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PRODUCTIVITY, EMPLOYMENT AND TECHNICAL CHANGE IN CANADIAN TELECOMMUNICATIONS: THE CASE FOR BELL CANADA

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Final Report to the
Department of Communications

Contract 17ST.36100-8-0690

March 1979

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EXECUTIVE SUMMARY

1. The Project

The main purpose of this project is to measure and interpret the growth in productivity over the 1952-76 time period for one of Canada's major telecommunications firms, Bell Canada. A second purpose of the project is to estimate the effects on employment of the diffusion of two particular technological innovations which occurred during this period. The two technological innovations that are included in the analysis are (i) the introduction of direct-distance dialing facilities, and (ii) the introduction in central offices of modern switching facilities such as Number 5 Crossbar, Electronic and SP1.

2. The Measurement of Productivity

It is customary in economic analysis to use productivity performance in order to measure a firm's progress in the presence of technological innovations. The most satisfactory measure of the growth of productivity for this purpose is that of total factor productivity growth - the proportionate excess of output growth over input growth. It is generally agreed that the most theoretically valid index of total factor productivity is the Divisia index based on gross output. We have computed this index and compared it to the official Bell Canada Laspeyres real value-added index prepared under the direction of Robert Olley. The rate of growth of our index is 3.67% per year for the 1952-76 period while the Bell Canada index grows at the rate of 4.03% per year. A rate of growth of total factor productivity of 3.67% is very impressive, being about 4 times the rate of growth experienced by Canadian manufacturing during this period. It should be noted, however, that this result is highly dependent on the constant dollar output concept used by Bell Canada in its submission to the CRTC. Using an alternative measure of output - messages produced - caused the productivity growth rate to fall to 1.38%. We believe that the 3.67% and 1.38% figures represent upper and lower bounds to Bell Canada's actual productivity growth rate. Due to the wide range observed in the growth rates computed using alternate reasonable definitions of output, one of the major recommendations arising from this project is the need to devote more research effort to the conceptualization and measurement of telecommunications service outputs.

3. The Interpretation of Productivity

It is common in the telecommunications industry to claim that the impressive growth in total factor productivity since 1952 for firms such as Bell Canada is evidence of rapid technological progress. However, conventional measures of total factor productivity are not obtained from direct estimation of a production structure which incorporates the effects of technical change, but are constructed using more easily obtained observed price and quantity data. Hence they contain the influences of a number of economic phenomena in addition to technical progress. Non-constant returns to scale, non-marginal cost pricing, and rate of return regulation each cause the measured total factor productivity index to deviate from an index which could be thought of as measuring technical progress in its "pure" form - i.e., technical progress which shifts the production functions so that more output can be produced with the same amount of inputs. Since these three phenomena are likely to be present in the telecommunications sector, it is necessary to develop a method of separating the effects in order to interpret observed growth in the productivity index. We have accomplished this task theoretically in Chapter 4 of the report and quantitatively in Chapter 7. We find that at least two-thirds of the observed growth in total factor productivity can be attributed to the effects of non-marginal cost pricing and efficiency gains due to larger scale production. The remaining one-third of growth is estimated to be attributable to efficiency gains associated with the diffusion of the major technological innovations studied in this project - direct-distance dialing and advanced switching facilities. It must be noted, however, that the quantitative decomposition of productivity growth presented above is not particularly robust to moderate changes in the data. A precise separation of efficiency gains into those due to larger scale production and those due to the introduction of innovative technology is very difficult, and probably requires more extensive data than are currently available in the Bell Canada data set.

4. The Structure of Production and Aggregate Employment Effects of Innovations

The decomposition of the total factor productivity index discussed in Section 3 requires knowledge of the production structure which can be obtained from econometric estimation of the cost function. In addition, employment effects of the diffusion of innovations can also be obtained from an estimated cost function, as long as the diffusion is incorporated explicitly into the specification of the function. We have estimated two different specifications of cost functions. In the first instance, we assume Bell Canada produces a single aggregate output and we incorporate into the cost function one technological change indicator: the percentage of telephones with access to direct-distance dialing facilities (A). In the second instance, we disaggregate output into three service categories: (i) local service plus miscellaneous, (ii) message toll, and (iii) other toll (WATS plus private line). In this case we incorporate two technical change indicators: (i) A, and (ii) the percentage of telephones connected to central offices with modern switching facilities (S).

The major findings resulting from these estimations are as follows:

(1) All three aggregate inputs (labour, capital, and materials) exhibit own price elasticities less than unity (in absolute value) and hence demands are inelastic. Labour and capital and labour and materials are substitutes in production whereas capital and materials are (weak) complements in production.

(2) Diffusion of the technical innovations (represented by A and S) results in reductions in the total cost of producing a given level of output. For example, in the aggregate output case, an increase in A from 53% to 53½% yields a total cost saving of 0.12%. The pattern of cost savings is different for the two innovations. Increases in A lead to reduced levels of labour and materials and increased levels of capital, for

a given output. By contrast, increases in S result in reductions in the requirements of all three factors of production.

(3) Increases in diffusion of both A and S are accompanied by substantial reductions in the employment intensity of production. For example, an increase in A from 53% to 53½% results in a 0.24% decrease in labour demanded per unit of output produced; while an increase in S from 19.8% to 20.0% results in a 0.17% decrease in labour demanded. Innovative activity in telecommunications is labour-saving and definitely retards employment prospects in this sector.

(4) Reductions in average costs due to larger scale production are estimated to be considerable and of greater magnitude than the effect of innovative activity. The increasing returns to scale phenomenon implied by these results is estimated (in the three output model) to be associated almost entirely with larger scale local service output. This result is consistent with the view that the provision of local services is at the centre of any natural monopoly that exists with respect to Bell Canada's technology. On the other hand, it is also consistent with our view, expressed in Section 2, that the constant dollar output measure overstates the trend in output growth. This is especially true for local services, where optional equipment included in the output index with a weight based on the price charged (which exceeds the correct weight based on marginal cost) has become an increasingly important component during the latter part of the sample period.

5. The Effects of Innovation on Employment by Types of Workers

We have utilized disaggregated labour data available for the 1952-72 period to analyse in some detail the employment effects of the diffusion of innovations. The labour categories used were (1) telephone operators, (2) plant craftsmen, (3) clerical workers, and (4) an aggregation of other non-supervisors, foremen and supervisors, executives, and part-time workers, which we labelled "white collar workers". The model used in this analysis is the two-stage cost function model originally developed by one of the authors (M. Fuss) to analyse the demand for categories of energy (fuel oil, natural gas, electricity, etc.). According to the two-stage model as used in this project, a cost-minimizing firm is envisaged as choosing input levels in two stages. In the first stage the firm chooses the proportions of employment by labour categories in order to minimize the cost per unit of aggregate labour, given the output level. In the second stage, the firm combines aggregate labour, capital, and materials to minimize the cost of producing the given output. The technology indicator used in this section of the analysis was A, the percentage of telephones with access to direct-distance dialing facilities. The major results of the estimation were as follows:

(1) All employment categories exhibit inelastic response to changes in their own prices except the operators category which exhibits elastic response. All labour components are substitutes except plant craftsmen and clerical workers which appear to be complements.

(2) The effects of innovative activity on the mix of employment are particularly striking. For a given level of output, an increase in access

to direct-distance dialing facilities is accompanied by a decline in employment of operators and clerical workers and an increase in employment of plant craftsmen and white collar employees. Hence the decline in total employment caused by diffusion of new technology noted in the previous section masks interesting changes in the mix of employees which can only be discovered by a disaggregation of the labour category. In addition, increases in A result in increases in capital intensity. This fact shows clearly the substitution of capital for the labour categories of operators and clerical workers and the complementary relationship between capital and the other two categories which accompanies the diffusion of the direct-distance dialing innovation.

6. Summary

In this project we have measured total factor productivity growth for Bell Canada and developed a framework within which productivity growth can be interpreted. While on the surface Bell Canada's productivity growth rate appeared impressive, this fact does not necessarily mean technical progress was similarly impressive. Problems in output measurement, the effects of scale economies, and non-marginal cost pricing practices combined to cause total factor productivity growth to overstate the efficiency gains due to innovative activity.

We have also demonstrated ways in which the effects of particular innovations can be incorporated into econometric estimation of the characteristics of Bell Canada's technology. Within this framework the employment effects of the diffusion of new technology were analysed. The increases in telephones connected to direct-distance dialing facilities and modern switching facilities were both accompanied by reductions in the employment intensity of production. For particular labour categories, increases in access to DDD facilities resulted in employment losses for operators and clerical workers and employment gains for plant craftsmen and white collar workers. The employment effects of innovative activity were substantial. An especially striking effect was the reduction in employment opportunities for operators.

Chapter 1

Introduction

One of the earliest revolutions in the information economy was the invention and practical adoption of telephone services. Basic telephone service is accepted in North America as a necessity not far beyond food and shelter. In the first half of this century, the telephone in some form was installed in a very high percentage of Canadian dwelling units. Since the 1950s the acceleration of innovation in electrical engineering and solid state physics has provided a knowledge base for what many believe will be another major revolution in communications. The introduction of this new technology is expected to have considerable impact in the future on productivity and employment in the telecommunications sector. A knowledge of these effects is necessary for the development of intelligent policies within the Department of Communications.

One input into future policy formulation is a detailed knowledge of the past effects of innovations. In this report we present a case study designed to provide this knowledge - an analysis of productivity and employment changes over the 1952-76 period for one of Canada's major telecommunications firms, Bell Canada. In particular we concentrate on the links between the introduction of new technology such as direct-distance dialing facilities and modern switching techniques, and changes in productivity and employment.

