calculation is simply the original:

$$\text{(A.14)} \quad \lambda' = \ell'(I - A)^{-1}$$

which embodies measurement errors as stated, and the second calculation contains all the required adjustments needed to correct and eliminate measurement errors. It is easily shown that the adjusted formula would then be:

$$\text{(A.15)} \quad \lambda^{*\prime} = \ell'T(I - T^{-1}AT)^{-1}$$

where T is a diagonal matrix stated in partitioned form:

$$\text{(A.16)} \quad T = \begin{pmatrix} I & O \\ O & \hat{k} \end{pmatrix}$$

and $\hat{k}$ is a diagonal matrix composed of positive nonunity elements in its diagonal array, each of which represents the adjustment factor needed to correct the incorrect output price deflator for the respective industries of the second set. By manipulating formula (A.15), we see that:

$$\text{(A.15}a\text{)} \quad \lambda^{*\prime} = \ell'T(T^{-1}T - T^{-1}AT)^{-1}$$
$$= \ell'T[T^{-1}(I - A)^{-1}T]$$
$$= \ell'(I - A)^{-1}T$$

Thus using (A.14) and (A.16), it is found that:

$$\text{(A.15}b\text{)} \quad \lambda^{*\prime} = \lambda'T$$

This means that the total (direct plus indirect) labour coefficients of the first set of industries are entirely unaffected by the presence of measurement errors in the second set of industries. On the other hand, the total labour coefficients for each of the second set of industries are affected by measurement errors, but only to the extent that a simple correction factor is required to adjust each of their own measurement errors, irrespective of measurement errors elsewhere. There is just one additional qualification needed. It is not realistic to treat the International trade "industry" as a potential member of the second set with a unique correction adjustment factor. The presence of this pure exchange industry in our model does raise certain complications, but even these can be handled by a more sophisticated treatment. The basic propositions with respect to the invariance property of calculation (A.14) continue to hold for most useful applications of the propositions. The invariance property is also discussed in Leontief (1953, p. 41) and Carter (1970, p. 23).

The Mathematics of Decomposition Analysis

This section provides the mathematics and rationale of the decomposition procedure used in Chapter 3. Specifically, we are concerned with decomposing changes over time in total (direct plus indirect) labour coefficients; the resulting decomposition must be interesting and relevant from the viewpoint of industry productivity growth analysis. All decompositions stem from the basic calculation (A.14). Thus, for an initial time period, we calculate:

$$\text{(A.17)} \quad \lambda_1' = \ell_1'(I - A_1)^{-1}$$

where the subscript unity now refers to time period one. Then for time period two:

$$\text{(A.18)} \quad \lambda_2' = \ell_2'(I - A_2)^{-1}$$

so subscript two means time period number two. The decomposition procedure is applied to:

(A.19) $\lambda_2' - \lambda_1' = \Delta\lambda'$

It is similarly convenient to define:

$$\Delta\ell' = \ell_2' - \ell_1'$$

$$\Delta A = A_2 - A_1$$

$$\ell' = \tfrac{1}{2}(\ell_1' + \ell_2')$$

$$A = \tfrac{1}{2}(A_1 + A_2)$$

Also, it is known that:

$$(I - A_1)^{-1} = I + A_1 + B_1$$

where:

$$B_1 = (I - A_1)^{-1}A_1^2 = A_1^2 + A_1^3 + A_1^4 + \ldots$$

Then:

$$\Delta B = B_2 - B_1$$

where the definition of B_2 is analogous to that of B_1, and:

$$B = \tfrac{1}{2}(B_1 + B_2)$$

One other piece of notation is required. Let $\hat{a}_1$ represent the diagonal matrix formed from the diagonal elements of A_1; and $\hat{a}_2$ is similarly formed from A_2. Then:

$$\hat{a} = \tfrac{1}{2}(\hat{a}_1 + \hat{a}_2)$$

We are now prepared to state the basic decomposition formula.[3] The change over time, from period one to period two, of the row vector of total (direct plus indirect) labour coefficients can be written as:

(A.20) $\Delta\lambda' = \Delta_D' + \Delta_I'$

where:

(A.21) $\Delta_D' = \Delta\ell'(I + \hat{a}) + \ell'(\Delta A)$

and:

(A.22) $\Delta_I' = \Delta\ell'(A - \hat{a} + B) + \ell'(\Delta B)$

Before explaining the interpretation of the decomposition row vectors Δ_D' and Δ_I', we must first check that identity (A.20) holds. This can be shown by noting that:

(A.23) $\Delta\lambda' = \lambda_2' - \lambda_1'$
$= \ell_2'(I + A_2 + B_2) - \ell_1'(I + A_1 + B_1)$
$= \Delta\ell' + \Delta\ell'(A_2 + B_2) + \ell_1'(\Delta A + \Delta B)$

But the same change over time could also be written as:

(A.24) $\Delta\lambda' = \Delta\ell' + \Delta\ell'(A_1 + B_1) + \ell_2'(\Delta A + \Delta B)$

Then, taking the simple average of (A.23) and (A.24), we find, using (A.21) and (A.22), that:

(A.24*a*) $\Delta\lambda' = \Delta\ell' + \Delta\ell'(A + B) + \ell'(\Delta A + \Delta B)$
$= \Delta_D' + \Delta_I'$

as required. The interpretation of the two decomposition expressions is as follows.

The first expression, Δ_D', represents the change in the total labour coefficients due to own effects (the own effects change). This is a row vector of dimension equal to the number of industries, including the International trade exchange industry, in the basic I-O model. Thus, each element in turn gives the own effects change over time in the total labour coefficients for the respective industries. In Chapter 3, it is stated that the own effects changes account for those changes that can be directly traced to technological changes in each of the respective industries and nowhere else. Each industry is directly responsible for the change in its own direct labour coefficient, and this is indicated by the inclusion of the term $\Delta\ell'$ in Δ_D', as seen in (A.21). Similarly, each industry is directly responsible for changes in its own set of intermediate (including capital replacement) input coefficients, whether of domestic or foreign production. But any such changes must be transformed into a common denominator – namely, labour. All this is accomplished by the term $\ell'\Delta A$ in (A.21). To this we add $\Delta\ell'\hat{a}$, which again is composed of a technological change directly traceable to each industry in turn (and nowhere else). This, then, exhausts the sources of own effects change by definition. Indeed, since $\Delta\lambda' - \Delta'_D = \Delta'_I$, we can check each term in the expression Δ'_I given by (A.22) to be sure that all own effects terms have been captured in Δ'_D.

Thus, consider the expression Δ'_I. In Chapter 3, this expression represents the change in total labour coefficients due to input effects (the input effects change). The expression is essentially a "residual," but each term has some meaning. First, consider the term $\Delta\ell'(A - \hat{a})$. Since all diagonal elements of the matrix $(A - \hat{a})$ equal zero, it is clear that the term yields a row vector of changes in total labour coefficients, which are traceable, in terms of technological changes, to all industries of the business sector other than the respective industry associated with the respective elements in the vector. Another term in the expression Δ'_I is $\Delta\ell'B = \Delta\ell'(B - \hat{b}) + \Delta\ell'\hat{b}$, where $\hat{b}$ represents a diagonal matrix formed from the diagonal elements of matrix B. For the subterm $\Delta\ell'(B - \hat{b})$, the argument is identical to that for $\Delta\ell'(A - \hat{a})$. There remains the subterm of $\Delta\ell'\hat{b}$. Strictly speaking, it might be argued that this "change" belongs with the own effects change of expression Δ'_D. We do not make this assignment, since the elements in the vector b cannot be directly associated with any one industry. Finally, we come to the last term in expression (A.22) – namely, $\ell'(\Delta B)$. Again the "correct" assignment of this term is a little controversial. The composition of the term appears symmetrical to $\ell'(\Delta A)$, which certainly belongs to Δ'_D by definition. Nevertheless, we do not make this assignment, since no element of ΔB can be directly associated with any one industry, and so, for this reason, $\ell'(\Delta B)$ is designated as part of Δ'_D, which accounts for those technological changes stemming from all other industries. However, as we shall soon see, the defence of the given decomposition procedure is not dependent only on "theoretical" argument – there is also empirical evidence!

The productivity decomposition analysis can be extended by simply inverting expression (A.22) in order to yield a column vector of row summations rather than a row vector of column summations. Thus, consider now the column vector:

$$\Delta_S = \widehat{\Delta\ell}(A - \hat{a} + B)i + \hat{\ell}(\Delta B)i \qquad \text{(A.25)}$$

where $\widehat{\Delta\ell}$ is a diagonal matrix formed from the row vector $\Delta\ell'$, $\hat{\ell}$ is a diagonal matrix formed from the row vector ℓ', and i is a column vector of unities. This expression describes the changes in total labour coefficients due to output effects (the output effects change), discussed in Chapter 3. There it is stated that the grand summation of all input effects must equal the grand summation of all output effects. The proof is trivial:

$$\begin{aligned} i'\Delta_S &= i'\widehat{\Delta\ell}(A - \hat{a} + B)i + i'\hat{\ell}(\Delta B)i \\ &= \Delta\ell'(A - \hat{a} + B)i + \ell'(\Delta B)i \\ &= \Delta'_D i \end{aligned}$$

as required. In Chapter 3, we associate each element of the column vector Δ_S as an output effect of the respective industries. For example, if a particular element of Δ_S is negative, then technological changes associated with that particular industry would directly or indirectly lower total labour coefficients in all other industries of the economy (taken as a whole) and, therefore, also raise labour productivity levels throughout the economy. Is this a reasonable interpretation of the specific expression (A.25)? First, consider the term $\widehat{\Delta\ell}(A - \hat{a})i$ in Δ_S. Clearly this term fits the required description; a particular industry's output effects transmitted by this term are direct. Next, consider the term $\widehat{\Delta\ell}Bi$. Here, again, the output effects are clearly associated with each particular industry's technological change (actually, direct labour coefficient change), but the output effects transmitted by the term are indirect, and also affect the particular industry itself (matrix B includes the diagonal elements). Finally, we examine the last term in the expression (A.25) – namely, $\hat{\ell}(\Delta B)i$. The case for associating each element in this column vector term with a particular industry's output effects, as described, seems rather weak. After all, each element of ΔB reflects technological changes (actually the indirect intermediate input coefficient changes) of all industries simultaneously. Nevertheless, the common denominator weights $\hat{\ell}$ are correct, but the term mainly embodies the net impact of intermediate input substitutions[4] ultimately associated with the respective industries of the column vector. For this reason, it seems best to distinguish the term $\hat{\ell}(\Delta B)i$ in (A.25) when performing an analysis of output effects change based on the formulation of Δ_S.

In Chapter 3, the empirical results of decomposition analysis are shown specifically based on the formulations (A.20), (A.21), (A.22), and (A.25) for the time interval 1961-76 (see Tables 3-1 and 3-2).[5] The individual terms composing each decomposition expression are not shown, only the total net result of the terms. In view of the above analysis, it is therefore instructive to observe the individual terms, and this is now shown in Tables A-1, A-2, and A-3. From Table A-1, it is clearly evident that the term $\Delta\ell'(I + \hat{a})$ dominates the own effects change expression Δ'_D. This result is not surprising: the prime source of own effects change in total labour requirements per unit of output is the simple technological change of reductions (in almost all cases) in the direct labour coefficients of industries. Note that, for some industries, the term $\ell'(\Delta A)$ is positive and significant, usually indicating substitution of direct intermediate inputs (correctly labour-weighted) for direct labour input. In Table A-2, we are mainly concerned with the relative magnitudes of the first (combined) term $\Delta\ell'(A - \hat{a} + B)$ and the second term $\ell'(\Delta B)$; recall that the interpretation of the second term is not entirely clear. Again it is evident that the first term

Table A-1

Decomposition of Change in Total Labour Requirements Due to Own Effects, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Total own effects change	First-term own effects change	Second-term own effects change
1 Agriculture	-108.7	-108.7	-0.0
2 Forestry	-28.4	-32.6	4.2
3 Fishing and hunting	10.7	5.7	5.0
4 Metal mines	-7.2	-14.9	7.7
5 Mineral fuels	-7.2	-12.9	5.7
6 Nonmetal mines	-23.2	-23.6	0.3
7 Services to mining	1.8	8.9	-7.1
8 Food and beverages	-17.8	-13.7	-4.1
9 Tobacco products	-15.6	-12.6	-2.9
10 Rubber and plastics	-30.0	-26.7	-3.3
11 Leather products	-39.0	-31.8	-7.2
12 Textiles	-43.2	-40.8	-2.4
13 Knitting mills	-59.4	-52.8	-6.6
14 Clothing	-35.3	-35.7	0.4
15 Wood products	-23.3	-22.2	-1.1
16 Furniture and fixtures	-23.9	-23.9	0.1
17 Paper and allied products	-9.4	-10.0	0.6
18 Printing and publishing	-20.7	-20.9	0.2
19 Primary metals	-6.1	-7.3	1.2
20 Metal fabricating	-22.4	-20.7	-1.6
21 Machinery	-22.3	-21.7	-0.6
22 Transportation equipment	-32.3	-27.8	-4.5
23 Electrical products	-29.8	-26.8	-2.9
24 Nonmetallic mineral products	-20.9	-20.2	-0.8
25 Petroleum and coal products	-0.3	-2.9	2.6
26 Chemicals	-19.5	-17.9	-1.6
27 Miscellaneous manufacturing	-29.5	-27.9	-1.5
28 Construction	-11.2	-12.1	0.9
29 Transportation and storage	-39.4	-38.0	-1.4
30 Communications	-46.5	-39.3	-7.2
31 Electric power and gas	-11.3	-9.9	-1.4
32 Wholesale trade	-24.7	-20.4	-4.3
33 Retail trade	-31.3	-25.1	-6.2
34 Finance, insurance, and real estate	2.5	0.4	2.1
35 Education and health	-4.1	-4.1	0.0
36 Amusement and recreation	-10.1	-12.1	2.0
37 Services to business	-3.8	-5.4	1.6
38 Accommodation and food	17.7	15.5	2.2
39 Other personal services	48.8	47.7	1.1
40 International trade	-7.1	0.0	-7.1

*Constant 1971 dollars.