It is customary in economic analysis to use productivity performance in order to measure a firm's progress in the presence of technological innovations. The most satisfactory measure of productivity for this purpose is that of total factor productivity. Total factor productivity is a means of evaluating intertemporal changes in a firm's production process. However, underlying the computational method employed in moving from a postulated production process to the observable prices and quantities used in the construction of an index of total factor productivity is the imposition of a number of assumptions. These assumptions include the existence of constant returns to scale, marginal cost pricing, and a lack of administrative intervention in the marketplace (e.g. rate of return regulation). For regulated industries, the above assumptions are often inappropriate. When conventional total factor productivity indices are calculated in these inappropriate situations, biased measures of technical change result. In order to eliminate the biases, structural information about the production process is needed. This information can be obtained by estimating the firm's cost function. As we demonstrate in Chapter 4, elements of the cost function which are of particular importance to correct measurement of the relationship between total factor productivity and technical change are cost elasticities (with respect to outputs) and the value of the Lagrangian multiplier in the rate-of-return model. One result of special interest emerges which has not been previously noted in the regulation literature. For firms which are subject to effective rate of return regulation, there exists a productivity measurement analogue to the Averch-Johnson over-capitalization effect.[1] For example, we show that in inflationary periods when the prices of expensed factors of production and the allowed rate of return are increasing, measured total factor productivity using conventional indices always overstates true productivity. This result is also developed in Chapter 4.

The employment effects of technological change can be obtained from an analysis of the firm's demand functions for various categories of labour. These demand functions can be obtained directly from the estimated cost function using Shephard's Lemma. The necessary relationships are developed in Chapter 6.

Estimation of Bell Canada's cost function plays a central role in the interpretation of the growth of total factor productivity and the determination of the employment effects of innovations, thus it is necessary that estimates of the cost structure for Bell Canada be provided. The required estimates are presented in Chapter 5, and extended in Chapter 6 to an analysis of the employment effects of technological innovations. Finally, in Chapter 7 we combine the conceptual results of Chapter 4 and the empirical results of Chapter 5 to analyse the discrepancy between total factor productivity and technical change which results when the assumptions of constant returns to scale, marginal cost pricing, and a lack of effective rate of return regulation are incorrect.

Chapter 2

Bell Canada and Canadian Telecommunications

2.1 Introduction

Bell Canada is the largest telephone company in Canada. It provides telecommunications services primarily in the populous provinces of Ontario and Quebec. A private company, Bell Canada earned profits of $233 million on sales of 2,133 million in 1977. At the beginning of our sample period, 1952, there were 2 million phones in the Bell Canada network used to place approximately 3 billion calls. By 1977, 12 billion calls were placed using 8.5 million phones. In 1952, the network was run by about 30,000 employees using a capital stock of 626 million constant dollars. By 1976, 48,000 employees and a capital stock of 4 billion constant dollars were servicing the Bell Canada system. A wide variety of telephone and telecommunications services are provided within Bell Canada's geographic region. Bell is linked with other Canadian companies through the Trans-Canada Telephone System and internationally through Teleglobe to offer toll services throughout Canada and the rest of the world.

All Canadian telephone companies are subject to some form of regulation by the governments of Canada. In Manitoba, Saskatchewan and Alberta, telephone services are provided by public enterprises regulated by a variety of direct government controls. Bell Canada is a private company with a federal charter and is subject to regulation by the Federal Government. The Canadian Radio-Television and Telecommunications Commission (CRTC) is directly in charge of regulating Bell Canada.

Regulation has recently taken the form of a constraint on the permitted upper levels of the rates of return on total capital and equity capital. This is a very complex procedure since detailed accounting issues become sources of strong disagreement. Rate changes must be approved and rates are supposed to be just and reasonable. In practice it is very difficult to know that rates are either just or reasonable since detailed information about company practices is not widely available. There is little doubt that the flat rate charged for the basic level service is politically constrained. As an implicit social policy this service is thought to be a necessity that should be available at a low flat monthly rate.

During the last 25 years, many specific technical innovations have been introduced. Perhaps the most significant one is Direct Distance Dialing (DDD). Beginning in the late 1950s, DDD is now available throughout most of the urban areas of Bell's territory. It was clearly this change that permitted Bell to substantially reduce the number of telephone operators that it employed. Before DDD can be implemented, additional switching equipment is required in order to monitor usage. In 1952, step-by-step switching was predominant. By 1965, most of the older, pre-step-by-step switches had been eliminated and Number 5 Crossbar switches had grown rapidly. Since 1965, step-by-step switching has remained stagnant in absolute terms. Growth was taken up by Number 5 Crossbar and, since 1972, by rapid growth in electronic switching. In Chapter 5, we use some indicators of the rate of adoption of these innovations in our estimation of the changing characteristics of the production process.

2.2 Growth of Outputs and Inputs

To present a quick picture of the growth of Bell Canada, the rates of growth of total revenue, aggregate real output, total costs and aggregate real inputs have been calculated for several sub-periods of 1952-76 (Table 2.1).

Total revenues have grown at average rates that exceed 7.8 per cent a year in all sub-periods. Revenue growth slipped over the first fifteen years but has climbed sharply during the past ten years. If we extract the effects of price changes, aggregate output has grown at a somewhat stabler but still high rate. The very rapid growth in the middle 1950s has never been equalled. Primarily, this was a period of very rapid growth in the number of main telephones and new subscribers. This rapid increase in new customers was never achieved again. Until the 1970s, aggregate output had grown almost as quickly as total revenue. This indicates the modest price increases that characterized this period.

Total costs have grown more rapidly than total revenue in four of the five sub-periods portrayed in Table 2.1 . Costs are calculated to include a user cost of capital. Consequently, these costs are not equivalent to any cost figures calculated by the company. A detailed description of the variables used is included in the Appendix. In general, costs increased very rapidly in the first period and during the last decade. If we consider the growth in aggregate inputs we can understand the growth in costs. After the first period, there has been a dramatic decline in the growth of real inputs. From a high average rate of increase of 8.5 per cent a year in 1952-57, the growth rate has fallen to below 5 per cent for the following twenty years.

TABLE 2.1

Growth of Outputs and Inputs in Current and Constant Dollars, Bell Canada, 1952-76

(percentage rates of growth)

	Revenue	Output	Cost	Inputs
1952-57	9.9	9.7	10.5	8.5
1958-62	8.8	7.8	7.3	4.8
1963-66	7.8	8.0	8.0	4.9
1967-70	9.4	8.5	10.5	3.8
1971-76	11.7	8.3	13.4	3.9

Within this latter period Bell was able to reduce the rate of growth of inputs by a further twenty-five per cent in the last decade.

Since output growth has shown no tendency to decline over the past twenty years, we can infer that the sharp decline in the growth of inputs implies impressive productivity growth. Productivity growth will be analyzed in detail in Chapter 3. It is useful to consider how each output and input has contributed to these aggregate patterns.

In Table 2.2, the average annual rates of growth of real output for six aggregate outputs are displayed. Local Service (column one) is the largest output that Bell produces. Throughout most of the quarter century, constant dollar local service output has grown at roughly seven per cent. The only period of more rapid growth was the mid 1950s. It must be remembered that local services include seventy-five or eighty separately priced services. Some of the most rapidly growing items are auxiliary equipment services for which separate data are not available.

The next three aggregate outputs comprise message toll outputs. A substantial difference exists in their growth rates. Intra-Bell message toll has grown much more slowly than the two longer distance toll categories. Intra-Bell toll is the largest of the message toll outputs but the other two types are rapidly catching up.

The final toll category is "other toll". This is a mix of WATS and private line services. It is in this area that many of the specialized data transmissions services are included. Although other toll has not grown at significantly higher rates than the non-Bell message toll, it is expected that future growth may be high in this area. The last aggregate

Table 2.2

Average Rates of Growth of Real Outputs, Bell Canada, 1952-76

(percentages)

	Local	Bell-Toll	Trans-Toll	U.S.-Toll	Other Toll	Misc.
1952-57	9.23	8.23	22.60	14.98	30.47	7.85
1958-62	7.34	7.68	12.43	6.55	16.72	7.62
1963-66	6.83	7.85	12.06	16.54	19.96	1.42
1967-70	7.03	9.29	12.25	11.78	14.97	6.82
1971-76	7.31	8.58	15.60	14.03	12.78	-7.22

output is a mixture of miscellaneous revenues that were approximately five per cent of total revenue in 1967. The negative rate of growth during 1971-76 is due to the formation of Tele-direct, a separate corporation to handle directory advertising.

Aggregate output has been growing at an average rate of over eight per cent a year for the last fifteen years. The very rapid growth in longer distance message toll and other toll has only managed to raise the aggregate output growth about one per cent above the growth rate for local service outputs. The continued importance of the large local service output is evident in these figures.

Throughout most of the study we are concerned with only three aggregate inputs: labour, capital and materials. The rates of growth of these inputs have had very distinct and different patterns. These are shown in Table 2.3 .

For all three inputs, very fast rates of growth were experienced from 1952-57. However, in the four later periods the individual patterns diverged. Labour input actually declined from 1958-62 at an annual average rate of two per cent a year. This was primarily due to the introduction of Direct Distance Dialing. Labour inputs grew modestly during 1963-66 and 1971-76. In between, from 1967-70, labour growth was practically zero. It would appear that Bell went through a belt-tightening period in the late 1960s.

In real terms, the growth of the capital stock has continuously slowed. From 1952-62, growth was at a rate above ten per cent a year. Since that time the growth rate has declined steadily, falling below five per cent

Table 2.3

Average Annual Rates of Growth of Real Outputs,
Labour, Capital and Materials
(percentages)

	Labour	Capital	Materials
1952-57	5.05	11.74	9.71
1958-62	-2.00	10.02	6.04
1963-66	2.37	6.69	4.50
1967-70	0.13	5.71	4.72
1971-76	2.53	4.40	4.33

throughout the seventies. Material inputs have also grown at slower rates through time.