SOURCE Based on data from Statistics Canada and Table 3-1.

Table A-2

Decomposition of Change in Total Labour Requirements Due to Input Effects, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Total input effects change	First-term input effects change	Second-term input effects change
1 Agriculture	-27.3	-26.6	-0.7
2 Forestry	-12.7	-18.7	6.0
3 Fishing and hunting	-8.7	-24.0	15.4
4 Metal mines	-5.9	-14.4	8.5
5 Mineral fuels	-6.0	-12.3	6.2
6 Nonmetal mines	-17.3	-16.5	-0.8
7 Services to mining	-27.4	-16.2	-11.2
8 Food and beverages	-59.2	-58.1	-1.1
9 Tobacco products	-50.1	-49.1	-1.1
10 Rubber and plastics	-26.7	-24.1	-2.5
11 Leather products	-29.5	-24.4	-5.0
12 Textiles	-32.6	-26.1	-6.4
13 Knitting mills	-37.6	-31.2	-6.4
14 Clothing	-27.8	-29.8	2.0
15 Wood products	-25.2	-29.0	3.8
16 Furniture and fixtures	-23.2	-24.4	1.3
17 Paper and allied products	-19.9	-27.0	7.1
18 Printing and publishing	-12.2	-15.5	3.2
19 Primary metals	-20.3	-25.6	5.4
20 Metal fabricating	-20.3	-20.0	-0.3
21 Machinery	-14.7	-21.0	6.3
22 Transportation equipment	-23.2	-27.9	4.7
23 Electrical products	-23.1	-20.4	-2.6
24 Nonmetallic mineral products	-20.4	-19.5	-0.9
25 Petroleum and coal products	-31.4	-32.3	0.9
26 Chemicals	-25.0	-24.0	-1.0
27 Miscellaneous manufacturing	-20.2	-20.5	0.3
28 Construction	-21.6	-20.3	-1.2
29 Transportation and storage	-18.2	-14.8	-3.4
30 Communications	-24.9	-16.2	-8.7
31 Electric power and gas	-11.9	-15.2	3.2
32 Wholesale trade	-14.8	-10.3	-4.4
33 Retail trade	-18.0	-13.5	-4.6
34 Finance, insurance, and real estate	-5.6	-7.1	1.4
35 Education and health	-7.0	-9.1	2.1
36 Amusement and recreation	-8.3	-13.0	4.6
37 Services to business	-4.5	-6.2	2.6
38 Accommodation and food	-17.9	-22.6	4.6
39 Other personal services	-8.5	-12.4	3.9
40 International trade	-49.6	-47.5	-2.1

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada and Table 3-1.

largely accounts for the input effects changes Δ'_I. Indeed, for all industries, Δ'_I and the first term are negative and significant. There are some positive industry elements in $\ell'(\Delta B)$, but these are typically small in absolute magnitude compared with the corresponding industry element magnitudes of $\Delta\ell'(A - \hat{a} + B)$. Even if the term $\ell'(\Delta B)$ were included as part of the own effects change expression, the empirical results would not alter in any significant way for the great majority of industries.

Finally, we consider Table A-3. In this case, it is not evident that the first (combined) term $\widehat{\Delta\ell}(A - \hat{a} + B)i$ dominates the second term $\hat{\ell}(\Delta B)i$. There are important examples where the industrial magnitudes of the second term are at least equal to those of the first term, and the elements of the two terms do not necessarily possess the same arithmetic sign. Observe, for example, Rubber and plastics (no. 10), Transportation equipment (no. 22), Communications (no. 30), Wholesale trade (no. 32), and Services to

Table A-3

Decomposition of Transmission Change in Total Labour Requirements Associated with Output Effects, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Total output effects change	First-term output effects change	Second-term output effects change
1 Agriculture	-263.5	-203.4	-60.1
2 Forestry	-55.7	-38.6	-17.1
3 Fishing and hunting	-2.4	0.5	-2.9
4 Metal mines	-30.3	-22.8	-7.5
5 Mineral fuels	-10.5	-13.9	3.5
6 Nonmetal mines	-6.6	-7.8	1.2
7 Services to mining	4.5	2.1	2.4
8 Food and beverages	-23.5	-19.4	-4.1
9 Tobacco products	-1.2	-0.9	-0.3
10 Rubber and plastics	-3.7	-14.3	10.6
11 Leather products	-5.0	-2.4	-2.6
12 Textiles	-34.9	-36.9	2.0
13 Knitting mills	-3.4	-5.3	1.9
14 Clothing	-2.4	-3.8	1.3
15 Wood products	-28.3	-25.6	-2.7
16 Furniture and fixtures	-2.6	-2.9	0.2
17 Paper and allied products	-35.5	-22.2	-13.4
18 Printing and publishing	-21.8	-15.8	-6.0
19 Primary metals	-30.7	-19.5	-11.2
20 Metal fabricating	-20.3	-27.8	7.5
21 Machinery	-17.0	-24.1	7.1
22 Transportation equipment	5.5	-59.0	64.5
23 Electrical products	-21.5	-25.4	3.9
24 Nonmetallic mineral products	-9.2	-9.8	0.5
25 Petroleum and coal products	-2.6	-2.6	0.0
26 Chemicals	-21.4	-24.7	3.3
27 Miscellaneous manufacturing	-8.9	-11.8	3.0
28 Construction	-49.6	-37.9	-11.6
29 Transportation and storage	-107.8	-117.3	9.5
30 Communications	-24.9	-36.6	11.7
31 Electric power and gas	-6.0	-9.0	3.0
32 Wholesale trade	-33.5	-45.9	12.5
33 Retail trade	-21.7	-21.3	-0.4
34 Finance, insurance, and real estate	1.8	1.0	0.8
35 Education and health	0.1	-0.0	0.1
36 Amusement and recreation	-2.4	-1.3	-1.1
37 Services to business	23.1	-7.2	30.4
38 Accommodation and food	0.7	5.9	-5.3
39 Other personal services	14.8	20.1	-5.4
40 International trade	0.0	0.0	0.0

*Constant 1971 dollars.
SOURCE Based on data from Statistics Canada and Table 3-2.

business (no. 37). This result may seem surprising in the light of Table A-2, particularly since the industrial summation of the second term in Table A-2 is identically equal to the same summation of the second term in Table A-3, that is:

$$\ell'(\Delta B)i \equiv i'\hat{\ell}(\Delta B)i$$

But these simple summations overlook industrial distribution and arithmetic cancellations! It is stated earlier in this section, that the interpretation of the term $\hat{\ell}(\Delta B)i$ as part of the output effects changes among industries is controversial. We also now know that industrial magnitudes of this term can be, and are, important. Therefore it is of critical significance to distinguish this term when performing an analysis of output effects changes based on the expression Δ_S in formula (A.25). Some concrete examples of this distinction, from the viewpoint of industrial productivity policy implications, are given in Chapters 5 and 6.

There is one other development of decomposition analysis that can be shown. It should be clear that both the input effects change row vector Δ_I' and the output effects change column vector Δ_S come from the same input-output effects change matrix – namely:

$$\text{(A.26)} \quad \widehat{\Delta \ell}(A - \hat{a} + B) + \hat{\ell}(\Delta B)$$

The column sums of the matrix (A.26) yield the row vector Δ_I', and the row summations of the matrix yield the column vector Δ_S. Indeed, each element of the matrix (A.26) represents simultaneously both an input effects change and an output effects change. Table A-4 exhibits the complete matrix for the 40 industries of our analysis during 1961-76. Thus, each element of this matrix is an input effects change "captured" by the industry (number) denoted in the column headings. At the same time, each element is an output effects change "transmitted" by the industry denoted in the row heading. The total input effects row (last row) repeats the results already given in Table A-2; the total output effects column (last column) repeats the results given in Table A-3. Since this matrix itself is a summation of two matrices, one of which – namely, $\hat{\ell}(\Delta B)$ – is somewhat difficult to interpret, one must therefore be careful in utilizing the individual elements of the total matrix. Some important examples of such utilization are offered in Chapter 6.

A Modification of Decomposition Analysis

This section explains a minor modification of the decomposition procedure that is used in Chapters 4 and 5 to establish certain productivity growth results. The modification arises because of the peculiar nature of the International trade industry, which is a pure exchange industry rather than a production industry. This industry has no direct labour input; therefore, the last element (actually, element number 40) of the direct labour coefficient row vector ℓ' is zero. This fact *per se* raises no difficulty in the basic calculation:

$$\text{(A.14)} \quad \lambda' = \ell' (I - A)^{-1}$$

nor in the change over time vector:

$$\text{(A.19)} \quad \Delta\lambda' = \lambda_2' - \lambda_1'$$

Thus, all calculations with respect to total labour requirements (per unit of output), total labour productivity levels, and total labour productivity growth rates remain unmodified. However, a difficulty does arise when considering the decomposition expression for the own effects change:

$$\text{(A.21)} \quad \Delta_D' = \Delta\ell' (I + \hat{a}) + \ell' (\Delta A)$$

with respect to the term $\ell' (\Delta A)$. Since the last element of the row vector ℓ' is always zero, this means that the term is not sensitive to any positive or negative components in the last row of the matrix ΔA. We know from the basic I-O model (A.11) that this last row comes from:

$$A_{21} = i'\hat{\mu} (B + C) + i^{*\prime}N$$

and:

$$A_{22} = 0$$

so the last row of matrix ΔA accounts for all changes over time in total imported intermediate input coefficients. Thus, for example, an industry that has increased its consumption of imported intermediate inputs *ceteris paribus* is not "penalized" by this arrangement in terms of lower own effects productivity growth, since the immediate labour weight transformation is zero. Therefore, it is desirable to create an "artificial" nonzero direct labour coefficient for the International trade industry, which can be reasonably utilized in decomposition analysis. Note that we maintain the convention that the change over time in this artificial direct labour coefficient is zero, since this convention creates no difficulty.

For time period number one, the International trade direct labour coefficient scalar is set equal to:[6]

$$\text{(A.27)} \quad \ell_{(40)1} = \ell_1' \begin{bmatrix} (Da)_1 \\ 0 \end{bmatrix}$$

where $(Da)_1$, using the formulations following (A.11), is merely the last column vector of the matrix A in period one. Note that $(Da)_1$ represents the industry composition pattern vector of total exports in time period one and so $i'(Da)_1$ = unity. Also, since the International trade industry essentially "produces" imports in exchange for exports, the formulation (A.27) seems eminently reasonable – a weighted average of all industries' direct labour coefficients with weights proportional to the relative importance

Table A-4

Matrix Decomposition of Input Effects and Output Effects Contributions to Total Labour Requirement Changes, in Man-Years per One Million Dollars* of Output, 40 Industries, 1961-76