Overall, it may be said that in the last fifteen years inputs have grown much more slowly than in the first decade. The exception for labour is due to a major technological change.

2.3 Difficulties in the Measurement of Output

Bell Canada sells an enormous variety of outputs and the diversity in products has increased during the last twenty-five years. The best available output measures are those produced by Bell Canada. These are the primary measures that we have used and they are discussed in the Data Appendix. In this section, we wish to introduce an alternative output measure that illustrates some of the difficulties with accurately measuring outputs when there are a large number of products. The alternative measure of aggregate output discussed here is an underestimate of Bell's output and must be interpreted as an example.

The largest share of Bell's revenue comes from local services and toll message revenue. In these areas, the telephone network produces telephone calls both locally and throughout wider geographical areas. Suppose we measure output by the number of calls for each of these services. Local service is currently sold at a flat rate per unit of time based on the number of phones that can be reached in the local exchanges. Substantial local service revenue is derived from auxiliary services charged on a recurring or non-recurring basis. Our alternative local service output quantity is the number of calls. If one makes a local call on a red Contempra touchtone extension phone with a long cord one may be making an expensive phone call under current pricing schedules but it is still a local call. The price of local service output is the implicit price, given the output quantity and the total local service revenue. Our alternative estimate of local service output is similar to an output measure unadjusted for quality change. Output growth is understated while the rate of increase in price is overstated. It might be an indicator of the minimum rate of growth of local service output.

For toll message output, the current Bell pricing schedules charge by time, distance, time of day, day of week, and type of call, at least. Using the number of toll calls understates output predominantly because the distance factor is not included. There has been a significant relative shift of toll calls into the larger distance bands. The price of toll message output is the implicit price given total toll revenue. This is another indicator of the minimum increase in output in these services.

It is beyond the scope of this report to discuss a preferred output measure. However, the following important issues are involved in correctly measuring output. If the prices of many services do not equal their marginal costs then output aggregation using prices will be incorrect. Cross-subsidies will be present in these cases. Further, monopoly rents are being generated and redistributed among services by this process. In this report we can only indicate some rough indicators of the quantitative differences.

If our alternative call measure of local service output is substituted for the standard measure, local output growth is reduced by about 2 per cent a year. For toll calls, the switch to number of calls reduces the rate of growth of output by a larger amount. A crude guide to the magnitudes that might be involved in changing output definitions can be seen from Table 2.4 . The value of seven indicators in 1976 (1952 = 1.00) are shown. Constant dollar local service revenue (line 2) is much larger than local calls (line 1) or any of the three measures of the number of telephones (items 3-5). Similarly, the constant dollar toll revenue indicator is 64 per cent larger in 1976 than the indicator of the number of calls.

In Chapter 3, we will report on a productivity index based on substituting the number of local and toll calls for the constant dollar output measures in these two areas. All other output and input variables will remain the same.

Table 2.4

Alternative Output Indicators, 1976

(Indexes 1952 = 1.00)

1.	local calls, number	3.85
2.	local service revenue, constant dollars	5.81
3.	telephones, number	4.03
4.	residential main stations, number	3.35
5.	business main stations, number	3.63
6.	toll calls, number	6.19
7.	message toll revenue, constant dollars	10.17

Chapter 3

The Measurement of Total Factor Productivity for Bell Canada

3.1 Alternative Measures of Productivity

Productivity measures have been calculated for a long period of time. Historically, labour productivity has been the most common measure computed. In a rough sense output per unit of labour input is a measure of the capability of mankind to utilize his labour to produce output. The focus on labour suggests that it was the welfare of individuals that the concept was initially designed to measure. More output per unit of work, for whatever reasons, permitted the community to be better off through an increase in output per unit of labour or a decrease in labour per unit of output. Labour productivity can be thought of as a crude indicator of welfare.

Applications of productivity measurement in recent years have tended to de-emphasize the welfare aspect and replace it with an emphasis on overall productive capability. The productivity measure corresponding to this new emphasis is the total factor productivity index which measures the output per unit of aggregate input. Labour is no longer singled out since all inputs are taken into account. Nevertheless the total factor productivity measure may still be related to welfare. The capability of all resources to contribute to output indicates the potential outputs that the community's resources can produce and hence the potential welfare levels which can be attained.

The two concepts - labour productivity and total factor productivity - can be related to one another in the following way. Suppose that labour and other resources, called capital and materials are used to produce output. It can be shown that the rate of growth of labour productivity equals the rate of growth of total factor productivity plus the weighted rates of growth of the capital and materials intensities of production.[1] This simply states that labour productivity grows because workers have more other resources per person to work with as well as because all resources are becoming more productive, increasing total factor productivity. The specific relationship between labour productivity and total factor productivity is given by

$$\dot{LP} = \dot{TFP} + s_K \dot{(K/L)} + s_M \dot{(M/L)} \qquad (3.1)$$

where

$\dot{LP}$ = proportional rate of growth of labour productivity

$\dot{TFP}$ = proportional rate of growth of total factor productivity

$\dot{(K/L)}$ = proportional rate of growth of capital intensity

$\dot{(M/L)}$ = proportional rate of growth of materials intensity

s_K = share of capital in total cost

s_M = share of materials in total cost

The rates of growth of the capital and materials intensities are weighted by capital's share and material's share in total cost respectively.[2]

During the period 1952-76, Bell Canada's production structure was characterized by increasing K/L, M/L and s_K and by relatively constant s_M. Hence from (3.1) it can be seen that labour productivity increased more rapidly than total factor productivity over this period. This analytical result is illustrated using Bell Canada data in Table 3-1. Note that the contribution of total factor productivity growth to labour productivity growth is less than 100% in all sub-periods considered. Hence labour productivity growth exceeds total factor productivity growth in all sub-periods.

TABLE 3-1

Analysis of the Growth of Labour Productivity

Period	Growth of Labour Productivity	Relative Importance of Alternative Contributors to the Growth of Labour Productivity (in %)		
	$\dot{LP}$	$\dot{TFP}$	$s_K(\dot{K/L})$	$s_M(\dot{M/L})$
1952-57	4.6	22.0	56.8	21.2
1958-62	9.8	29.6	56.8	13.6
1963-66	5.6	51.9	41.4	6.7
1967-70	8.4	56.7	35.4	7.9
1971-76	5.8	80.2	12.1	7.7

The above results utilize estimates of total factor productivity which as yet has not been carefully defined. We now turn to the definition of total factor productivity used in this report.

3.2 The Divisia Index of Total Factor Productivity

From a conceptual point of view, the most defensible method of aggregation for use in productivity analysis is Divisia aggretation. This fact has become well-established through the research of Jorgenson and Griliches (1967), Richter (1966), Hulten (1975), Diewert (1976) among others. For our purposes the most important feature of Divisia aggregation is the fact that it produces a chain index with continuously shifting weights. Diewert (1976) has shown that this fact means that the productivity index obtained could have been generated by a second order approximation to any arbitrary production function. By contrast, a Laspeyres aggregate index with its constant weights[3] is consistent only with a hyperbolic (Cobb-Douglas) production function. Recent empirical evidence (Fuss and Waverman (1977)) indicates that the Cobb-Douglas function is too restrictive a functional form to adequately represent Bell Canada's technology.

The Divisia index of total factor productivity is obtained in the following way. First we define total factor productivity (TFP) as the ratio of aggregate output (Q) to aggregate input (F). Aggregate output (input) is an index of disaggregated outputs (inputs). The Divisia indices for aggregate output (Q) and input (F) are defined in terms of proportionate rates of growth ($\dot{Q}$ and $\dot{F}$) as

$$\dot{Q} = \sum_j \frac{P_j Q_j}{R} \cdot \dot{Q}_j \qquad (3.2)$$

where

P_j = price of output j

Q_j = quantity of output j

$\dot{Q}_j$ = proportion rate of growth of output j

$R = \sum_j P_j Q_j$ = total revenue

and

$$\dot{F} = \sum_i \frac{w_i X_i}{C} \cdot \dot{X}_i \qquad (3.3)$$

where

w_i = price of input i

X_i = quantity of input i

X_i = proportionate rate of growth of input i

$C = \sum_i w_i X_i$ = total cost

Since TFP = Q/F, the proportionate rate of growth of total factor productivity ($\dot{TFP}$) is defined by

$$\dot{TFP} = \dot{Q} - \dot{F} \qquad (3.4)$$

The formulas (3.2 - 3.4) are in terms of instantaneous changes. For data obtainable at yearly intervals, discrete approximations to the continuous formulae (3.2) and (3.3) can be defined by

$$\Delta \log Q = \log (Q_t/Q_{t-1}) = \tfrac{1}{2} \sum_j (r_{jt} + r_{j,t-1}) \log (Q_{jt}/Q_{j,t-1})$$

where Q_{jt} = quantity of j produced in period t

$r_{jt} = \dfrac{P_{jt}Q_{jt}}{\sum_j P_{jt}Q_{jt}}$ = revenue share of output Q_j in total revenue during period t

and

$$\Delta \log F = \log (F_t/F_{t-1}) = \tfrac{1}{2} \sum_i (s_{it} + s_{i,t-1}) \log (X_{it}/X_{i,t-1}) \qquad (3.6)$$

where X_{it} = quantity of input X_i used in period t

s_{it} = $(w_i X_i)/\sum_i w_i X_i$, the cost share of input X_i in the total cost during period t.

Finally, a discrete approximation to (3.4) is provided by

$$\Delta TFP = \Delta Q - \Delta F \qquad (3.7)$$

Choosing the index to equal 1.0 in a particular year, and accumulating the measure in accordance with (3.7) provides estimates of what we call the conventional index of total factor productivity. As we demonstrate in section , the conventional index when linked to the theory of production implies constant returns to scale, marginal cost pricing and an absence of a rate of return constraint, as well as cost-minimizing behaviour. This index requires modification when the above assumptions are incorrect. The modifications are developed in section . However, before proceeding to an analysis of total factor productivity indices in terms of the theory of production, it is useful to describe the performance of Bell Canada for the 1952-76 period as measured by the conventional Divisia index of total factor productivity.

The productivity index was calculated using seven outputs, seven labour inputs, a capital and a materials input index. The data are explained in an appendix on the Bell Canada data. The index from 1952-76, with 1967 = 100.0 is shown in Table 3-2. This index grew at an average annual rate of 3.67 per cent a year which is a very rapid growth in productivity. For comparison, in Canadian manufacturing, a comparable index grew at only one per cent a year. Bell Canada's performance was far above the manufacturing sector's performance.[4]

While average productivity growth was rapid, there was substantial variation within the period. In Table 3-3 column one, the average growth of total factor productivity is shown for several sub-periods. Productivity has grown at a much faster rate after 1958. Until 1970, this growth was increasing during each sub-period. A levelling off in the growth rate of productivity has occurred during the 1970s.

To understand the importance of total factor productivity in accounting for the growth of output we can make use of the following relationship

$$\dot{Q} = \dot{TFP} + \dot{L} + s_K \dot{K/L} + s_M \dot{M/L} \qquad (3.8)$$

TABLE 3-2

Total Factor Productivity for Bell Canada, 1952-76

	Index (1967 = 100)	Rate of Change (percentage)
1952	66.9	-
	68.4	2.23
	68.7	0.46
1955	68.7	0.05
	68.9	0.33
	71.2	3.19
	7.16	0.54
	73.8	3.03
1960	75.8	2.75
	78.7	3.76
	82.8	4.97
	83.5	0.84
	86.4	3.48
1965	89.6	3.61
	93.7	4.45
	100.0	6.54
	104.7	4.64
	108.5	3.53
1970	112.8	3.91
	112.6	-0.23
	118.6	5.20
	125.4	5.62
	132.9	5.81
1975	144.0	8.01
1976	147.4	2.34
Average: 1952-76		3.67

TABLE 3-3

Determinants of Total Factor Productivity Growth

			Relative Importance of Alternative Contributors to the Growth of Output (Q)			
	$\dot{TFP}$	$\dot{Q}$	$\dot{TFP}$	$\dot{L}$	$s_K(\dot{K/L})$	$s_M(\dot{M/L})$
1952-57	1.4	9.7	13.4	51.0	27.4	8.2
1958-62	3.0	7.8	37.9	-27.9	72.9	17.1
1963-66	3.1	8.0	37.0	29.9	28.7	4.4
1967-70	4.7	8.5	55.3	1.2	36.2	7.3
1971-76	4.5	8.3	48.4	28.7	15.1	7.8

The second column of Table 3-3 shows the rate of growth of output $\dot{Q}$. The remaining columns show the relative importance of growth in total factor productivity, labour, capital intensity and materials intensity in the growth of output. These columns add to 100 per cent and are the individual terms in (3.8) converted to percentages.

From 1952-57, output growth was very high but total factor productivity was low and contributed only thirteen per cent of the growth in output. Over half of the output growth was accounted for by the growth in labour. Increased capital and materials per unit of labour accounted for the remaining thirty-six per cent of output growth.

The period from 1958-62 is perhaps the most interesting. Output grew more slowly in this period but total factor productivity accelerated and grew at double the rate of the earlier period. Although output grew rapidly, labour input actually fell at an average rate of over two per cent a year. As a consequence, productivity growth became much more important. During this period almost forty per cent of the output growth was due to productivity. Since labour was declining, the intensities with which capital and materials were combined with labour substantially increased.

For the next two sub-periods, 1963-66 and 1967-70, output grew at 8.0 and 8.5 per cent respectively, and productivity accounted for about 37% and 55% of growth. The major difference in the sub-periods was the return to steady labour growth in the first period and almost zero labour growth in the second period.

Since 1970, both output and total factor productivity have grown slightly more slowly than during the 1967-70 period. The growth in labour has increased and is at a rate comparable to the 1963-66 period. The relative importance of productivity growth remains high, but has slipped somewhat from the very high level of the 1967-70 period.

3.3 A Comparison of Two Alternative Total Factor Productivity Measures for Bell Canada

Under the direction of Professor Robert Olley, Bell Canada has prepared estimates of productivity since 1952. These estimates differ from the ones reported in this paper primarily because of differences in the methodology. Smaller variations arise from the changes in the data that we have described in detail in the Data Appendix.

Since our methodology has been described in section 3.2, the emphasis in this section will be on clarifying the differences by analyzing the Bell Canada methodology. Output is measured by real value-added in Olley's studies. From aggregate gross output, aggregate real materials are subtracted to measure double deflated real value-added. Both outputs and materials are aggregated using a Laspeyres quantity index with 1967 = 1.00.

Our methodology uses real gross output, not real value-added, as the output measure. Our indexes are discrete approximations to the Divisia index and not Laspeyres indexes.

For aggregate gross output and real materials, the use of different index formulae creates almost no difference in the two sets of results over the whole period. Although gross output must grow faster than real value-added, it may be shown that value-added measures of productivity will grow more quickly than gross output productivity measures. This is shown, for example, in May and Denny (1979).

On the input side only primary inputs, capital and labour, are aggregated (using a Laspeyres quantity index) in the Bell study. Primary inputs and real materials are aggregated in this study to form an aggregate index of all inputs (using an approximation to the Divisia index).

Ignoring any differences in the data, Olley's methodology would lead to larger increases in total factor productivity than the methodology used in this study. As stated above, this fact is due to Olley's use of value-added output rather than gross output.

There are two reasons to prefer our methodology. First, real value-added output measures imply that the underlying production technology is separable, i.e., it may be written $Q = f(g(K, L),M)$. Double deflated real value-added measures require that the technology be of the form $Q = f(g(K, L) + h(M))$. Our tests have rejected these restrictions on the production function for Bell Canada. Consequently gross output is the sensible measure of output.

While the choice of index numbers does not alter the aggregates significantly, there are theoretical reasons for preferring the Divisia approximation. As noted in section 3.2, the Divisia index is consistent with a second order approximation to any arbitrary production function. The Laspeyres index used by Olley implies that the production function is Cobb-Douglas (a first order approximation). Our test results (and those of Fuss and Waverman (1977) reject the Cobb-Douglas model and thus further confirm the validity of our methodology.

There are a number of small differences in data and one major one. The latter will be discussed first and the others briefly mentioned. In our study, capital services are measured in a different manner from that used in the Bell Canada studies. The Bell method is as follows. Constant dollar capital services equal the constant dollar capital stock multiplied by the ratio of capital service income in 1967 to the value of the capital stock in 1967. In 1967, the constant dollar capital service input equals the value of the capital income, (value-added minus labour costs). In all other years, the index of capital services equals the constant dollar capital stock weighted by the 1967 share of capital in value-added (a constant). The constant share has a value of 66.3 per cent of value-added. Our method also weights the constant dollar capital stock by the share of capital. However, our share of capital in value-added is variable, ranging from a low of about 40 per cent in the early years to a high of 57 per cent in the later years. Consequently, capital is more important in Olley's measure of aggregate input. Since the capital service input grows much faster than labour or materials, Olley's higher weight implies that his index of aggregate input will grow much more rapidly than our index. The more rapid growth of aggregate input will reduce his growth in productivity relative to ours if ours were computed on a value-added basis.

Why are the capital shares so different? Ours are variable and increase somewhat erratically from 1952-76. However, in 1967 our share is

56 per cent of value-added compared to Olley's 66 per cent. The difference arises from the treatment of profits. Olley attributes all residual income to capital after the subtraction of labour and materials costs. Our method explicitly calculates a user price. This price times the quantity of capital services does not equal total revenue minus labour and material costs. A residual remains that is economic profit above normal profits. Our method reflects the opportunity costs of capital inputs to Bell Canada while Olley's does not. This explains the difference.

Other data differences are too small to significantly alter our results or any comparison with the Bell Canada series generated under Olley's direction. As described in the data appendix, we have changed the materials series. Olley used a materials series that was the sum of materials and indirect taxes. We did not wish to treat indirect taxes as an input. The new materials input series is much smaller than Olley's series. For productivity measurement (in contrast with econometric estimation), this change made very little difference in our results. It would probably tend to raise Olley's productivity series modestly.

The two indexes of productivity are shown in Table 3-4. The Olley index grew at an average annual rate of 4.03 per cent compared to 3.67 per cent for the Denny-Fuss index. The Olley index should grow faster since real value-added productivity index must grow faster. However, if we roughly convert our index into a real value-added index, the growth rate would have been 4.6 per cent a year. This is higher than the Olley index and reflects the very high capital share weight used by Olley which lowered his index.

TABLE 3-4

Bell Canada Productivity, 1952-76
(1967 = 1.00)

	Bell (Olley)	Bell (Denny-Fuss)
1952	0.57	0.67
1955	0.60	0.69
1960	0.73	0.76
1965	0.90	0.90
1967	1.00	1.00
1970	1.13	1.13
1972	1.19	1.19
1976	1.48	1.47
rate of growth	4.03%	3.67%

3.4 Total Factor Productivity of Bell Canada Using Alternative Output Measures

We complete the measurement of total factor productivity chapter by demonstrating the sensitivity of TFP growth to alternative output measures. Table 3-5 presents the measurement of TFP using the concept of messages as output discussed in Chapter 2. The result is striking-total factor productivity growth declines from 3.67% per annum to 1.38% per annum. This estimate is likely be a lower bound since only messages are considered to be output in local and message toll services. However, we believe that constant dollar output measures overstate actual output growth, so that 3.67% is likely to be an upper bound. Clearly more research effort needs to be devoted to the conceptualization and measurement of service outputs.