	Industry number									
	1	2	3	4	5	6	7	8	9	10
1 Agriculture	-8.12	-3.59	-3.84	-2.06	-2.00	-3.69	-4.98	-40.16	-34.68	-6.04
2 Forestry	-1.08	-0.41	-0.73	-0.41	-0.40	-0.97	-0.98	-1.29	-1.40	-1.29
3 Fishing and hunting	-0.09	-0.03	-0.05	-0.01	-0.02	-0.05	-0.10	-0.08	-0.08	-0.09
4 Metal mines	-0.74	-0.26	-0.31	-0.23	-0.25	-0.49	-0.78	-0.71	-0.55	-0.74
5 Mineral fuels	-0.37	-0.11	-0.05	-0.02	-0.04	-0.28	-0.28	-0.25	-0.18	-0.17
6 Nonmetal mines	-0.22	-0.05	-0.08	-0.12	-0.05	-0.11	-0.25	-0.15	-0.11	-0.19
7 Services to mining	0.09	0.09	0.14	0.44	0.48	0.24	0.05	0.07	0.06	0.07
8 Food and beverages	-1.68	-0.36	-0.22	-0.19	-0.19	-0.42	-0.64	-0.95	-0.80	-0.71
9 Tobacco products	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.54	-0.02
10 Rubber and plastics	-0.03	-0.02	0.21	0.01	0.03	-0.10	-0.19	-0.03	-0.02	0.07
11 Leather products	-0.05	-0.02	-0.02	-0.02	-0.01	-0.04	-0.05	-0.05	-0.04	-0.27
12 Textiles	-0.32	-0.15	-0.69	-0.04	-0.02	-0.34	-0.23	-0.34	-0.41	-1.90
13 Knitting mills	-0.00	0.01	0.02	0.01	0.00	-0.00	-0.01	-0.00	-0.00	-0.30
14 Clothing	-0.01	-0.01	0.03	0.00	0.00	-0.02	-0.04	-0.01	-0.00	-0.10
15 Wood products	-0.83	-0.33	-0.43	-0.23	-0.21	-0.61	-0.87	-0.78	-0.63	-0.79
16 Furniture and fixtures	-0.05	-0.03	0.00	-0.01	-0.02	-0.06	-0.09	-0.06	-0.06	-0.06
17 Paper and allied products	-1.08	-0.36	-0.33	-0.23	-0.27	-0.89	-1.18	-1.36	-1.51	-1.45
18 Printing and publishing	-0.52	-0.42	-0.16	-0.27	-0.30	-0.56	-0.81	-0.81	-0.94	-0.86
19 Primary metals	-1.00	-0.31	-0.21	-0.26	-0.22	-0.61	-1.18	-0.92	-0.70	-0.94
20 Metal fabricating	-0.57	-0.40	0.06	-0.21	-0.08	-0.49	-0.86	-0.72	-0.36	-0.50
21 Machinery	-1.02	-0.28	-1.38	-0.33	-0.30	-0.54	-0.84	-0.80	-0.68	-0.47
22 Transportation equipment	-0.35	0.05	-0.09	0.28	0.16	0.05	-0.40	0.02	0.17	0.49
23 Electrical products	-0.46	-0.34	-0.52	-0.22	-0.21	-0.46	-0.86	-0.43	-0.31	-0.43
24 Nonmetallic mineral products	-0.23	-0.12	-0.03	-0.12	-0.01	-0.20	-0.28	-0.33	-0.16	-0.23
25 Petroleum and coal products	-0.17	-0.07	-0.12	-0.03	-0.02	-0.10	-0.11	-0.14	-0.10	-0.05
26 Chemicals	-0.87	-0.24	-0.10	-0.42	-0.16	-0.67	-0.65	-0.69	-0.43	-2.49
27 Miscellaneous manufacturing	-0.19	-0.14	-0.13	-0.08	-0.07	-0.22	-0.29	-0.23	-0.22	-0.25
28 Construction	-1.73	-1.28	-0.39	-1.15	-1.85	-1.81	-2.27	-1.46	-1.20	-1.24
29 Transportation and storage	-3.17	-4.63	-1.46	-1.21	-0.97	-2.50	-4.16	-4.04	-2.85	-3.48
30 Communications	-0.53	-0.19	-0.04	-0.03	-0.24	-0.40	-0.91	-0.61	-0.57	-0.80
31 Electric power and gas	-0.20	-0.01	0.07	-0.21	-0.19	-0.34	-0.25	-0.12	-0.07	-0.20
32 Wholesale trade	-1.57	-0.54	-0.22	-0.35	-0.16	-1.09	-1.63	-1.39	-0.92	-1.15
33 Retail trade	-0.87	-0.53	-0.23	-0.19	-0.09	-0.75	-1.05	-1.03	-0.65	-0.64
34 Finance, insurance, and real estate	-0.04	0.37	0.49	0.45	0.36	0.08	-0.36	-0.07	-0.02	-0.08
35 Education and health	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36 Amusement and recreation	-0.01	-0.00	0.03	0.01	-0.01	-0.01	-0.05	-0.03	-0.03	-0.04
37 Services to business	0.65	0.79	1.32	0.84	0.84	0.50	-0.00	0.57	0.53	0.46
38 Accommodation and food	-0.09	0.06	0.10	0.08	0.07	-0.03	-0.10	0.02	0.09	-0.02
39 Other personal services	0.23	1.21	0.67	0.65	0.41	0.71	0.28	0.26	0.21	0.24
40 International trade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input effects	-27.30	-12.68	-8.68	-5.88	-6.04	-17.27	-27.40	-59.16	-50.14	-26.68

Table A-4 (cont'd)

	Industry number									
	11	12	13	14	15	16	17	18	19	20
1 Agriculture	-8.90	-8.27	-6.76	-6.82	-5.09	-4.43	-4.56	-2.70	-5.09	-4.56
2 Forestry	-0.95	-1.60	-1.37	-1.07	-10.98	-2.46	-5.29	-1.61	-0.97	-0.96
3 Fishing and hunting	-0.15	-0.13	-0.10	-0.08	-0.03	-0.05	-0.03	-0.03	-0.06	-0.07
4 Metal mines	-0.43	-1.00	-0.80	-0.64	-0.27	-0.61	-0.36	-0.26	-4.91	-1.89
5 Mineral fuels	-0.11	-0.23	-0.18	-0.12	-0.12	-0.11	-0.12	-0.06	-0.28	-0.19
6 Nonmetal mines	-0.10	-0.25	-0.19	-0.14	-0.06	-0.11	-0.14	-0.06	-0.20	-0.15
7 Services to mining	0.06	0.06	0.05	0.06	0.07	0.07	0.10	0.05	0.22	0.09
8 Food and beverages	-1.81	-0.88	-0.71	-0.56	-0.40	-0.43	-0.40	-0.25	-0.46	-0.47
9 Tobacco products	-0.02	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02
10 Rubber and plastics	-1.41	-0.15	0.03	0.07	-0.00	-0.58	-0.00	0.05	0.09	-0.02
11 Leather products	-2.82	-0.08	-0.15	-0.14	-0.02	-0.11	-0.03	-0.02	-0.04	-0.04
12 Textiles	-1.13	-2.18	-12.06	-7.86	-0.12	-1.71	-0.40	-0.20	-0.08	-0.13
13 Knitting mills	-0.12	-0.67	-0.07	-1.80	0.00	-0.35	0.00	-0.01	0.01	0.00
14 Clothing	-0.18	-0.59	-1.14	-0.12	-0.00	-0.01	-0.00	-0.00	0.01	-0.00
15 Wood products	-0.55	-1.10	-0.88	-0.66	-0.67	-2.46	-1.01	-0.09	-0.69	-0.71
16 Furniture and fixtures	-0.05	-0.13	-0.13	-0.06	-0.09	-0.03	-0.07	-0.08	-0.04	-0.07
17 Paper and allied products	-0.94	-1.85	-1.57	-1.13	-0.42	-0.88	-0.59	-1.99	-0.87	-0.92
18 Printing and publishing	-0.77	-0.76	-0.76	-0.55	-0.41	-0.54	-0.52	-0.37	-0.34	-0.51
19 Primary metals	-0.51	-1.29	-1.03	-0.77	-0.31	-0.76	-0.42	-0.30	-0.87	-2.44
20 Metal fabricating	-0.43	-0.44	-0.31	-0.09	-0.42	-1.17	-0.30	-0.14	-0.39	-0.50
21 Machinery	-0.31	-0.62	-0.51	-0.23	-0.24	-0.27	-0.40	-0.19	-0.57	-0.53
22 Transportation equipment	0.55	0.58	0.66	0.90	0.10	0.43	0.47	0.35	0.63	0.26
23 Electrical products	-0.30	-0.52	-0.45	-0.24	-0.31	-0.46	-0.33	-0.24	-0.33	-0.60
24 Nonmetallic mineral products	-0.15	-0.26	-0.21	-0.14	-0.18	-0.25	-0.18	-0.09	-0.30	-0.25
25 Petroleum and coal products	-0.05	-0.07	-0.06	-0.04	-0.06	-0.04	-0.07	-0.01	-0.06	-0.05
26 Chemicals	-0.70	-1.26	-0.90	-0.46	-0.35	-0.54	-0.58	-0.31	-0.50	-0.48
27 Miscellaneous manufacturing	-0.42	-0.40	-0.21	-0.40	-0.12	-0.35	-0.14	-0.15	-0.17	-0.17
28 Construction	-0.95	-1.49	-1.32	-0.87	-1.15	-0.95	-1.19	-0.72	-1.40	-1.09
29 Transportation and storage	-2.75	-4.06	-3.42	-2.52	-3.20	-2.65	-3.42	-1.98	-3.04	-2.68
30 Communications	-0.72	-0.71	-0.76	-0.54	-0.33	-0.57	-0.32	-1.09	-0.25	-0.60
31 Electric power and gas	-0.11	-0.25	0.20	-0.09	-0.12	-0.10	-0.34	-0.09	-0.27	-0.15
32 Wholesale trade	-1.57	-1.53	-1.13	-0.93	-0.79	-1.12	-0.54	-0.36	-0.84	-0.89
33 Retail trade	-1.30	-0.79	-0.82	-0.56	-0.36	-0.37	-0.26	-0.23	-0.07	-0.38
34 Finance, insurance, and real estate	-0.04	-0.20	-0.31	-0.01	0.11	0.02	0.17	0.10	0.21	-0.01
35 Education and health	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36 Amusement and recreation	-0.03	-0.01	-0.00	0.01	-0.01	-0.02	-0.00	-0.05	0.01	-0.03
37 Services to business	0.46	0.46	0.33	0.63	0.64	0.56	0.81	0.46	0.99	0.49
38 Accommodation and food	-0.08	-0.09	-0.13	-0.01	0.01	-0.00	0.04	0.11	0.03	-0.01
39 Other personal services	0.28	0.15	0.04	0.16	0.56	0.25	0.55	0.35	0.64	0.36
40 International trade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input effects	-29.48	-32.65	-37.60	-27.81	-25.15	-23.19	-19.88	-12.22	-20.28	-20.33

Table A-4 (cont'd)

	Industry number									
	21	22	23	24	25	26	27	28	29	30
1 Agriculture	-4.09	-6.93	-4.98	-4.34	-9.70	-6.48	-4.55	-4.04	-3.35	-3.34
2 Forestry	-0.79	-1.29	-1.02	-1.00	-1.77	-1.33	-1.42	-1.53	-0.77	-0.81
3 Fishing and hunting	-0.04	-0.07	-0.08	-0.06	-0.16	-0.10	-0.06	-0.06	-0.05	-0.06
4 Metal mines	-0.98	-1.23	-1.42	-0.69	-1.28	-0.73	-1.13	-0.91	-0.52	-0.63
5 Mineral fuels	-0.11	-0.15	-0.17	-0.28	-4.35	-0.32	-0.13	-0.17	-0.23	-0.13
6 Nonmetal mines	-0.12	-0.18	-0.17	-1.07	-0.32	-0.39	-0.14	-0.24	-0.13	-0.14
7 Services to mining	0.09	0.10	0.06	0.11	0.47	0.12	0.07	0.15	0.07	0.04
8 Food and beverages	-0.35	-0.59	-0.53	-0.48	-0.97	-0.90	-0.48	-0.40	-0.36	-0.38
9 Tobacco products	-0.01	-0.03	-0.02	-0.02	-0.04	-0.02	-0.02	-0.01	-0.01	-0.01
10 Rubber and plastics	-0.09	-0.35	-0.26	-0.09	0.12	-0.14	-0.23	-0.15	-0.22	-0.13
11 Leather products	-0.03	-0.07	-0.05	-0.04	-0.08	-0.05	-0.16	-0.04	-0.04	-0.03
12 Textiles	-0.07	-0.54	-0.24	-0.25	-0.14	-0.31	-0.62	-0.23	-0.19	-0.16
13 Knitting mills	0.01	-0.00	-0.01	-0.01	0.00	-0.00	-0.06	0.00	-0.00	-0.00
14 Clothing	0.02	0.02	-0.01	-0.01	0.01	-0.01	-0.01	-0.01	-0.02	-0.01
15 Wood products	-0.47	-0.80	-0.73	-0.65	-1.40	-0.75	-0.95	-1.69	-0.79	-0.86
16 Furniture and fixtures	-0.07	-0.07	-0.14	-0.09	-0.04	-0.08	-0.06	-0.10	-0.08	-0.12
17 Paper and allied products	-0.61	-1.11	-1.08	-1.05	-1.95	-1.44	-0.93	-0.80	-0.68	-0.78
18 Printing and publishing	-0.47	-0.56	-0.66	-0.58	-0.50	-1.07	-0.72	-0.41	-0.46	-0.62
19 Primary metals	-1.24	-1.63	-1.81	-0.74	-1.62	-0.92	-1.08	-1.03	-0.78	-0.98
20 Metal fabricating	-1.20	-1.11	-1.08	-0.55	-0.36	-0.69	-0.75	-1.69	-0.78	-0.88
21 Machinery	-0.04	-0.29	-0.60	-0.45	-0.46	-0.49	-0.31	-0.47	-0.34	-0.39
22 Transportation equipment	0.63	0.57	0.29	0.11	0.88	0.46	0.47	0.14	-0.81	-0.06
23 Electrical products	-1.11	-0.81	-0.74	-0.47	-0.37	-0.46	-0.56	-0.99	-0.61	-3.27
24 Nonmetallic mineral products	-0.13	-0.44	-0.33	-0.31	-0.24	-0.38	-0.33	-1.11	-0.40	-0.43
25 Petroleum and coal products	-0.03	-0.05	-0.05	-0.08	-0.05	-0.12	-0.05	-0.06	-0.14	-0.06
26 Chemicals	-0.28	-0.48	-0.65	-0.57	-0.91	-0.58	-0.80	-0.42	-0.33	-0.36
27 Miscellaneous manufacturing	-0.11	-0.27	-0.25	-0.26	-0.23	-0.32	-0.08	-0.24	-0.24	-0.25
28 Construction	-0.79	-1.17	-1.16	-1.33	-1.21	-1.36	-1.01	-0.80	-2.17	-2.59
29 Transportation and storage	-1.99	-3.06	-2.89	-3.42	-5.55	-4.05	-2.64	-2.77	-1.67	-3.67
30 Communications	-0.60	-0.53	-1.00	-0.56	-0.40	-0.96	-0.80	-0.39	-0.87	-0.46
31 Electric power and gas	-0.06	-0.11	-0.16	-0.36	-0.20	-0.36	-0.13	-0.09	-0.13	-0.15
32 Wholesale trade	-0.62	-0.71	-1.02	-1.06	-0.54	-1.19	-0.93	-1.26	-1.15	-1.20
33 Retail trade	-0.22	-0.43	-0.50	-0.63	-0.37	-0.68	-0.46	-0.58	-0.83	-0.82
34 Finance, insurance, and real estate	0.11	0.06	-0.16	-0.00	0.24	0.09	0.03	0.04	-0.01	-0.39
35 Education and health	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36 Amusement and recreation	-0.02	-0.01	-0.05	-0.02	0.00	-0.06	-0.04	-0.01	-0.02	-0.60
37 Services to business	0.72	0.87	0.38	0.47	1.66	0.61	0.52	0.38	0.37	0.03
38 Accommodation and food	0.05	-0.04	-0.03	-0.01	0.05	0.08	0.09	-0.04	0.04	-0.11
39 Other personal services	0.35	0.30	0.22	0.47	0.43	0.42	0.27	0.45	0.49	-0.08
40 International trade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input effects	-14.67	-23.19	-23.05	-20.37	-31.37	-24.96	-20.21	-21.58	-18.18	-24.91

Table A-4 (concl'd)

	Industry number										Total output effects
	31	32	33	34	35	36	37	38	39	40	
1 Agriculture	-2.08	-2.57	-6.69	-1.1	-1.5	-1.8	-1.2	-9.7	-2.1	-16.4	-263.51
2 Forestry	-0.61	-0.57	-0.55	-0.2	-0.2	-0.3	-0.2	-0.5	-0.6	-3.7	-55.67
3 Fishing and hunting	-0.02	-0.05	-0.04	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-2.44
4 Metal mines	-0.33	-0.31	-0.30	-0.1	-0.1	-0.1	-0.0	-0.2	-0.1	-2.7	-30.27
5 Mineral fuels	-0.06	-0.13	-0.12	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.6	-10.46
6 Nonmetal mines	-0.07	-0.07	-0.07	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.5	-6.59
7 Services to mining	0.14	0.02	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.1	4.46
8 Food and beverages	-0.16	-0.35	-0.39	-0.1	-0.1	-0.1	-0.1	-2.3	-0.2	-1.4	-23.51
9 Tobacco products	-0.01	-0.01	-0.01	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-1.15
10 Rubber and plastics	0.04	-0.10	-0.10	-0.0	0.0	0.0	0.0	0.0	-0.0	0.0	-3.68
11 Leather products	-0.01	-0.03	-0.02	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-4.97
12 Textiles	-0.03	-0.19	-0.20	-0.0	-0.1	-0.0	-0.0	-0.3	-0.3	-0.4	-34.93
13 Knitting mills	0.00	-0.01	-0.01	0.0	0.0	0.0	0.0	0.0	-0.0	-0.0	-3.38
14 Clothing	0.01	-0.02	-0.11	-0.0	-0.0	0.0	-0.0	-0.0	-0.0	-0.0	-2.45
15 Wood products	-0.66	-0.41	-0.39	-0.1	-0.1	-0.1	-0.0	-0.2	-0.4	-1.9	-28.33
16 Furniture and fixtures	-0.08	-0.06	-0.06	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-2.64
17 Paper and allied products	-0.29	-0.64	-0.61	-0.2	-0.2	-0.1	-0.1	-0.4	-0.2	-2.2	-35.53
18 Printing and publishing	-0.24	-0.73	-0.54	-0.3	-0.3	-0.7	-0.3	-0.3	-0.3	-0.6	-21.84
19 Primary metals	-0.48	-0.44	-0.44	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-1.4	-30.71
20 Metal fabricating	-0.62	-0.42	-0.39	-0.1	-0.1	-0.2	-0.0	-0.1	-0.1	-0.5	-20.29
21 Machinery	-0.24	-0.26	-0.33	-0.1	-0.1	-0.1	-0.0	-0.2	-0.1	-1.1	-17.05
22 Transportation equipment	0.32	-0.20	-0.20	0.0	0.0	0.1	-0.0	0.1	0.1	-2.9	5.46
23 Electrical products	-1.23	-0.40	-0.43	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	-0.7	-21.49
24 Nonmetallic mineral products	-0.38	-0.14	-0.14	-0.0	-0.0	-0.0	-0.0	-0.1	-0.0	-0.3	-9.24
25 Petroleum and coal products	-0.05	-0.06	-0.06	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-2.56
26 Chemicals	-0.27	-0.25	-0.26	-0.0	-0.3	-0.1	-0.0	-0.1	-0.7	-0.9	-21.40
27 Miscellaneous manufacturing	-0.16	-0.16	-0.16	-0.0	-0.2	-0.6	-0.0	-0.1	-0.2	-0.3	-8.87
28 Construction	-3.04	-1.04	-1.07	-0.9	-0.4	-0.7	-0.3	-0.4	-0.4	-2.0	-49.59
29 Transportation and storage	-1.30	-2.78	-1.88	-0.7	-0.8	-1.1	-0.7	-1.4	-1.0	-6.0	-107.83
30 Communications	-0.28	-1.42	-1.22	-0.9	-1.3	-0.6	-0.9	-0.3	-0.4	-0.5	-24.91
31 Electric power and gas	0.01	-0.13	-0.23	-0.0	-0.0	-0.1	-0.0	-0.0	-0.0	-0.2	-6.04
32 Wholesale trade	-0.55	-0.47	-0.76	-0.2	-0.3	-0.2	-0.1	-0.5	-0.4	-1.4	-33.47
33 Retail trade	-0.27	-0.65	-0.38	-0.2	-0.3	-0.8	-0.3	-0.8	-0.4	-0.7	-21.72
34 Finance, insurance, and real estate	0.14	-0.13	-0.13	0.1	0.1	-0.0	0.2	0.2	0.1	-0.1	1.80
35 Education and health	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06
36 Amusement and recreation	-0.00	-0.08	-0.08	-0.0	-0.0	-0.8	-0.0	-0.1	-0.0	-0.0	-2.36
37 Services to business	0.63	0.05	0.14	0.3	0.3	0.5	0.4	0.6	0.4	1.1	23.15
38 Accommodation and food	0.03	0.11	0.04	0.0	0.0	0.1	0.1	0.0	0.0	-0.0	0.68
39 Other personal services	0.23	0.25	0.18	0.2	0.5	0.6	0.4	0.3	0.1	0.2	14.75
40 International trade	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Total input effects	-11.95	-14.81	-17.97	-5.5	-6.9	-8.3	-4.4	-17.9	-8.5	-49.5	-858.50

*Contant 1971 dollars.

SOURCE Based on data from Statistics Canada and Tables 3-1 and 3-2.

of the industries' exports in total exports. Similarly for time period number two, we set:

$$(A.28) \quad \ell_{(40)2} = \ell_2' \begin{bmatrix} (Da)_2 \\ 0 \end{bmatrix}$$

with the notation and meaning entirely analogous to that explained for time period one. Then the artificial direct labour coefficient for international trade as used in our modification procedure is simply:

$$(A.29) \quad \ell_{(40)} = \tfrac{1}{2} (\ell_{(40)1} + \ell_{(40)2})$$

Now we define a new row vector:

$$(A.30) \quad {}^*\ell' = (0, \ldots, 0, \ell_{(40)})$$

which in our case consists of all zero elements (actually 39 zero elements) followed by the artificial direct labour coefficient from (A.29). We are now prepared to state the complete modified decomposition formulae:

$$(A.31) \quad {}^*\Delta_D' = \Delta\ell' (I + \hat{a}) + \ell' (\Delta A) + {}^*\ell' (\Delta A)$$

$$(A.32) \quad {}^*\Delta_I' = \Delta\ell' (A - \hat{a} + B) + \ell' (\Delta B) - {}^*\ell' (\Delta A)$$

$$(A.33) \quad {}^*\Delta_S = \widehat{\Delta\ell} (A - \hat{a} + B)i + \hat{\ell} (\Delta B)i - \widehat{{}^*\ell} (\Delta A)i$$

It is easily seen from (A.30) and (A.31) that the modified expression for own effects change ${}^*\Delta_D'$ is now sensitive to any industry changes in total imported intermediate input coefficients and that this sensitivity is in the correct direction and of a reasonable magnitude. The modified input effects change expression ${}^*\Delta_I'$ in (A.32) follows directly from the requirement that:

$${}^*\Delta_D' + {}^*\Delta_I' = \Delta\lambda' = \lambda_2' - \lambda_1'$$

Finally, the new modified expression for output effects change ${}^*\Delta_S$ in (A.33) satisfies the identity:

$$i'{}^*\Delta_S = {}^*\Delta_I' i$$

In fact, it is easily seen that all industrial component elements of the column vector ${}^*\Delta_S$ remain unchanged as a result of the modification except for the International trade industry's output effects, which entirely absorb the modifications (previously, with Δ_S as in (A.25), the International trade industry's output effects change was identically zero).

The impacts of the modification to the empirical results of the decomposition analysis are generally very small. So the modification is applied in the text only in cases where more sensitivity of the decomposition results is required – for example, in Chapter 4. A complete comparison of unmodified estimates with modified productivity estimates can be found in Chapter 5. Again, all total labour productivity results are unaffected by the modification described in this section.

The Mathematics of Research and Development Analysis

The research and development (R & D) analysis of Chapter 4 is based on estimates of each industry's total (direct plus indirect) R & D content per unit of output delivered to final demand. The statistical sources of R & D raw data together with the transformations required to yield R & D input estimates are discussed in Appendix B. The purpose of this section is to show the mathematical formulae used to produce total R & D content calculations and their decomposition.

In Chapter 4, it is stated that a R & D content analysis is similar to an analysis of total labour requirements (per unit of output), but there are subtle differences in orientation. Briefly, the row vector of total R & D content per unit of output is simply:

$$(A.34) \quad \rho' = r'(I - A_{11}^*)^{-1}$$

where r' is a row vector of direct R & D coefficients for each production industry (there are 39) of the analysis (each coefficient is the ratio of industry R & D input to industry gross output) and the matrix A_{11}^* comes from a modification of the basic input-output model described in the first section, where now:

$$(A.35) \quad A_{11}^* = D(B + C)$$

using the notation following basic equation (A.11). In effect, then, the modification abstracts from International trade. We do not wish to assume that the R & D content of Canadian intermediate imports is ultimately derived from the R & D content of Canadian exports; at the same time, we do not have direct observations on the R & D embodied in Canadian intermediate and physical capital replacement imports. The modification (A.35) essentially implies that the R & D content of Canadian imports is equivalent to the R & D contents of the outputs of Canadian (domestic) import-competing industries that are displaced by competitive imports. (Our experiments show that this is the most effective and pragmatic assumption in terms of the regression analysis in Chapter 4.)

For about 10 production industries, the direct R & D coefficients in the row vector r' are zero. Thus, the formulation in (A.34) and (A.35) is somewhat analogous to the row vector of total labour requirements per unit of output given in equation (A.14) above. However, when considering a decomposition analysis of formula (A.34), as used in Chapter 4, a difference becomes apparent. R & D analysis is solely concerned with tracing the industrial origin of each industry's total R & D content. We are not interested in an industry's total R & D requirements leading to an R & D "productivity" analysis. Because of this difference in orientation, it is possible and reasonable to define the industries' direct and own R & D contents per unit of output as simply the direct R & D input coefficient row vector r'. Then the row vector of indirect R & D content per unit of output, or the indirect R & D input coefficient row vector, becomes:

$$\text{(A.36)} \quad r'(I - A^*_{11})^{-1} - r' = r'(I - A^*_{11})^{-1}A^*_{11}$$

Note that the decomposition is now more straightforward: direct R & D coefficients and indirect R & D coefficients are well-defined at each point in time, and the transformation into changes over time and corresponding growth rates is easy to perform. Clearly, using r' and (A.36), it is evident that the simple total of the direct R & D coefficients and the indirect R & D coefficients satisfies condition (A.34). The difference between the decomposition treatment of total labour requirements and total R & D contents is one example of various definitions that can be applied in I-O analysis (see Parikh, 1975, for a more general account).

It is again possible to translate the row vector of indirect R & D input coefficients (A.36) into a column vector of indirect R & D output coefficients by:

$$\text{(A.37)} \quad \hat{r}(I - A^*_{11})^{-1}A^*_{11}i$$

where $\hat{r}$ is a diagonal matrix composed of the direct R & D coefficients in its diagonal array, and i is a column vector of unities. However, for the growth rate analysis performed in Chapter 4, it turns out that the R & D direct input growth rates calculated from r' are strongly correlated with the R & D indirect output coefficient growth rates estimated using (A.37). This is not surprising, since the elements of the column vector:

$$(I - A^*_{11})^{-1}A^*_{11}i$$

change very little over time relative to the elements of the row vector r'.

Finally, it should be noted that the R & D analysis performed in Chapter 4 is carried out with respect to both intramural and extramural R & D in Canada during 1966-76.

An Extension of the Basic Model

In Chapter 6, an extended calculation concerning total labour requirements per unit of output delivered to final demand is described. The extension involves incorporating the labour equivalent of physical capital interest and dividend payments from the operating surplus on the production account into the basic calculation. It is easy to extend the basic model to account for this additional factor although, as we shall see, the incorporation is effected by an alternative (and equivalent) procedure. The model could be simply extended, with basic equation (A.2) becoming:

$$\text{(A.2}a\text{)} \quad q + m = Bg + Cg + Rg + e^* + x$$

where matrix R is formed from:

$$\text{(A.38)} \quad R = K\hat{p}$$

where K represents a net physical capital stock pattern matrix (disaggregated according to the commodity of origin and the industry of destination of the capital stock) so that $i'K = i'$; $\hat{p}$ is a diagonal matrix formed from the elements of vector p, each of which represents the ratio of total interest and dividend payments to total gross output, for each respective industry; and $e^* = e - Rg$. All other equations of the basic model remain unchanged. If this extension is carried out, then the row vector of total labour requirements per unit of output, formerly (A.14), now becomes:

(A.14*a*) $\lambda^{*\prime} = \ell'(I - A^*)^{-1}$

where:

$$A^* = \begin{pmatrix} A_{11}^* & A_{12} \\ A_{21}^* & A_{22} \end{pmatrix}$$

and:

$$A_{11}^* = D(I - \hat{\mu})(B + C + R)$$

$$A_{21}^* = i'\hat{\mu}(B + C + R) + i^{*\prime}N$$

A_{12} and A_{22} are the same as before.