TABLE 3-5

Alternative Total Factor Productivity
for Bell Canada, 1952-76

	Index (1967 = 100)	Rate of Change (percentage)
1952	92.2	-
	91.4	-0.89
	88.4	-3.33
1955	88.1	-0.40
	87.8	-0.28
	86.8	-1.13
	87.1	0.30
	88.1	1.15
1960	88.6	0.62
	90.1	1.64
	93.2	3.36
	93.2	0.00
	95.2	2.08
1965	95.6	0.48
	96.7	1.15
	100.0	3.32
	103.5	3.47
	105.6	2.02
1970	108.4	2.62
	107.7	-0.70
	113.9	5.57
	117.1	2.82
	125.5	6.90
1975	126.1	0.51
1976	128.4	1.77

Chapter 4

Total Factor Productivity and the Theory of Production

4.1 The Case of a Single Output

In this chapter we develop the links between the measurement of productivity and the theory of production which permits us to adjust the conventional Divisia index for the market imperfections usually encountered in regulated industries. We begin with the case of single output (Q) produced by inputs X_i, i = 1,...n. The production possibilities are described by the production function

$$Q = f(X_1,\ldots X_n,t) \quad . \tag{4.1}$$

Define $\dot{A} = \frac{\partial f}{\partial t} \cdot \frac{1}{f}$, the proportional shift in the production function with time. The shifting of the production function through time is called technical change and it is technical change which we wish to measure using the productivity index. If we totally differentiate the production function with respect to time we obtain

$$\frac{dQ}{dt} = \sum_i \frac{\partial f}{\partial X_i} \cdot \frac{\partial X_i}{\partial t} + \frac{\partial f}{\partial t} \quad . \tag{4.2}$$

Dividing (4.2) by Q and rearranging results in

$$\dot{Q} = \sum_i \frac{\partial f}{\partial X_i} \cdot \frac{X_i}{Q} \cdot \dot{X}_i + \dot{A} \quad . \tag{4.3}$$

Assume that the firm minimizes the cost of producing Q . Then the first order conditions for cost minimization imply $\frac{\partial f}{\partial X_i} = w_i / \frac{\partial C}{\partial Q}$ where $\frac{\partial C}{\partial Q}$ is the marginal cost of production. Substituting for $\frac{\partial f}{\partial X_i}$ in (4.3) we obtain

$$\dot{Q} = \sum_i \frac{w_i X_i}{\partial C/\partial Q \cdot Q} \cdot \dot{X}_i + \dot{A} \quad . \tag{4.4}$$

Define the elasticity of cost with respect to output (ε_{CQ}) as

$$\varepsilon_{CQ} = \frac{\partial C}{\partial Q} \cdot \frac{Q}{C} \quad . \tag{4.5}$$

Substituting (4.5) into (4.4) we obtain an expression for the proportionate rate of growth of output

$$\dot{Q} = \sum_i \varepsilon_{CQ}^{-1} \cdot \frac{w_i X_i}{C} \cdot \dot{X}_i + \dot{A} \quad . \tag{4.6}$$

For the case of a single output, $\dot{Q}$ is identical to the proportionate rate of growth of output in the measurement of total factor productivity. The index of aggregate inputs F is defined by the growth equation (see equation (3.3))

$$\dot{F} = \sum_i \frac{w_i X_i}{C} \cdot \dot{X}_i \tag{4.7}$$

Substituting (4.7) into (4.6), we obtain

$$\dot{A} = \dot{Q} - \varepsilon_{CQ}^{-1} \dot{F} \quad . \tag{4.8}$$

We now proceed to compare the measure of technical change $\dot{A}$ with our total factor productivity measure $\dot{TFP} = \dot{Q} - \dot{F}$. A rearrangement of (4.8) yields

$$\dot{A} = \dot{TFP} + (1 - \varepsilon_{CQ}^{-1})\dot{F} \tag{4.9}$$

or

$$\dot{TFP} = \dot{A} + (\varepsilon_{CQ}^{-1} - 1)\dot{F} \quad . \tag{4.10}$$

In order to interpret equation (4.10) we begin by noting that the inverse of the elasticity of cost with respect to output is the scale elasticity.

Therefore, if production is subject to constant returns to scale $\varepsilon_{CQ} = 1$ and

$$\dot{A} = \dot{TFP} \quad . \tag{4.11}$$

In this case the total factor productivity growth rate is identically equal to the rate of technical change. We now can see the effect of a departure from one of the assumptions used to construct the total factor productivity index of Chapter 3 - the constant returns to scale assumption. Without constant returns to scale, total factor productivity will not identically measure shifts in the technology. In telephone companies such as Bell Canada, it is believed that increasing returns to scale may be present. With increasing returns to scale $(\varepsilon_{CQ}^{-1} - 1)$ is positive, hence estimates of total factor productivity $\dot{TFP}$ will overestimate shifts in the technology alone. If increases in inputs lead to scale effects on output, it is the scale effects that are being measured by the second term in (4.10). The standard measure of total factor productivity is not erroneous. Rather it includes the static efficiency effects of scale as well as the dynamic efficiency effects of technical progress. The standard productivity measure cannot distinguish between these two effects.

Since we wish to measure the separate efficiency effects of scale and technical progress, we require more information than standard productivity analysis uses. From equation (4.10) it is obvious that to separate the scale effects from the technical change effects we require an estimate of the cost elasticity, ε_{CQ} . This requires estimation of the cost function which is accomplished in Chapter 5. Estimates of the decomposition of total factor productivity growth into that attributable to scale and that attributable to technical change are presented in Chapter 7.

Before proceeding to a discussion of the estimation of the cost function, it is useful to analyse shifts in the technology in terms of the cost function rather than the production function. This change in emphasis will allow us to deal with the multiple output case more easily. It will also allow us to analyse the effects on the relationship between total factor productivity and technical change of departures from the market assumptions of marginal cost pricing and no effective rate of return regulation.

Under the assumption of cost-minimizing behaviour, the theory of duality between cost and production implies that for any production function of the firm (4.1) there exists a cost function that provides an equivalent description of the technology. Suppose we represent the cost function by the equation,

$$C = g(w_1,\ldots w_n,Q,t) \quad . \tag{4.12}$$

Totally differentiating the cost function with respect to time we obtain

$$dC/dt = \sum_i \frac{\partial g}{\partial w_i} \cdot \frac{\partial w_i}{\partial t} + \frac{\partial g}{\partial Q} \cdot \frac{\partial Q}{\partial t} + \frac{\partial g}{\partial t} \quad . \tag{4.13}$$

Re-arranging equation (4.13) by dividing through by C and setting $\partial g/\partial w_i = X_i$ (from Shephard's Lemma) yields

$$\frac{1}{C}\frac{dC}{dt} = \sum_i \frac{w_i X_i}{C} \cdot \dot{w}_i + \frac{\partial g}{\partial Q} \cdot \frac{Q}{C} \cdot \dot{Q} + \frac{1}{C}\frac{\partial g}{\partial t} \quad . \tag{4.14}$$

Define $\dot{B} \equiv \frac{1}{C}\frac{\partial g}{\partial t}$, the proportionate shift in the cost function. Then equation (4.14), after re-arrangement, becomes

$$\dot{B} = \dot{C} - \sum_i \frac{w_i X_i}{C} \cdot \dot{w}_i - \varepsilon_{CQ}\dot{Q} \tag{4.15}$$

where $\varepsilon_{CQ} = \frac{Q}{C}\frac{\partial C}{\partial Q} = \frac{Q}{C}\frac{\partial g}{\partial Q} =$ the cost elasticity, as before. The proportionate shift in the cost function $(\dot{B})$ equals the change in costs minus the change in aggregate inputs minus the scale effect $(\varepsilon_{CQ}\cdot\dot{Q})$.

It is useful to relate $\dot{B}$ to the proportionate shift in the production function $(\dot{A})$ and the rate of growth of total factor productivity $(\dot{TFP})$. Totally differentiating $C = \sum_i w_i X_i$ with respect to time and re-arranging yields the equation

$$\sum_i \frac{w_i X_i}{C} \dot{w}_i = \dot{C} - \sum_i \frac{w_i X_i}{C} \cdot \dot{X}_i \tag{4.16}$$

Substituting this equation into (4.15) we obtain

$$- \dot{B} = \varepsilon_{CQ}\dot{Q} - \sum_i \frac{w_i X_i}{C} \dot{X}_i \tag{4.17}$$

or

$$- \dot{B} = \varepsilon_{CQ}\dot{Q} - \dot{F} \tag{4.18}$$

Multiplying (4.8) by ε_{CQ} puts that equation in the form

$$\varepsilon_{CQ}\dot{A} = \varepsilon_{CQ}\dot{Q} - \dot{F} \tag{4.19}$$

A comparison of (4.18) and (4.19) shows that

$$- \dot{B} = \varepsilon_{CQ}\dot{A} \tag{4.20}$$

Shifts in the cost function are not identical to shifts in the production function unless the production structure exhibits constant returns to scale $(\varepsilon_{CQ} = 1)$.

Using (4.18) and the definition $\dot{TFP} = \dot{Q} - \dot{F}$ we obtain the relationship between shifts in the cost function and the growth in total factor productivity

$$-\dot{B} = \dot{TFP} + (\varepsilon_{CQ} - 1)\dot{Q} \quad . \tag{4.21}$$

If constant returns to scale exist then once again $\varepsilon_{CQ} = 1$ and $-\dot{B} = \dot{TFP}$. This is the case where changes in total factor productivity measure the shifts in both the production and cost functions since $\dot{TFP} = \dot{A} = -\dot{B}$.