This procedure, however, is not utilized in the actual calculations reported in Table 6-1. Instead, we work directly with the original *A* matrix is as follows.

Consider an alternative procedure in which the original *A* matrix is augmented by the following matrix bordering arrangement:

(A.39) $$E = \begin{pmatrix} A & Q \\ P & O \end{pmatrix}$$

where:

$$Q = \begin{bmatrix} D(I - \hat{\mu})K \\ i'\hat{\mu}K \end{bmatrix}$$

and:

$$P = (\hat{p} \;\; o)$$

noting that the diagonal matrix $\hat{p}$ must also be augmented to conform with matrix *A*, and that the additional column contains all zeros (representing zero interest payments for the International trade "exchange" industry, which has no effect on our analysis). Now suppose the extended total labour requirements calculation is performed as:

(A.40) $\lambda^{**\prime} = \ell^{**\prime}(I - E)^{-1}$

where:

(A.41) $\ell^{**\prime} = (\ell', 0, \ldots 0)$

In our case, there will be 39 zeros added on. We may also write:

(A.42) $\lambda^{**\prime} = (\lambda_1^{**\prime}, \lambda_2^{**\prime})$

where the first subvector contains 40 elements, and the second subvector contains 39 elements in our case. The key issue now is:

(A.43) $\lambda^{*\prime} \overset{?}{=} \lambda_1^{**\prime}$

If this equality holds, then we could obtain the results for the extended labour requirements more directly and without modifying the original *A* matrix. Indeed, the augmented *E* matrix (A.39) itself has an economic interpretation sometimes utilized in I-O analysis.

It is straightforward to see, since our interest focuses only on the subvector $\lambda_1^{**\prime}$ in $\lambda^{**\prime}$ of (A.42), that the proof of conjecture in equality (A.43) depends on the northwest corner submatrix in the inverse matrix expression $(I - E)^{-1}$, with *E* coming from (A.39). Using the well-known partitioned inverse matrix formula in Almon (1967), it turns out that:

$$(I - E)^{-1} = \begin{bmatrix} (I - A) & -Q \\ -P & I \end{bmatrix}^{-1} = \begin{pmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{pmatrix}$$

while:

$$F_{11} = (I - A)^{-1} + (I - A)^{-1} \times Q\,[I - P(I - A)^{-1}\,Q]^{-1}\,P(I - A)^{-1}$$

We can further show that F_{11} reduces to simply $(I - A - QP)^{-1}$, using a series of matrix algebra identities. Therefore, recalling (A.40) and (A.41), we find that:

$$\lambda_1^{**\prime} = \ell'\,(I - A - QP)^{-1}$$

But:

$$QP = \begin{bmatrix} D(I - \hat{\mu})K \\ i'\hat{\mu}K \end{bmatrix} (\hat{p} \;\; o) = \begin{bmatrix} D(I - \hat{\mu})K\hat{p} & o \\ i'\hat{\mu}K\hat{p} & o \end{bmatrix}$$

and:

$$K\hat{p} = R$$

So the proof of equality (A.43) is immediate, recalling the composition of matrix A^* following (A.14*a*) and of matrix A following the basic model formulation (A.11).

In Chapter 6, it is stated that the empirical results of the extended calculation for the years 1973 and 1978 should be regarded as experimental. The reason is that the required statistical data to form diagonal matrix $\hat{p}$ are only available for the year 1976 (at the time of writing); some adjustments of the 1976 data are performed to conform with available 1973 and 1978 data.[7] Also our statistical approximation of the required K matrix for both 1973 and 1978 is rather crude. Indeed, to the K matrix should also be added an inventory stock matrix disaggregated according to the commodity of origin and the industry of destination; but no such matrix or its approximation is currently available. It is, however, believed that the results displayed in Table 6-1 are not significantly biased by our adjustment and approximation methods.

B Statistics

by Lesle Wesa

Input-Output Data Requirements

Data were required from the Structural Analysis Division of Statistics Canada at various times during our work. Each request had to be satisfied six times – once each for 1961, 1966, 1971, 1973, 1976, and 1978. The valuation was always in 1971 constant prices, and the aggregation level was always a modified Aggregation M. It is assumed that the reader is familiar with the terminology used by the Structural Analysis Division of Statistics Canada. A description of their notation usually appears at the beginning of publications containing the (I-O) tables (see, for example, *The Input-Output Structure of the Canadian Economy, 1961-1974*, Statistics Canada, cat. no. 15-508E).

The aggregation was achieved by two important adjustments to the conventional I-O Aggregation M. First, Owner-occupied dwellings (corresponding to industry no. 34 and commodity no. 82) was completely removed. This implied that row 82 and column 34 of the (transposed) Make Matrix were eliminated, as were row 82 and column 34 of the Use Matrix, and the industries following in Aggregation M were subsequently renumbered accordingly, as indicated in the tables used throughout this study. Second, three dummy industries were eliminated, and integrated into the conventional real industry and commodity space. The three industries were Transportation margins (industry no. 41 and commodity no. 90), Operating, office, lab and food (industry no. 42 and commodity no. 91), and Travel and advertising, promotion (industry no. 43 and commodity no. 92). They were simply removed from the Make Matrix and the Use Matrix; but their real commodity input had to be reassigned to all other real industries according to the latters' commodity input use of the three dummy commodities. For Transportation margins, this reassignment was trivial, since there is a one-to-one correspondence (in the Aggregation M system) between the dummy commodity Transportation margins and the real commodity Transportation and storage (no. 74). For the two remaining dummy commodities, the reassignment was less trivial, and involved the preliminary step of forming a unit pattern vector of real commodity inputs into these two dummy industries. The pattern vectors were deployed to translate dummy commodity input of real industries into real commodity input, according to the magnitude of their dummy commodity input use, as revealed in the Use Matrix. The resulting "modified Aggregation M" consisted of 39 (43 minus 4) real industries and 88 (92 minus 4) real competitive commodities.

Our basic request consisted of two vectors and two matrices for each of the six years. The competitive import commodity coefficient vector μ, implicitly defined as $m = \hat{\mu}(Bg + e^* - a - v)$ for the 88 commodities, was necessary.[1] Also required were the matrix products $D(I - \hat{\mu})B$ and $D\hat{\mu}B$, where D is a domestic market share matrix and B is an industry technology matrix, and where both matrix products are of the order of 39 x 39. Finally, we needed the export commodity unit pattern vector transformed into industry space – namely, Da, where $a = (i'x)^{-1}x$, where x is restricted to allocated competitive commodity space.

Derivation of the Capital Replacement Coefficient Matrix

Most of the calculations leading to the capital replacement coefficient matrix were completed at the Economic Council, although the original input data came from Statistics Canada. The first step towards this matrix was the generation of a ratio of total capital to output for each of the 39 industries in the modified Aggregation M. Gross fixed capital stock at mid-year in 1971 constant dollars was used to measure capital. It was retrieved from the CANSIM database, but it is also published annually in *Fixed Capital Flows and Stocks*, Statistics Canada, cat. no. 13-211. Building construction and Engineering construction were summed to get Construction capital stock; and Machinery and equipment and capital items charged to operating expenses were summed to get Machinery and equipment capital stock. The industrial disaggregation was quite different from the modified Aggregation M; consequently several adjustments had to be made.

Table B-1 shows how the capital stock industries were mapped into the industries of Aggregation M. In two cases, the capital stock aggregation was finer than in Aggregation M. This was resolved by summing the components of the capital stock aggregation to yield Aggregation M in particular, Transportation and storage (no. 29) and Communications (no. 30). In the other cases, the capital stock aggregation was less detailed than in Aggregation M. For example, capital stock was only available for the whole of the mining sector, whereas it was needed for each of Metal mines (no. 4), Mineral fuels (no. 5), Nonmetal mines (no. 6), and Services to mining (no. 7). Rather than estimate capital stock for each of the components – something Statistics Canada did

Table B-1

Mapping of the Capital Stock Industry Aggregation into the Modified Industry Aggregation M

Modified Aggregation M	Capital stock aggregation
1 Agriculture	Agriculture
2 Forestry	Forestry
3 Fishing and hunting	Fishing
4 Metal mines	Mining, quarries, and oil wells
5 Mineral fuels	
6 Nonmetal mines	
7 Services to mining	
8 Food and beverages	Food and beverages
9 Tobacco products	Tobacco products
10 Rubber and plastics	Rubber
11 Leather products	Leather
12 Textiles	Textiles
13 Knitting mills	Knitting mills
14 Clothing	Clothing
15 Wood products	Wood products
16 Furniture and fixtures	Furniture and fixtures
17 Paper and allied products	Paper and allied products
18 Printing and publishing	Printing and publishing
19 Primary metals	Primary metals
20 Metal fabricating	Metal fabricating
21 Machinery	Machinery
22 Transportation equipment	Transportation equipment
23 Electrical products	Electrical products
24 Nonmetallic mineral products	Nonmetallic mineral products
25 Petroleum and coal products	Petroleum and coal products
26 Chemicals	Chemicals
27 Miscellaneous manufacturing	Miscellaneous manufacturing
28 Construction	Construction
29 Transportation and storage	Air transport
	Railway transport
	Water transport
	Motor transport
	Urban and suburban transport
	Pipelines
	Toll highways and bridges
	Grain elevators
	Warehousing
30 Communications	Broadcasting
	Telephones
31 Electric power and gas	Electric, light, power, and gas distribution
32 Wholesale trade	Trade
33 Retail trade	
34 Finance, insurance, and real estate	Finance, insurance, and real estate
35 Education and health	Commercial services
36 Amusement and recreation	
37 Services to business	
38 Accommodation and food	
39 Other personal services	

SOURCE See text.

not feel adequately informed to do – we considered only the total stock for the aggregate mining industry. When it came time to compute the ratios of capital to output, we took aggregate capital over aggregate output, and applied the same ratio to each of the components. Hence, we used one ratio for all four industries in the mining sector, one ratio for Wholesale trade (no. 32) and Retail trade (no. 33), and one ratio for Education and health (no. 35), Amusement and recreation (no. 36), Services to business (no. 37), Accommodation and food (no. 38), and Other personal services (no. 39). Note that Education and health (no. 35) has been assigned the same capital-to-output ratio as the commercial services sector. We did investigate Education and health in some detail, but we were unable to propose a ratio for it with sufficient confidence.

The denominator of each ratio corresponded to total output appearing in the I-O tables. One correction had to be made to Communications (no. 30). The capital stock measure for Communications did not include Post offices, and therefore the output of Post offices had to be subtracted from Communications output.

In order to allocate each of the 39 capital-to-output ratios over 39 industries, we needed a "capital matrix" showing final demand by each industry for capital from each industry. An approximation of this was received from Statistics Canada. We requested the value of commodity inputs (at Aggregation S) flowing into final demand for Construction and Machinery and equipment by industry (at Aggregation L). Item 46 of Aggregation S, Net indirect taxes, was to be set equal to zero. The data were to be in two forms – in 1971 constant dollars, with column totals also shown, and in normalized form – such that the sum of the elements in a column equaled unity. Unfortunately, we were unable to get the data in the requisite aggregation, and adjustments again became necessary. Table B-2 shows the mapping of commodities into Aggregation M, and Table B-3 shows the mapping of industries (that is, the columns) into Aggregation M in the cases where adjustments had to be made.

Since we had separate data on final demand by industry for Machinery and equipment and for Construction, the normalized capital matrix was of the order of 39 x 78. The first 39 columns, showing final demand for Machinery and equipment, had zero in row 28 and a value between (and including) zero and unity in all other rows. The last 39 columns, showing final demand for Construction, had unity in row 28 (corresponding to Construction) and zero in all other rows.

The Machinery and equipment capital-to-output ratio for industry *i* could then be distributed according to the industrial distribution of demand for Machinery and equipment by industry *i*, that is, according to the coefficients in column *i* of the normalized capital matrix. Similarly, the Construction capital-to-output ratio for industry *i* could be distributed according to the coefficients in column 2*i* of the normalized capital matrix. This would imply that 100 per cent of the Construction capital-to-output ratio for industry *i* would appear in row 28, column 2*i*, of the new matrix. These operations were performed, and the final 39 columns of the new matrix were shifted to the left into the first 39 columns in order to yield a 39 x 39 "capital-output matrix."

Table B-2

Mapping of the Capital Matrix Commodities into Modified Industry Aggregation M

Modified Aggregation M	Capital matrix commodities
10 Rubber and plastics	Rubber, leather, and plastic fabricated products
12 Textiles	Textile products
15 Wood products	Lumber, sawmill, and other wood products
16 Furniture and fixtures	Furniture and fixtures
18 Printing and publishing	Printing and publishing
20 Metal fabricating	Metal fabricated products
21 Machinery	Machinery and equipment
22 Transportation equipment	Autos, trucks, and other transportation equipment
23 Electrical products	Electrical and communications products
24 Nonmetallic mineral products	Nonmetallic mineral products
27 Miscellaneous manufacturing	Miscellaneous manufactured products
32 Wholesale trade	Wholesale margins
33 Retail trade	Retail margins
29 Transportation and storage	Transportation margins

SOURCE See text.

Table B-3

Mapping of the Capital Matrix Industries into Modified Industry Aggregation M, Special Cases Only

Modified Aggregation M	Capital matrix industries
1 Agriculture	Agriculture and fishing
3 Fishing and hunting	Agriculture and fishing
4 Metal mines	Mines, quarries, and oil wells
5 Mineral fuels	Mines, quarries, and oil wells
6 Nonmetal mines	Mines, quarries, and oil wells
7 Services to mining	Mines, quarries, and oil wells
13 Knitting mills	Clothing and knitting
14 Clothing	Clothing and knitting
29 Transportation and storage	Railway transport
	Urban transit
	Water transport
	Motor transport
	Grain elevators
	Air transport
30 Communications	Telephones
	Broadcasting
31 Electric power and gas	Electric power
	Gas distribution
32 Wholesale trade	Trade
33 Retail trade	Trade
35 Education and health	Commercial services
36 Amusement and recreation	Commercial services
37 Services to business	Commercial services
38 Accommodation and food	Commercial services
39 Other personal services	Commercial services

NOTES Where the capital matrix industries were more aggregate than modified Aggregation M, the normalized column vector of the aggregate was replicated for each of the components. Where the capital matrix industries were more disaggregated than modified Aggregation M, the sum of each commodity input (in 1971 dollars) was taken over all the component industries. The resulting vector was normalized, and became the observation for the Aggregation M industry.

SOURCE See text.

What we then had was a matrix showing capital stock in industry *j* derived from industry *i*, relative to output of industry *j*. What we wanted was capital stock used by industry *j* in year *t* derived from industry *i*, relative to the output of industry *j* – a "capital replacement coefficient matrix." This was reached by dividing each element of the capital-output matrix by a life assumption matrix. The latter was of the order of 39 x 39, and represented the life expectancy of each element in the capital-to-output ratio.

The life assumptions were drawn from three sources. For the industries Rubber and plastics (no. 10), Leather products (no. 11), Textiles (no. 12), Wood products (no. 15), Furniture and fixtures (no. 16), Printing and publishing (no. 18), Metal fabricating (no. 20), most of Transportation equipment (no. 22), Electrical products (no. 23), Nonmetallic mineral products (no. 24), and Chemicals (no. 26), the life assumptions were inferred from an earlier study by Postner (1979), which required similar assumptions, or from a study by Grosse (1953), which made assumptions for selected U.S. industries. For most of these industries, the service life assumed for capital derived from the industry was the same, regardless of which industry used it.

For Machinery (no. 21), part of Transportation equipment (no. 22), and Construction (no. 28), the values were derived from data appearing in *Fixed Capital Flows and Stocks*, Statistics Canada, cat. no. 13-211. The service life of capital from each of these three industries differed, depending on which industry used it. In some cases, the information was very detailed. In Agriculture (no. 1), for example, different service lives were foreseen for Passenger vehicles and for Commercial vehicles. The service life of capital from Transportation equipment into Agriculture was then calculated as a weighted average of the two service lives, where the weights were the relative proportions of Passenger vehicles and Commercial vehicles in Agriculture's capital stock. Building construction and Engineering construction also had different service lives for most industries, and the resolution of a service life for Construction (no. 28) was handled in a similar manner.

The life assumptions for capital flowing from Transportation and storage (no. 29), Wholesale trade (no. 32), and Retail trade (no. 33) into industry *j* were calculated as a weighted average of the service lives of the Machinery and equipment (not Construction capital) of the other capital-supplying industries to industry *j*. The weights were determined by the relative importance of the capital-supplying industries, as indicated by the normalized capital matrix.

We performed a few checks on the capital replacement coefficient matrix implied by our set of life assumptions, and judged the expected service lives for Transportation equipment (no. 22) to be too short. The life expectancy for capital flowing from this industry was therefore increased by 30 per cent across all recipient industries.

One of the checks compared the product of the capital replacement coefficient matrix and the vector of gross outputs with the vector of final demand by business for Machinery and equipment and for Construction. Data for the two vectors were available from the published I-O tables. Essentially, this is a comparison of annual replacement investment satisfied by an industry relative to total gross annual investment satified by that industry. A ratio of about 0.5 was considered reasonable, and a ratio exceeding unity impossible.

Another check involved a comparison of the vector of column totals of the capital replacement coefficient matrix and a vector of the ratio of operating surplus to gross output (both of which were measured in current dollars). Other operating surplus appears in the Use Matrix of the I-O tables. It includes capital consumption allowances, profits and other investment income, and inventory valuation adjustments. As such, the ratio of operating surplus to gross output should exceed the column total of the capital replacement coefficient matrix in the case of each industry. Fishing and hunting (no. 3) broke this rule by a fairly large margin, thereby flagging this as an industry posing a potential problem. Adjustments were made to Fishing and hunting in a subsequent stage – more particularly, the values appearing in column 3, rows 21 (Machinery) and 40 (International trade) were reduced by one-third in the interindustry coefficient matrix.

Alternate Measures of Labour Input

We did a fair amount of investigation before we made a decision on what measure of labour input to use. For our basic calculations, we chose "man-years employed." It is not the best measure of labour input from a conceptual point of view, but it is the measure used by the Structural Analysis Division at Statistics Canada, and it has therefore already been adjusted to meet the needs of the I-O data. The fact that it is in the same industrial aggregation saved us from making adjustments and assumptions in order to get the breakdowns to correspond.

Essentially, "man-years employed" in any given industry is the sum of "paid workers" and "other than paid workers" less employment in "own account construction." The latter is reallocated to the Construction industry. A paid worker is a person drawing pay for services rendered or for paid absence during the survey reference week and for whom an employer makes Canada/Quebec Pension Plan and/or Unemployment Insurance contributions. It includes full-time employees, part-time employees (those who regularly work fewer hours than the standard work week of the firm), and casual employees (those who are hired for discontinuous periods and who have worked at least seven hours during the reference period). It includes employees working for part of the reference period but unemployed or on strike for the rest. It does not include persons providing services to an establishment on a contract basis. Data on paid workers were drawn from a variety of sources, depending on the industry. *Estimates of Employees by Province and Industry*, Statistics Canada, cat. no. 72-008, was the source for industries engaged in forestry, construction, transportation, communication and other utilities, trade, finance, insurance, and real estate, and community, business and personal services. *Manufacturing Industries of Canada: National and Provincial Areas*, Statistics Canada, cat. no. 31-203, was the source for the manufacturing sector; *General Review of the Mineral Industries*, Statistics Canada, cat. no. 26-201, for the mining sector; and *The Labour Force*, Statistics Canada, cat. no. 71-001, for industries engaged in agriculture and fishing and trapping.

Workers other than paid workers include the self-employed, unpaid family workers, and working owners and partners of unincorporated businesses and professional practices. Data for most industries were provided by special tabulations by the Labour Force Survey Division. In the case of the manufacturing sector, data covering workers other than paid workers were taken from *Manufacturing Industries of Canada, National and Provincial Areas*, Statistics Canada, cat. no. 31-203, under "working owners and partners." For the mining sector, the data were obtained from the decennial censuses.

The sum of paid workers and other than paid workers yielded total employment in an industry, including those employed in construction within the industry. An estimate of "own account construction" employment was derived as follows. Total wages and salaries in industry *i* were divided by paid workers in industry *i* to yield average wages and salaries in *i*. Assuming that construction workers were paid at the same rate as other workers within the industry, wages and salaries paid to own account construction workers were divided by average wages and salaries to give employment in own account construction in industry *i*. This figure was then subtracted from total employment in industry *i* and added to employment in the Construction industry.

Also included within the business sector part of the Construction industry was employment in government sector construction and government own account construction and employment in personal sector own account construction.

The drawbacks in using "man-years employed" are as follows. Included within the measure are those who work less than the standard work week (part-time), those who work for discontinuous periods (casual), and those who are absent for part of the survey reference period (due to strike, illness, or vacation). No allowance is made for employees who work overtime. In the case of a multiple job holder, the individual is recorded on the payroll records of each of his employers and, if both his jobs are in the same industry, there is double counting of employees. Failure to consider such circumstances results in some distortion of the actual labour input.

A better measure of labour service is "man-hours worked." It is the sum of man-hours spent at the place of employment by persons employed. It is an improvement, since it reflects only the hours actually worked by part-time and casual persons and captures hours spent in overtime. It also excludes hours for which payment is made but during which no work is done – time on vacation, illness, accident, or jury duty.

In the case of nonmanufacturing industries, "man-hours worked" was calculated as the product of the number of persons employed and the average number of hours worked in each year. Average hours worked were obtained from tabulations by the Labour Force Survey Division. Estimates were made independently for paid workers and other than paid workers, and, for the period since 1975, the latter class was further divided into self-employed and unpaid family workers. In the case of the manufacturing industries, "man-hours worked" was calculated as the sum of man-hours worked by production workers, man-hours worked by salaried employees, and man-hours worked by other than paid workers. The source for the first component was *Manufacturing Industries of Canada: National*, Statistics Canada, cat. no. 31-203, and for the second component, *Employment, Earnings and Hours*, Statistics Canada, cat. no. 72-002, and *Labour Costs in Canada: Manufacturing*, Statistics Canada, cat. no. 72-612. The third component was the product of other than paid workers in each manufacturing industry and average hours worked per year in all manufacturing by other than paid workers. The source here was *The Labour Force*, Statistics Canada, cat. no. 71-001.

Calculation of Traditional Productivity Growth Measures

Traditional productivity levels and growth rates were calculated for comparison with the measures derived from our analysis. For a given year, the traditional productivity level was calculated as gross domestic product at factor cost for that year, divided by employment.[2] Data for the numerator were available from the Use Matrix of the I-O tables, and data for the denominator were the same as used in our productivity measures.

Derivation of an R&D Stock

Data on R & D expenditures by industry are published by the Education, Science and Culture Division of Statistics Canada and, in recent years, appear in *Annual Review of Science Statistics*, Statistics Canada, cat. no. 13-212. Publication of the data began in 1955, but getting consistent time-series of expenditures by industry is very difficult. Statistics Canada has varied its presentation of the data over the years – neither the industrial aggregation nor the definition of "R & D expenditures" has remained constant. To illustrate the change in definition, only current R & D expenditures are available for 1955 and 1956, while, for subsequent years, these are combined with capital R & D expenditures to produce a total. Also, R & D expenditures funded by government R & D prime contracts are not included for 1955 and 1956, but they are included for later years. There has been a lack of consistency in reporting procedures: reporting units change, firms shift from industry to industry, and data are revised from year to year. With considerable interpolation and extrapolation of data, we were able to construct a series of R & D expenditures at a suitable disaggregation by industry from 1957 on.

R & D expenditure data were much less disaggregated for the R & D industries than were the data for the 39 I-O industries in our model. We were able to relate only 15 of the I-O manufacturing industries to the R & D industries, with the fifteenth being Miscellaneous manufacturing (no. 27) and being judged so rough a match as to not warrant inclusion. The breakdown of R & D by nonmanufacturing industries was very limited. In 1955, there were three groups: Mining, quarrying, and oil wells; Transportation, storage, communication, and public utilities; and Other nonmanufacturing. For 1976, only one additional category was available: the primary industries category was divided into Mines and Gas and oil wells.[3]

Industries not covered by the R & D data included those engaged in agriculture, forestry, fishing and trapping, trade, finance, insurance, real estate, and community (some of the) business, and personal service industries. Statistics Canada found the activities of these industries to involve little or no R & D.

Table B-4 shows how the R & D expenditure industry groups have been mapped into the I-O industry groups.