The point of the above analysis is to demonstrate that when scale effects are present conventional total factor productivity estimates measure neither shifts in the production function nor the cost function. However, when the cost elasticity is known, scale effects and intertemporal shifts can be separated.

4.2 The Multiple Output Case

Telecommunication firms such as Bell Canada produce a number of different services. In this section we extend the analysis of the previous section to the multiple output case. If a producer is minimizing the cost of producing m outputs using n inputs the cost function may be written as

$$C = g(w_1,\ldots w_n, Q_1,\ldots Q_m,t) \quad . \tag{4.22}$$

Totally differentiating this function with respect to time and re-arranging we obtain (analogously to (4.17))

$$-\dot{B} = \sum_j \varepsilon_{CQ_j}\dot{Q}_j - \sum_i \frac{w_i X_i}{C} \cdot \dot{X}_i \quad , \tag{4.23}$$

where $\varepsilon_{CQ_j} = \partial C/\partial Q_j \cdot Q_j/C$ is the cost elasticity of the jth output. Equation (4.23) may be rewritten as

$$- \dot{B} = \sum_j \varepsilon_{CQ_j} \dot{Q}_j - \dot{F} \tag{4.24}$$

since the last term in (4.23) is $\dot{F}$, the index of aggregate inputs. Given information on the growth in outputs and the cost elasticities, we can utilize (4.24) to calculate shifts in the cost function due to technological change.

We now proceed to link shifts in the cost function $(-\dot{B})$ to the measure of total factor productivity growth $(\dot{TFP})$. Aggregate output in the productivity index was defined by the growth equation

$$\dot{Q} = \sum_j \frac{P_j Q_j}{R} \cdot \dot{Q}_j \tag{4.25}$$

where $R \equiv \sum_j P_j Q_j$ (total revenue) and P_j is the price of output j. Re-arranging (4.24) and using (4.25) we obtain

$$- \dot{B} = \sum_j \left(\varepsilon_{CQ_j} - \frac{P_j Q_j}{R} \right) \dot{Q}_j + \dot{Q} - \dot{F} \tag{4.26}$$

or

$$- \dot{B} = \sum_j \left[\frac{MC_j \cdot Q_j}{C} - \frac{P_j \cdot Q_j}{R} \right] \dot{Q}_j + \dot{TFP} \quad . \tag{4.27}$$

A re-arrangement of (4.27) yields

$$- \dot{B} = \dot{TFP} + \sum_j \left[\frac{(MC_j - P_j) Q_j}{C} \right] \dot{Q}_j + \sum_j \left(\frac{P_j Q_j}{C} - \frac{P_j Q_j}{R} \right) \dot{Q}_j \tag{4.28}$$

or

$$\dot{TFP} = -\dot{B} + \sum_j \left[\frac{(P_j - MC_j)Q_j}{C}\right]\dot{Q}_j + \sum_j \left[(P_jQ_j)(\frac{1}{R} - \frac{1}{C})\right]\dot{Q}_j \quad (4.29)$$

The complicated equation (4.27) may be interpreted relatively easily. If producers sell at prices that equal marginal costs and if there are no economies of scale then the term in brackets equals zero. In this case $\dot{TFP}$ correctly represents the effects of technical change as measured by shifts in the cost function.[1] Equation (4.29) provides a number of insights into the measurement of productivity for a regulated multi-product firm such as Bell Canada. First, suppose there exist no economies of scale but due to imperfect competition $P_j > MC_j$. Then $R > C$ as well. Assuming all outputs are increasing $(\dot{Q}_j > 0)$ then $\dot{TFP}$ overstates $(-\dot{B})$ due to the second term in (4.29) and understates $(-\dot{B})$ due to the third term. The net direction of the discrepancy is unknown. However, if $R = C$, perhaps due to the diseconomies of scale and/or scope, then $\dot{TFP}$ overstates $(-\dot{B})$. Suppose the firm engages in marginal cost pricing $(P_j = MC_j)$ but economies of scale exist so that $R < C$. Then $\dot{TFP}$ overstates $-\dot{B}$. Now suppose the firm is engaging in cross-subsidization, so that some $P_j > MC_j$ and some $P_j < MC_j$, and that the firm earns a positive profit (in excess of the cost of capital) so that $R > C$. Then $\dot{TFP}$ understates $(-\dot{B})$ from the third term. However, the second term has some components which lead to understatements and some which lead to overstatements. Finally, a particularly interesting case occurs when cross-subsidization is accompanied by a zero profit constraint $(R = C)$ as would happen if the Ramsey-optimal pricing rule were chosen by the regulated firm. The discrepancy between $\dot{TFP}$ and $(-\dot{B})$

now depends only on the second term. Once again the direction of the discrepancy is unknown a priori. However, as with all the cases discussed above, the magnitude of the discrepancy can be computed once marginal costs are estimated. These marginal costs can be obtained from the estimated cost function.

4.3 Productivity Measurement and Rate of Return Regulation

In this section we explore the case where rate of return regulation is effective (i.e., the regulated firm expects to earn the allowed rate of return). We demonstrate that in this instance there is a discrepancy between measured total factor productivity growth and the shift in the cost (or production) function in excess of those discussed previously. In particular, if prices of expensed factors of production and the allowed rate of return are increasing over time (perhaps due to inflation), then estimates of technical change which ignore rate of return regulation overestimate the true underlying technical change.

To demonstrate the above assertions, we utilize a model of rate of return regulation developed by Fuss and Waverman (1977). Suppose a regulated firm such as Bell Canada minimizes the cost of producing a given output Q[2] using inputs of labour (L), materials (M), and capital (K) subject to a constraint that limits the rate of return on capital to be less than or equal to s. Assuming the firm expects to earn the allowed rate of return, there exists a "constrained" cost function dual to the production function of the form

$$C = C(w,m,r,s,Q,t) \qquad (4.30)$$

where w , m are the prices of labour and materials respectively. A modified Shephard's Lemma yields the following relationships (see Fuss and Waverman (1977))

$$\begin{aligned} \frac{\partial C}{\partial w} &= (1 - \lambda)\cdot L \\ \frac{\partial C}{\partial m} &= (1 - \lambda)\cdot M \\ \frac{\partial C}{\partial r} &= K \\ \frac{\partial C}{\partial s} &= - \lambda K \end{aligned} \tag{4.31}$$

where L , M and K are the constrained cost-minimizing input levels and λ is the Lagrangian multiplier associated with the rate of return constraint $(0 \leq \lambda < 1)$. Totally differentiating (4.30) with respect to time we obtain

$$\frac{dC(w,m,r,s,Q,t)}{dt} = \frac{\partial C}{\partial w}\frac{dw}{dt} + \frac{\partial C}{\partial m}\frac{dm}{dt} + \frac{\partial C}{\partial r}\frac{dr}{dt} + \frac{\partial C}{\partial s}\frac{ds}{dt} + \frac{\partial C}{\partial Q}\frac{dQ}{dt} + \frac{\partial C}{\partial t} \tag{4.32}$$

Using (4.31), (4.32) becomes

$$\frac{dC}{dt} = [(1-\lambda)L]\frac{dw}{dt} + [(1-\lambda)M]\frac{dm}{dt} + [K]\frac{dr}{dt} - [\lambda K]\frac{ds}{dt} + \frac{\partial C}{\partial Q}\frac{dQ}{dt} + \frac{\partial C}{\partial t} \tag{4.33}$$

or

$$\dot{C} = [(1-\lambda)s_L]\,\dot{w} + [(1-\lambda)s_M]\,\dot{m} + [s_K]\,\dot{r} - [\frac{\lambda sK}{C}]\,\dot{s} + \varepsilon_{CQ}\cdot\dot{Q} + \dot{B} \tag{4.34}$$

Totally differentiating $C = wL + mM + rK$ with respect to time yields an alternative expression for $\dot{C}$ (see equation (4.16))

$$\dot{C} = s_L\dot{L} + s_L\dot{w} + s_M\dot{M} + s_M\cdot\dot{m} + s_K\dot{K} + s_K\dot{r} \tag{4.35}$$

Equating the right-hand sides of (4.34) and (4.35) and solving the resulting equation for $-\dot{B}$, we obtain

$$-\dot{B} = \left\{\varepsilon_{CQ}\dot{Q} - s_L\dot{L} - s_M\dot{M} - s_K\dot{K}\right\} - \left\{\lambda[s_L\dot{w} + s_M\dot{m} + (\tfrac{sK}{C})\dot{s}]\right\} \tag{4.36}$$

or

$$-\dot{B} = \{\varepsilon_{CQ}\dot{Q} - \dot{F}\} - \left\{\lambda[s_L\dot{w} + s_M\dot{m} + (\tfrac{sK}{C})\dot{s}]\right\}^{3} \tag{4.37}$$

Equation (4.37) permits us to analyse the effect of rate of return regulation on productivity measurement. Suppose the technology exhibits constant returns to scale $(\varepsilon_{CQ} = 1)$, and there is an absence of effective rate of return regulation $(\lambda = 0)$. Then the term in the first set of brackets is $\dot{TFP}$, the term in the second set is zero, and measured total factor productivity growth accurately represents technical change (the shift in the cost function).[4] However, with effective rate of return regulation, even under the constant returns to scale assumption $\dot{TFP}$ no longer measures technical change. In fact if $\dot{w}$, $\dot{m}$, and $\dot{s}$ are positive then measured total factor productivity (even corrected for scale effects) <u>overestimates</u> actual technical change. Combining equation (4.21) and (4.37) we obtain the equation

$$\dot{TFP} = -\dot{B} + (1-\varepsilon_{CQ})\dot{Q} + \lambda(s_L\dot{w} + s_M\dot{m} + (\tfrac{sK}{C})\dot{s}) \tag{4.38}$$

The conventional total factor productivity growth index now measures three effects: (i) the shift effect, (ii) the scale effect and (iii) the regulatory effect. In Chapter 7 we present estimates of the decomposition of $\dot{TFP}$ into these three effects.

4.4 Summary

There are a number of reasons why a conventional total factor productivity measure will fail to represent accurately shifts in the cost or production function attributable to technical change. In this chapter we have provided a detailed analysis of the effects of (a) non-constant returns to scale, (b) non-marginal cost pricing and (c) effective rate of return regulation. The linkages derived in this analysis will permit us to interpret the productivity performance of Bell Canada that we presented in Chapter 3.

Chapter 5

Estimation of the Cost Structure for Bell Canada

5.1 Introduction

Total factor productivity estimates can only provide evidence of the overall increase in aggregate output per unit of aggregate input. In Chapter 4 we showed how the theory of production and cost functions could be used to interpret productivity and separate measures of productivity into a number of effects. In particular, knowledge of cost elasticities are important. These elasticities can be obtained from estimates of the cost structure. In this report we obtain our information on the cost structure by estimating the cost function.

We begin with the case of a single aggregate output. This simplification in the output structure allows the incorporation of a general technical change specification. Then we proceed to a disaggregation of outputs into three categories - local service plus miscellaneous, message toll, and other toll (WATS plus private line). In this case we restrict the technical change to be "output augmenting". These specifications are described in detail below. In general, we find evidence of efficiency gains over time due to increasing returns to scale and/or technical change, but the ability of the models to separate the two effects is not robust to small changes in model specification and data. An illustration of this problem is given for the three output cases. We find that the percentage of telephones connected to direct-distance dialing facilities is an important technical change indicator in both the one output and three output cases. The percentage of telephones connected to central offices with modern switching facilities is also an important indicator in the three output cases where the local service output can be separated from the output aggregate. We begin our more detailed analysis with a discussion of these technical change indicators.

5.2 Indicators of Technical Change

An important element of the estimation of the cost function is the specification of the causes of shifts in the function, i.e., the specification of technical change indicators. The most common indicator used in econometric studies is the passage of time (t) . In telecommunications studies, one often finds the percentage of toll calls completed by direct-distance dialing (DDD) used with some success (see Dobell et al (1972)). In this study we have considered four indicators: t; DDD; the percentage of phones with access to direct-distance dialing facilities (A); and the percentage of phones connected to central offices with modern switching facilities (S).[1] We have found A to be an extremely important indicator of the cost reductions due to technical change. Since data on A are available only since 1962, a series had to be constructed for the period 1952-61. Details of the data constructed are contained in the Data Appendix. Table 5-1 presents the time path of the four indicators over the 1952-77 time period. A grows more rapidly than DDD in the early period, consistent with the learning curve relationship between A and DDD assumed in the data construction. S grows the least rapidly in the early period and the most rapidly in the latter period. Both A and DDD are indicators of the same phenomenon - the replacement of telephone operators by automatic equipment for the handling of long distance (toll) calls. In our econometric analysis, we have found

Table 5-1

Indicators of Technical Change

Time t	% of toll calls using direct-distance dialing DDD	% of phones with access to direct-distance dialing A	% of phones connected to modern switching facilities S
1952	0	0	0
1953	0	0	0
1954	0	0	0
1955	0	0	0
1956	.006	.039	.012
1957	.013	.069	.034
1958	.053	.235	.048
1959	.091	.337	.064
1960	.159	.499	.077
1961	.224	.602	.088
1962	.263	.578	.112
1963	.311	.619	.138
1964	.373	.712	.168
1965	.433	.729	.193
1966	.471	.736	.222
1967	.507	.721	.249
1968	.568	.785	.281
1969	.624	.823	.306
1970	.682	.821	.336
1971	.721	.822	.357
1972	.766	.840	.387
1973	.789	.842	.416
1974	.811	.841	.458
1975	.821	.849	.487
1976	.830	.847	.522
1977	.838	.846	.549

A to be a consistently superior indicator of technical change in comparison with DDD. This suggests to us that the reduction of operators occurred when direct-distance dialing facilities were available, rather than when they were used. Long-distance callers who requested operator assistance presumably suffered a loss in service quality in terms of longer waiting times; a situation which would have the effect of accelerating the diffusion of the use of direct-distance dialing facilities.

5.3 Estimation of Bell Canada's Cost Function for Aggregate Output

Suppose Bell Canada's cost function can be represented by

$$C = g(P_L, P_K, P_M, Q, T) \tag{5.1}$$

where P_i , $i = L, K, M,$ are the input prices of labour (L) , capital (K) and materials (M) respectively, Q is the aggregate output and T is an indicator of technical change. The cost function used to estimate the cost structure is the translog cost function, a second order approximation to an arbitrary cost function. The translog cost function is given by

$$\begin{aligned}\log C = {} & \alpha_o + \alpha_Q \log Q + \alpha_L \log P_L + \alpha_K \log P_K + \alpha_M \log P_M + \tfrac{1}{2} \gamma_{LL} (\log P_L)^2 \\ & + \gamma_{LK} \log P_L \log P_K + \gamma_{LM} \log P_L \log P_M + \tfrac{1}{2} \gamma_{KK} (\log P_K)^2 \\ & + \gamma_{KM} \log P_K \log P_M + \tfrac{1}{2} \gamma_{MM} (\log P_M)^2 + \gamma_{LQ} \log P_L \log Q \\ & + \gamma_{KQ} \log P_K \log Q + \gamma_{MQ} \log P_M \log Q + \tfrac{1}{2} \gamma_{QQ} (\log Q)^2\end{aligned}$$

$$+ \beta_{LT} \log P_L \log T + \beta_{KT} \log P_K \log T + \beta_{MT} \log P_M \log T$$

$$+ \beta_T \log T + \tfrac{1}{2} \beta_{TT} (\log T)^2 + \beta_{TQ} \log T \log Q \qquad (5.2)$$

The cost share equation for this technology may be obtained, using Shephard's Lemma, as

$$S_L = \alpha_L + \gamma_{LL} \log P_L + \gamma_{LK} \log P_K + \gamma_{LM} \log P_M + \gamma_{LQ} \log Q + \beta_{LT} \log T$$

$$S_K = \alpha_K + \gamma_{LK} \log P_L + \gamma_{KK} \log P_K + \gamma_{KM} \log P_M + \gamma_{KQ} \log Q + \beta_{KT} \log T \qquad (5.3)$$

$$S_M = \alpha_M + \gamma_{LM} \log P_L + \gamma_{KM} \log P_K + \gamma_{MM} \log P_M + \gamma_{MQ} \log Q + \beta_{MT} \log T$$

The share equations must sum to one which requires us to impose the following constraints:

$$\sum \alpha_i = 1 \ , \ \sum_i \gamma_{ij} = 0 \ , \ \sum_i \gamma_{iQ} = 0 \ , \ \sum_i \beta_{iT} = 0 \ , \quad i,j = K,L,M \qquad (5.4)$$

The constraints (5.4) imply that one of the share equations is redundant for estimation purposes. Which equation is deleted is unimportant as long as maximum likelihood estimates are obtained. Table 5-2 presents the parameter estimates obtained from estimating the cost function (5.2) and two of the three share equations (5.3). Table 5-3 presents the summary statistics. The technical change indicator used was $T = e^A$, where A is the percentage of phones with access to direct-distance dialing since this indicator was superior to t, DDD or S in terms of maximizing the likelihood function and randomness of the residuals. Attempts to use combinations of these indicators proved unsuccessful.

Table 5-2

Parameter Estimates - Aggregate Output Cost Function
(Standard Errors in Brackets)

Parameter	Estimate	Parameter	Estimate
α_o	6.66 (0.52)	γ_{MM}	0.056 (0.022)
α_Q	0.695 (0.071)	γ_{LQ}	-0.022 (0.009)
α_L	0.425 (0.007)	γ_{KQ}	0.032 (0.008)
α_K	0.396 (0.010)	γ_{MQ}	-0.010 (0.008)
α_M	0.179 (0.008)	γ_{QQ}	-0.219 (0.050)
γ_{LL}	0.0215 (0.0286)	β_{LT}	-0.152 (0.011)
γ_{LK}	-0.0625 (0.0203)	β_{KT}	0.171 (0.014)
γ_{LM}	0.0410 (0.0204)	β_{MT}	-0.0189 (0.0106)
γ_{KK}	0.159 (0.030)	β_T	-0.208 (0.149)
γ_{KM}	-0.097 (0.021)	β_{TT}	-0.079 (0.223)
β_{TQ}	-0.154 (0.105)		

Table 5-3

Summary Statistics

Equation	R^2	D.W. Statistic
Cost Function	0.9993	1.52
Labour Share	0.9932	1.32
Capital Share	0.9910	1.55

Table 5-4 presents the matrix of own and cross-price elasticities of factor demand, evaluated at the sample mean. The numbers in parentheses are approximate standard errors. Demand for each aggregate factor of production is inelastic, with labour being the most responsive to changes in its own price and capital being the least. Labour and capital and labour and materials are substitutes in production. Capital and materials show a weak complementarity relationship but an independence hypothesis would not be rejected.

Table 5-5 presents the response of total cost and factor demands to changes in the levels of output and access to direct-distance dialing facilities, evaluated at the sample mean. For example, a 1% increase in output leads to a 0.632% increase in cost and a 0.567% increase in employment. Since the capital-output elasticity is greater than any of the other input-output elasticities, higher output levels are characterized by more capital intensive production techniques. The cost elasticity (ε_{CQ}) evaluated at the mean is 0.632 indicative of economies of scale. This elasticity is highly trended, beginning with a value of 0.988 in 1952 and ending with a value of 0.399 in 1976. This result is highly suspicious and suggests a misspecification of the technical change indicator or the output variable.[2] One possibility is that the technical change indicator A cannot adequately represent technical change in the latter portion of the sample, since it implies a slowing up and eventual elimination of technical change as access saturation levels are reached. Clearly more research is needed on the correct specification of the technical change indicator.