Table B-4

Mapping of R & D (Intramural) Expenditure Industry Groupings into 15 I-O Manufacturing Industry Groupings

I-O manufacturing industry	R & D expenditure manufacturing industry	Date	Remarks
8 Food and beverages	Food and beverages	1957-70	
	Food, beverages, and tobacco	1971-76	An estimate of R & D expenditures by the tobacco industry was made. This amount was then reallocated to another I-O manufacturing industry.
10 Rubber and plastics	Rubber	1957-70	
	Rubber and plastic products	1971-76	
12 Textiles	Textiles	1957-76	
15 Wood products	Wood products	1957-59	R & D expenditures for Wood industries and Furniture and fixtures were shown as a total under Wood products. An estimate of the Wood industry component was made to correspond to I-O industry 15.
	Wood	1960-71	
	Wood	1972-76	R & D expenditures for Wood industries and Furniture and fixtures were again shown as a total under Wood. An estimate of the Wood industry component was made to correspond to I-O industry 15.
16 Furniture and fixtures	Wood products	1957-59	R & D expenditures for Wood industries and Furniture and fixtures were shown as a total under wood products. An estimate of the Furniture and fixtures component was made to correspond to I-O industry 16.
	Furniture and fixtures	1960-71	
	Wood	1972-76	Same correction applied as over 1957-59.
17 Paper and allied products	Paper	1957-72	
	Wood-based	1973-76	In recent publications, Paper and allied products industry R & D expenditures were grouped with other Wood-based expenditures. An estimate of that component was made to correspond to I-O industry 17.
19 Primary metals	Iron and steel products and Nonferrous metal products	1957-58	R & D expenditures were grouped as Iron and steel products and Nonferrous metal products. These combined groups encompassed I-O industries 19, 20, and 21. An estimate for I-O industry 19 was based on the percentage distribution of the three groups in 1959.
	Primary metals	1959-62	
	Primary metals (ferrous) plus Primary metals (nonferrous)	1963-76	R & D expenditures by Primary metals industries were published separately for ferrous and nonferrous metals. To correspond to I-O industry 19, the two were added.
20 Metal fabricating	Iron and steel products and Nonferrous metal products	1957-58	Same adjustment applied as for I-O industry 19 during that period.
	Metal fabricating	1959-76	

Table B-4 (concl'd)

I-O manufacturing industry	R & D expenditure manufacturing industry	Date	Remarks
21 Machinery	Iron and steel products and Nonferrous metal products	1957-58	Same adjustment applied as for I-O industry 19 during that period.
	Machinery	1959-70	
	Business machines and Other machinery	1971-76	R & D expenditures were published separately for Business machines and Other machinery. The two were summed to reach an estimate for I-O industry 21.
22 Transportation equipment	Transportation equipment	1957-62	
	Aircraft and parts and Other transportation equipment	1963-76	R & D expenditure are published separately for Aircraft and parts and Other transportation equipment. The two were summed to reach an estimate for I-O industry 22.
23 Electrical products	Electrical products	1957-76	
24 Nonmetallic mineral products	Nonmetallic mineral products	1957-76	
25 Petroleum and coal products	Petroleum and coal products	1957-62	
	Petroleum products	1963-76	
26 Chemicals	Chemical and chemical products	1957-62	
	Drugs and medicines and Other chemical products	1963-76	R & D expenditures were published separately for Drugs and medicines and Other chemical products. The two were summed to reach an estimate for I-O industry 26.
27 Miscellaneous manufacturing	Other manufacturing	1957-64	R & D expenditures by Other manufacturing industries included R & D by Tobacco, Leather, Printing and publishing, Knitting and clothing mills, in addition to the I-O industry 27 Miscellaneous manufacturing. No attempt was made to match these industries, as it was judged that the estimate would be too crude.
	Scientific and professional instruments and Other manufacturing	1965-76	

SOURCE See text.

R & D expenditures are classified as intramural or extramural. The former refers to expenditures for work performed within the reporting company, and the latter covers expenditures for work performed outside the reporting company by other firms and organizations. Extramural payments may be made to organizations within Canada or outside Canada. The simple sum of intramural and extramural does not yield total R & D expenditures, since there exists some minor double-counting. R & D performed within one reporting company, but funded by another reporting company, may be included twice. Table B-5 indicates relative magnitudes of these types of expenditures during selected years.

Statistics Canada also distinguishes between current R & D expenditures and capital R & D expenditures. Current expenditures cover labour costs and other current costs, such as noncapital purchases of materials, supplies, and equipment, but exclude capital depreciation. Capital expenditures cover expenditures on fixed assets used in the R & D program: land, buildings, instruments, and technology. Our analysis deals with the sum of the two.

Several steps were involved in the conversion of annual R & D expenditures into an R & D stock. We began by deflating the R & D expenditure series by the gross national expenditures Implicit Price Index for Machinery and equipment. This having been done, we selected a depreciation rate of 10 per cent, and assumed that R & D expenditures in the first observed year, 1957, were only adequate to cover depreciation in that year. With data on R & D expenditures (in 1971 dollars) known, the R & D stock in 1957 would be the product of R & D expenditures

Table B-5

R & D Expenditure by All Canadian Firms, Selected Years, 1961-76

	Intramural			Extramural		
	Current	Capital	Total	Inside Canada	Outside Canada	Total
	(Millions of dollars*)					
1961	114.0	13.5	127.5	4.3	31.2	35.5
1966	266.4	50.7	317.1	13.8	30.8	44.6
1971	401.3	63.2	464.5	31.5	51.6	83.1
1976	674.0	70.0	744.0	71.8	81.0	152.8

*Current dollars.

SOURCE *Industrial Research and Development Expenditures in Canada*, Statistics Canada, cat. no. 13-532, 1967. *Annual Review of Science Statistics*, Statistics Canada, cat. no. 13-212, 1978. *Standard Industrial R & D Tables 1972-1981*, Science Statistics Centre, Statistics Canada, Ottawa, November 1981.

(1957) times 10. The R & D stock in 1958 would then be the sum of R & D expenditures in 1958 and the R & D stock in 1957 less 10 per cent of the 1957 R & D stock lost through depreciation. In all following years, R & D stock year t would be the sum of R & D expenditures year t and R & D stock year ($t - 1$) less 10 per cent of the R & D stock year ($t - 1$). During the procedure, care had to be taken that the base observation (R & D expenditure in 1957) was not so large as to cause a gross overestimate of R & D stock and an associated depreciation rate that exceeded annual R & D expenditures. If such a case arose, an average of several years' annual expenditures was used to derive a base observation, instead of using the 1957 value.

R & D stock series were generated for total intramural expenditures from 1957, for total extramural expenditures made outside Canada from 1963 (the earliest year possible), for the sum of total intramural and extramural expenditures made outside Canada from 1963 on, and for total extramural expenditures made both inside and outside Canada from 1963 on. Once the stock series became available, it was a straightforward procedure to calculate average annual growth rates between selected years.

Sensitivity Tests

It is widely recognized that the measure of output in many service industries is inadequate. This is not without reason. It is not always clear what the commercial service industries produce. What is the output of banks, for example, or retail stores? Even assuming that this is settled, there remains the question of how to measure the volume of services produced over time and how to weight the relative importance of services within one industry. Market prices are generally used to weight the output of goods-producing industries, but explicit market prices are often not available for services. Such conceptual difficulties and data limitations prevent construction of the ideal measure of real value-added or net output. Instead, output indexes are developed from data relating to gross output, from employment data, and on the basis of the behaviour of other variables considered to be reasonable proxies for output.

In recent years, research has been under way to improve measures of service output. We were particularly interested in work relating to Finance, insurance, and real estate (no. 34). This covers banks and credit unions, insurance, other finance, and insurance, real estate, and government royalties on natural resources. Hirshhorn and Geehan (1977) (FIRE) propose a new methodology for measuring life insurance output, one analagous to that traditionally used for multi-product industries. Geehan and Allen (1978) make a similar proposal for savings and credit institutions. In an attempt to remove the suspected downward bias from our measure of output for this industry, we adjusted our data such that the rate of growth over the 1971-76 period was the same as that calculated by Geehan and Allen. Our rates of growth for 1961-66 and 1966-71 do not differ much from theirs; it is during the 1970s that the difference is most dramatic.

The ratio of the I-O 1976 output for FIRE to 1971 output was 1.272. The ratio of the output index as calculated by Geehan and Allen was 1.553. Their ratio was 1.221 times the I-O ratio. Assuming that the 1971 output levels were the same, this implied that the 1976 output level, as recorded by them, was 1.221 times the I-O level. This became our adjustment factor, and each time 1976 FIRE output appeared in our analysis, it was multiplied by 1.221. In particular, row 34 of the interindustry coefficient matrix was multiplied by 1.221; column 34 of the same matrix was divided by 1.221; and element 34 of the direct labour coefficient vector was divided by 1.221.

All matrix manipulations that were performed on the original data were then applied to the adjusted data.

Aggregation of the Productivity Growth Rates

For each of our five productivity measures and for every pair of years, there were 40 growth rates – one per industry. To calculate a growth rate aggregated over all industries for each of the productivity measures, it was necessary to again request data from Statistics Canada. They provided us with a vector of final demand in industry space for each of the four years. It was calculated by summing across the columns of the final demand matrix of the I-O tables, ignoring the domestic exports, re-exports, and imports columns, and by converting the rows from commodity space to industry space. Imputed rent from owner-occupied dwellings (commodity no. 82) was eliminated, and Operating, office, lab, and food (commodity no. 91) and Travel, advertising, and promotion (commodity no. 92) were integrated into other industries.

It was necessary to make several adjustments to these four final demand vectors. First, capital replacement demand (depreciation) was subtracted from final demand. Second, final demand for imports was removed from each industry and reallocated to International trade (no. 40). Also put into this industry were noncompeting imports. These were approximated by the element in the noncompeting imports row and the nondurable consumer expenditure column of the final demand matrix. Third, to allow for unbalanced trade, the normalized export pattern vector for each year was multiplied by the balance of trade in that year, and was added to the vector created in step two. Finally, the adjusted final demand vector was normalized, and the components became the weights in the subsequent aggregations.

The aggregate total labour productivity growth rate was calculated by multiplying each element of the vector of direct plus indirect labour requirements λ by its respective weight for each year, summing over all components of the resultant vector, taking the reciprocal, and calculating growth rates between the reciprocals in different years. To test for the impact of a change in weights on the growth rates, the vector of direct plus indirect labour coefficients for each year was aggregated not only according to the adjusted final demand weights of the corresponding year, but also according to the weights of the other three years. Rates of growth were then calculated between the reciprocal of the λs from different years, but were aggregated according to the same weights.

The impact of the adjustment to FIRE on aggregate total labour productivity growth was measured by repeating this whole process, but using the vector of direct and indirect labour requirements derived for 1976 in the previous section. Similarly, the impact of using "man-hours worked" data, instead of "man-years employed" data, was checked by substituting the vector for λ derived in that analysis.

The aggregation of the own effects, input effects, and output effects components and the total associated effects of the productivity growth rates was somewhat more complicated. To begin with, λ in year t was aggregated according to the weights in year t, and the reciprocal was taken. Then, the change in labour requirements over the period t to $(t + 5)$ was added to λ in year t. The 40 elements of the new vector were aggregated according to the weights in year $(t + 5)$, and the reciprocal was taken. The growth rates between the reciprocals were then calculated.

As a rough check on the calculations, the aggregate total labour productivity effect should approximate the sum of the aggregate own effects and input effects; and the aggregate total associated effects should approximate the sum of the aggregate own effects and output effects. The discrepancy in each case is the difference in aggregation weights between years $(t + 5)$ and t multiplied by λ_t.

Computer Program

All our programming needs were met by the Statistical Analysis System (SAS). This is an easy-to-use computer system with all the tools that we required for data analysis. These included information storage and retrieval, file handling, data modification and programming, and statistical analysis. Because of the nature of our work, one procedure within the package was particularly useful – namely, *PROC MATRIX*.

Notes

CHAPTER 2

1 Later in this study, and particularly in Chapter 6, we have much to say about the possibilities of performing the analysis at finer levels of industrial disaggregation.

2 Final demand, in our analysis, actually includes total consumer expenditures, total government (net) expenditures, total net fixed capital formation, and the international trade balance. The case for considering this study's final demand as final consumption is made in Scott (1979): net capital investment is a discounted future consumption and the trade balance is a form of net (dis)investment.

3 It must be noted that this formulation is a simplification of the more complete underlying input-output productivity model given in Appendix A. Also see comments to follow in this chapter.

4 The treatment of the international trade balance, either negative or positive, is explained in Appendix A. The Canadian trade balance of allocated commodities is never more than about 7 per cent (in absolute value) of either total commodity exports or total commodity imports during the time period analysed. The appendix I-O model also gives a full account of the adjustment required to reflect changes in international terms of trade.

5 Note that the presence of this factor tends to make traditionally measured industry productivity levels higher than productivity levels in corresponding industries measured using the alternative approach.

6 All productivity growth rates estimated in this study are rounded to the nearest decimal point; we do not claim any further significant accuracy.

7 The OECD *Economic Outlook* (July 1981) reports a separate average annual terms-of-trade productivity adjustment for Canada during 1972-75, worth 0.8 percentage points, using a different methodology.

8 The same cannot be said for the procedure in Nordhaus (1972), which concerns a similar problem.

9 For further details, see discussion in Chapter 6 and Tables 6-2 and 6-3.

CHAPTER 3

1 The procedure is essentially based on Wolff (1979), but we have introduced many modifications of the original decomposition process – all of which is provided in Appendix A.

2 Our experimental measure refers mostly to the financial components of FIRE; see Geehan and Allen (1978). We assume that the real output adjustment of the financial components (official vs. experimental measures) carries through for all other components of FIRE as well. Clearly our empirical results should be regarded as tentative.

3 Note that the correct revised aggregation must also reflect changes in final demand weights, since FIRE is an important component of the underlying model's final demand sector.

4 The final demand weights used for aggregation in the "projected" year 1981 is assumed to be the same as the observed final demand weights in the base year 1976.

5 This explains why the aggregate output effects productivity growth rates do not equal the aggregate input effects growth rates in the various tables (particularly Table 3-7). If each industry's output effects are correctly decomposed into their distributed input effects, then the summation of all decomposed aggregate input effects growth rates equals the aggregate input effects productivity growth given in the various tables (aside from a very small interaction effects approximation).

CHAPTER 4

1 There is some minor overlapping between the two "distinct" types of R & D; see Appendix B.

2 It should be noted that we are dealing here with multiple regression analysis, based on variable coefficients, rather than on constant coefficients; see Zellner (1962) and Postner (1971) for further discussion regarding implicit assumptions and a suggested interpretation.

3 The decompositon method used to yield the own effects component of productivity growth rates used in this chapter is a slight modification of the one described in Chapter 3. The rationale of the modification is explained in Chapter 5 and in Appendix A. It is argued that the modification produces productivity growth rates better suited to the purposes of the present R & D analysis.

4 A case can be made for also including an "indirect" (k/g) variable growth rate in the regression. Both the direct and indirect variables can be omitted, however,

if the own effects measure of productivity growth is extended to account for the labour-embodied cost of net physical capital stock input growth. Such an extension follows from the discussion in the last section of Appendix A. In this case, both physical capital replacement and physical capital expansion expenditures should be added to the current intermediate input matrix used to ultimately measure the indirect R & D contents, presumably yielding a full sensitivity to interindustry technology flows (see also Chapter 6). Clearly, then, the methodology of the present chapter is subject to improvement.

5 Since all "t" ratios except one in the empirical regression have absolute values greater than unity, there is little more to be gained in terms of "explanation" by successively eliminating the statistically insignificant variables; see Theil (1961) and Haitovsky (1969).

6 We cannot maintain both r_1 and r_1^* in the regression, since the two R & D input variables are strongly correlated, though r_1^* is more appropriate; similar comments apply to r_3 and r_3^*.

7 Northern Telecom and Bell-Northern both evidently "report" up the hierarchy through Bell Canada alone during the time period concerned.

8 The Canadian statistical R & D problem cannot be "swept under the rug" by appealing to the "law of large numbers."

Chapter 5

1 It is generally permissible to compare total labour productivity growth rates in Table 5-1 with those in Table 2-1 and Table 2-4 (subperiod analysis); similarly, one could compare traditional labour productivity growth rates in Table 5-2 with those in Tables 2-3 and 2-5.

2 The aggregate productivity growth estimates to two decimal places for the two measures are 0.25 per cent and 0.27 per cent, respectively.

Chapter 6

1 The following property applies both to total labour productivity levels and total labour productivity growth rates.

2 For example, we would argue that the theoretical assumptions ("producer equilibrium") usually underlying the translog-production function and productivity estimation are not satisfied (or approximately satisfied) by statistical observations generated by a central statistical agency. On the other hand, the "fixed coefficients" convention of input-output productivity analysis is entirely consistent with the commercial cost accountant's practice of estimating standard direct costs.

3 An increase in total (real) final consumption per capita does not necessarily raise economic welfare. The latter depends on distribution and the patterns of individual utility functions. There is a huge literature on this subject; see Chipman and Moore (1976) and Sen (1979). The safest course to guarantee a rise in economic welfare is the balanced productivity growth path described in the text. This path is essentially equivalent to the assumption of homothetic individual utility functions (income elasticities of final consumption commodities being unitary) – a necessary and sufficient condition for an increase in total (over all individuals and commodities) final consumption to always translate into an unambiguous rise in economic welfare.

4 Intuitively speaking, the special role of Transportation and storage is not surprising. It is an old economic development "trick" to emphasize an efficient transportation system. After a while, people begin saying, "All we have is efficient transportation, but it seems to help almost everything!" People, of course, are mainly interested in final consumption.

5 Actually, industrial physical capital stock is now increasingly rented rather than owned by the user industry; the gross rental service payments are part of Services to business or statistically assigned to Finance, insurance, and real estate. The incorporation of all input-output flows in our productivity analysis, together with the deployment of a physical capital stock matrix disaggregated by industry of origin and industry of destination, helps us avoid most of the problems associated with capital stock ownership and usage, as described in Garston (1983).

6 A similar technique can also be used to calculate the labour-embodied equivalent of depletion allowances with respect to Forestry (no. 2) and the four mining industries (nos. 4 to 7). Unfortunately, Canadian natural resource development expenditures are not capitalized, and their commodity composition are unknown, so this particular estimation cannot be reported at this time.

7 Consumption expenditures contain the commodity expenditures of Owner-occupied dwellings (see Chapter 2).

8 The case for considering this study's final demand as final consumption is made in Scott (1979): net capital investment is a discounted future consumption, and the trade balance is a form of net investment.

9 It is also potentially possible to endogenize the commodity sales of private nonprofit institutions, consolidated at present with personal consumption expenditures. Unfortunately, the required data are not available. But there are limits to "mixing" government and nonprofit institutions with the business sector.

10 The two tables are not entirely consistent. Aside from the difference in years, final demand weights in 1976 must be adjusted to reflect the endogenization of both physical capital replacement and interest payments (on the production account) in Table 6-1. If this is done, the final demand weight for Construction (no. 28) is affected most, and is adjusted downward.

11 Note that the objective of raising aggregate productivity levels may conflict with the ultimate goal of increasing economic welfare along the path described

earlier. In our view, the economic welfare goal should receive priority.

12 It should be noted, though, that there are severe measurement problems in "correctly" estimating total labour productivity levels in the service industries mentioned in this paragraph (see also the third section of Chapter 3).

Appendix A

1 The dimension of the noncompetitive commodity vector is not necessarily equal to that of the competitive commodity vector. It is assumed that noncompetitive commodities do not contain capital goods and that noncompetitive commodities are not exported. These assumptions are consistent with Statistics Canada conventions.

2 Total Canadian re-exports equal less than 2 per cent of total exports over the 1971-78 period. It is also possible to extend the balance-of-trade equation (A.6) to account for competitive import tariff revenue. The model solution then becomes considerably more complicated, but still feasible. We implicitly exclude tariff revenue, and consider this variable as a primary (indirect tax) input of a final demand category.

3 The decomposition formula described by (A.20), (A.21), and (A.22) is essentially similar to a formula given in Wolff (1979). The modifications made in our study yield a more symmetrical approach. There are also differences between the Wolff basic I-O model and the one used in this study, the major difference being with respect to international trade. Later in this appendix, an adjustment to the decomposition formula is introduced and defended. Note that the terminology used to describe the decomposition components in this study is not the same as that in Wolff (1979).

4 Examples of this phenomenon are given below and in Chapter 6.

5 Other tables in Chapter 3 exhibit the transformed results of decomposition analysis, showing only the derived average annual growth rates.

6 If $A_{22} \neq 0$ (see formulations following equation (A.11)), as, for example, with re-exports distinguished, the following modification development becomes a little more complicated, but still feasible and defendable.

7 The adjustments are made on the basis of observed data for operating surpluses and gross outputs among the industries for the years 1973, 1976, and 1978. Note that an alternative is to choose relevant interest rates for the two years 1973 and 1978, and thus infer the elements of vector p, using total physical capital stock for each industry. This alternative procedure is implicitly used by Carter (1970, pp. 158-59) in another context.

Appendix B

1 This notation is discussed in *The Input-Ouput Structure of the Canadian Economy, 1961-1974*, Statistics Canada, cat. no. 15-508E.

2 Traditional productivity growth rates are essentially the same, whether measured at factor cost or at (constant) market prices.

3 Subsequent to our analysis, a finer breakdown of the service industries was published for 1972-81. It separated out electrical power and engineering and scientific services.

List of Tables

Bibliography

ALMON, Clopper, Jr. 1967. *Matrix Methods in Economics*. Reading, Mass.: Addison-Wesley.

ARMSTRONG, Alan. 1974. *Structural Change in the British Economy, 1948-1968*. A Programme For Growth, edited by Richard Stone, vol. 12. New York: Halsted.

CARTER, Anne P. 1970. *Structural Change in the American Economy*. Studies in Technology and Society. Cambridge, Mass.: Harvard University Press.

CHIPMAN, John S., and MOORE, James C. 1976. "Why an Increase in GNP Need Not Imply an Improvement in Potential Welfare." *Kyklos* 29(3):391-418.

CLARK, Kim B., and GRILICHES, Zvi. 1982. "Productivity Growth and R & D at the Business Level: Results from the PIMS Data Base." National Bureau of Economic Research, Working Paper 916, Cambridge, Mass., June.

CLARK, Peter K. 1982. "Inflation and the Productivity Decline." *American Economic Review: Papers and Proceedings* 72(2):149-54.

DENISON, Edward Fulton. 1982. *The Sources of Economic Growth in the United States and the Alternatives before Us*. New York: Committee for Economic Development.

ECONOMIC COUNCIL OF CANADA. 1980. *Seventeenth Annual Review: A Climate of Uncertainty*. Ottawa: Supply and Services Canada.

———. 1983. *The Bottom Line: Technology, Trade, and Income Growth*. Ottawa: Supply and Services Canada.

GARSTON, Gordon J. 1983. "Canada's Capital Stock." Economic Council of Canada, Discussion Paper 226, Ottawa, February.

GEEHAN, Randall, and ALLEN, Len. 1978. "Measuring the Real Output and Productivity of Savings and Credit Institutions." *Canadian Journal of Economics* 11(4):669-79.

GRILICHES, Zvi. 1979. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics* 10(1):92-116.

GROSSE, Robert. 1953. "The Structure of Capital." In *Studies in the Structure of the American Economy*, edited by Wassily Leontief et al. New York: Oxford University Press.

HIRSHHORN, Ron, and GEEHAN, Randall. 1977. "Measuring the Real Output of the Life Insurance Industry." *The Review of Economics and Statistics* 59(2):211-19.

HAITOVSKY, Y. 1969. "A Note on the Maximization of $\bar{R}^2$." *American Statistician* 23(1):20-21.

JARRETT, J. Peter, and SELODY, Jack G. 1982. "The Productivity-Inflation Nexus in Canada, 1963-79." *Review of Economics and Statistics* 64(3):361-67.

LEONTIEF, Wassily. 1946. "Exports, Imports, Domestic Output and Employment." *Quarterly Journal of Economics* 60(2):171-97.

———. 1953. "Structural Change." In *Studies in the Structure of the American Economy*, by Wassily Leontief et al. New York: Oxford University Press.

———. 1967. "An Alternative to Aggregation in Input-Output Analysis and National Accounts." *Review of Economics and Statistics* 49(3):412-19.

MCFETRIDGE, D. G. 1977. *Government Support of Scientific Research and Development: An Economic Analysis*. Ontario Economic Council Research Study 8. Toronto: University of Toronto Press.

NORDHAUS, William D. 1972. "The Recent Productivity Slowdown." *Brookings Papers on Economic Activity* 1972(3):493-536.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT. 1981. *Information Activities, Electronics and Telecommunications Technologies: Background Reports*. Information Computer Communications Policy 6, vol. 2. Paris: OECD.

PARIKH, A. 1975. "Various Definitions of Direct and Indirect Requirements in Input-Output Analysis." *Review of Economics and Statistics* 57(3):375-77.

PETERSON, William. 1979. "Total Factor Productivity in the U.K.: A Disaggregated Analysis." In *The Measurement of Capital*, edited by K. D. Patterson and Kerry Schott. London: Macmillan.

POSTNER, Harry H. 1971. *An Analysis of Canadian Manufacturing Productivity: Some Preliminary Results*. Economic Council of Canada, Staff Study 31. Ottawa: Information Canada.

———. 1979. "Canada and the Future of the International Economy: A Global Modeling Analysis." Economic Council of Canada, Discussion Paper 129, Ottawa.

———. 1982. "Problems of Identifying and Measuring Intermediate (Producer) Services in the Compilation and Use of Input-Output Tables." *Review of Income and Wealth* 28(2):217-41.

RITZ, Philip. 1980. *Definitions and Conventions of the 1972 Input-Output Study*. Bureau of Economic Analysis Staff Paper, U.S. Department of Commerce. Washington, D.C.: GPO.

RUGGLES, Richard, and RUGGLES, Nancy D. 1982. "Integrated Economic Accounts for the United States, 1947-80." *Survey of Current Business* (U.S. Department of Commerce) 62(5):1-53.

RYMES, T. K. 1982. "More on the Measurement of Total Factor Productivity." Carleton University, Carleton Economics Papers 82-06, Ottawa, April.

SCHANKERMAN, Mark. 1981. "The Effects of Double-Counting and Expensing on the Measured Returns to R & D." *Review of Economics and Statistics* 63(3):454-58.

SCHERER, F. M. 1982*a*. "Demand-Pull and Technological Invention: Schmookler Revisited." *Journal of Industrial Economics* 30(3):225-37.

———. 1982*b*. "Inter-Industry Technology Flows and Productivity Growth." *Review of Economics and Statistics* 64(4):627-34.

SCOTT, M.F.G. 1979. "What Price the National Income?" In *Economics and Human Welfare: Essays in Honour of Tibor Scitovsky*, edited by M. Boskin. New York: Academic Press.

SEN, Amartya. 1979. "The Welfare Basis of Real Income Comparisons: A Survey." *Journal of Economic Literature* 17(1):1-45.

SHARPE, Andrew. 1981. "A Disaggregated Analysis of Price Changes and Productivity in the Canadian Economy, 1961-76: A Labour Value Approach," unpublished paper available from author.

SKOLKA, Jiři V., ed. 1982. *Compilation of Input-Output Tables: Proceedings of a Conference, Gouvieux, France, August 16-22, 1981*. Berlin: Springer-Verlag.

STATISTICS CANADA. 1969. *The Input-Output Structure of the Canadian Economy, 1961: Volume I*. Statistics Canada, cat. no. 15-501, August.

———. 1982*a*. *The Input-Output Structure of the Canadian Economy, 1971-78*. Statistics Canada, cat. no. 15-201E, April.

———. 1982*b*. *The Input-Output Structure of the Canadian Economy in Constant Prices, 1971-78*. Statistics Canada, cat. no. 15-202E, May.

THEIL, Henri. 1961. *Economic Forecasts and Policy*. Amsterdam: North-Holland.

UNITED NATIONS. 1968. *A System of National Accounts*. Studies in Methods, Series F, no. 2, rev. 3. New York: UN.

WOLFF, Edward. 1979. "Productivity Impacts from Changing Technology in the U.S. Economy, 1947-1967." Paper presented at Seventh International Conference on Input-Output Techniques, Innsbruck, Austria, April 1979.

ZELLNER, Arnold. 1962. "Estimation of Cross-Section Relations: Analysis of a Common Specification Error." *Metroeconomica* 14(2):111-17.

Economic Council
of Canada

Conseil économique
du Canada