The numbers in the second column of Table 5-5 measure the proportionate change in cost and factor demands when access is increased by

Table 5-4

Factor Price Elasticities*
(Evaluated at the Mean Observations)

	Labour	Capital	Materials
Labour	-0.591 (0.083)	0.218 (0.042)	0.594 (0.123)
Capital	0.307 (0.057)	-0.185 (0.061)	-0.097 (0.125)
Materials	0.284 (0.059)	-0.033 (0.043)	-0.497 (0.132)

* The first row presents the elasticity of the demand for labour, capital, and materials respectively with respect to the price of labour. The other rows are interpreted in an analogous manner.

Table 5-5

Output and Technical Change Indicator Elasticities
(Evaluated at the Mean Observations)

	Output	Technical Change Indicator
Cost	0.632 (0.016)	-0.124 (0.018)
Labour	0.567 (0.322)	-0.359 (0.029)
Capital	0.698 (0.013)	0.063 (0.012)
Materials	0.571 (0.056)	-0.185 (0.048)

one per cent. For example, when the percentage of phones with access to direct-distance dialing facilities is increased from its mean value of 53% to 53½% and output is held constant, total (and average) cost declines 0.124%. Employment declines 0.359%, materials 0.185% while capital increases slightly, by 0.063%. The access elasticities are also highly trended. For example, the cost-access elasticity begins with a value of 0 in 1952 (by definition) and ends with a value of -0.34 in 1976. This trend is partially explicable by the fact that a 1% increase in access in the later years of the sample involves connecting both a larger percentage and absolute number of telephones to direct-distance dialing facilities than a 1% increase in the early years of the sample. However, the strong trend is once again indicative of problems in technical change indicator specification and/or output measurement.

Finally, in Table 5-6 we present, using a likelihood ratio test, tests of specialized structures of technology which have often been imposed in previous studies of Bell Canada's cost or production structure. All of the specialized descriptions are decisively rejected. Of particular importance for our study is the rejection of constant returns to scale. As we demonstrated in Chapter 4, this fact means that $\dot{TFP}$ no longer measures only dynamic efficiency gains as represented by shifts in the cost or production function but the static scale efficiency effects as well.

Table 5-6

Tests of Hypotheses Concerning the Cost Structure

	χ^2 Statistic	Number of Additional Constraints	Critical Value (5%) of χ^2 Statistic
Homotheticity $\gamma_{iQ} = 0 \quad , \ i = L,K,M$	12.90	2	5.99
Constant Returns to Scale $\gamma_{iQ} = 0 \quad , \ i = L,K,M$ $\gamma_{QQ} = \beta_{TQ} = 0$ $\alpha_Q = 1$	132.51	5	11.07
No Technical Change $\beta_T = \beta_{TT} = \beta_{TQ} = 0$ $\beta_{iT} = 0 \ , \quad i = L,K,M$	87.42	5	11.07
Hicks Neutral Technical Change $\beta_{TQ} = 0$ $\beta_{iT} = 0 \quad , \ i = L,K,M$	60.77	3	7.82

5.4 Estimation of Bell Canada's Cost Function - The Three Output Case

It is likely that technical change has affected the provision of local and toll services in different ways. In addition, recent work by Fuss and Waverman (1977) has shown that aggregation of outputs into a single output is a restriction which is not supported by the data. In this section we report on the estimation of a disaggregated model which includes a three output cost function. The outputs chosen were (i) message toll (Q_1), (ii) other toll - private line services plus WATS (Q_2) and (iii) local service plus miscellaneous (Q_3). The model estimated was the one developed by Fuss and Waverman (1977), in which the regulated telecommunications firm chooses the profit maximizing levels of toll services (Q_1 and Q_2), but is constrained by the regulatory authorities to charge a price for local services below the profit-maximizing price.

The specification of the cost function chosen utilizes the technical change indicators in an unusual way. It is generally believed that during the sample period, the major technological innovation influencing the provision of toll services was the introduction of direct-distance dialing facilities. In contrast, the introduction of modern switching facilities at central offices had its major impact on the provision of local services. The effect of these innovations is to reduce the cost of providing a given level of services, but the impact is essentially service specific. To capture the above reasoning in an econometric cost function, we assume that the cost function can be written in the "output-augmenting" form

$$C = C[P_L, P_K, P_M, Q_1 \cdot h_1(A), Q_2 \cdot h_2(A), Q_3 \cdot h_3(S)] \qquad (5.5)$$

where A and S are the technical change indicators defined previously. The h_i functions are augmentation functions such that for any given Q_1, Q_2 and Q_3, an increase in A and/or S will lead to a decline in costs, but an increase in A will have as its major impact a decline in the marginal cost of toll services and an increase in S will have its major impact on the marginal cost of local service.[3] Define the "augmented" outputs by

$$Q_1^* = Q_1 \cdot h_1(A) = Q_1 e^{\lambda_1 A} \tag{5.6}$$

$$Q_2^* = Q_2 \cdot h_2(A) = Q_2 e^{\lambda_2 A} \tag{5.7}$$

$$Q_3^* = Q_3 \cdot h_3(S) = Q_3 e^{\lambda_3 S} \tag{5.8}$$

Then the cost function (5.5) becomes

$$C = C[P_L, P_K, P_M, Q_1^*, Q_2^*, Q_3^*] \tag{5.9}$$

which can be approximated by the second order translog cost function

$$\begin{aligned} \log C = {} & \alpha_o + \sum_i \alpha_i \log P_i + \sum_k \beta_k \log Q_k^* + \tfrac{1}{2} \sum_i \delta_{ii} (\log P_i)^2 \\ & + \sum_{\substack{i j \\ i \neq j}} \sum \gamma_{ij} \log P_i \log P_j + \tfrac{1}{2} \sum_k \delta_{kk} (\log Q_k^*)^2 \\ & + \sum_{\substack{k \ell \\ k \neq \ell}} \sum \delta_{k\ell} (\log Q_k^* \log Q_\ell^*) + \sum_{ik} \sum \rho_{ik} \log P_i \log Q_k^* \end{aligned} \tag{5.10}$$

where $i,j = L,K,M$

$k,\ell = 1,2,3$

and

$$\log Q_1^* = \log Q_1 + \lambda_1 A$$

$$\log Q_2^* = \log Q_2 + \lambda_2 A$$

$$\log Q_3^* = \log Q_3 + \lambda_3 S$$

The cost share equations can be obtained from Shephard's Lemma as

$$S_i = \alpha_i + \sum_i \gamma_{ij} \log P_j + \sum_k \rho_{ik} \log Q_k^* \qquad (5.11)$$

$$i = L,K,M \qquad k = 1,2,3$$

The fact that $\sum S_i = 1$ implies the constraints

$$\sum \alpha_i = 1 \; , \quad \sum_i \gamma_{ij} = 0 \; , \quad \sum_i \rho_{ik} = 0 \qquad (5.12)$$

The second order approximation property of the cost function implies the additional constraints

$$\gamma_{ij} = \gamma_{ji} \quad i \neq j \quad ; \qquad \delta_{k\ell} = \delta_{\ell k} \quad \ell \neq k \qquad (5.13)$$

Following Fuss and Waverman (1977), the profit-maximizing behaviour with respect to toll services implies the two additional equations:

$$\frac{P_1 Q_1}{C} = \left(\frac{1}{1 + \varepsilon_1}\right)^{-1} \cdot \left[\beta_1 + \sum_\ell \delta_{1\ell} \log Q_\ell^* + \sum_i \rho_{i1} \log P_i\right] \qquad (5.14)$$

$$\frac{P_2 Q_2}{C} = \left(\frac{1}{1 + \varepsilon_2}\right)^{-1} \cdot \left[\beta_2 + \sum_\ell \delta_{2\ell} \log Q_\ell^* + \sum_i \rho_{i2} \log P_i\right] \qquad (5.15)$$

$$i = L,K,M$$

$$\ell = 1,2,3$$

where $\varepsilon_1 = -1.435$ and $\varepsilon_2 = -1.639$ are the own-price elasticities of demand for message toll and other toll services respectively, taken from Fuss and Waverman (1977).

The system of equations estimated consists of the cost function (5.10), two of the three cost share equations (5.11) and the two revenue "share" equations (5.14) and (5.15). The maximum likelihood estimates of the parameters are presented in Table 5-7. Summary statistics appear in Table 5-8. Table 5-9 contains the factor price elasticity matrix while Table 5-10 presents the output and technical change indicator elasticities.

The factor price elasticities are reasonably similar to those obtained in the one output case. They appear relatively robust to the change in specification. The total cost elasticity is 0.68 at the sample mean, also relatively close to the estimate of 0.63 obtained in the aggregate output case. This cost elasticity is also highly trended, falling from 1.08 in 1952 to 0.45 in 1976. The downward trend is almost entirely accounted for by the trend in the local service cost elasticity which falls from 0.98 in 1952 to 0.31 in 1976. Hence, the increasing returns to scale phenomenon is estimated to be caused by increases in the local service output. This fact is consistent with the view that the provision of local services is at the centre of any natural monopoly that exists with respect to Bell Canada's technology. On the other hand, it is also consistent with our view, expressed earlier, that the constant dollar output measure overstates the trend in output growth, especially for local services where optional equipment, presumably priced above marginal cost has become an increasingly important component during the latter part of the sample period.

Table 5-7

Parameter Estimates - Three Output Cost Function
(Standard Errors in Brackets)

α_o	6.579 (0.024)	δ_{33}	-0.145 (0.054)
α_L	0.404 (0.008)	δ_{12}	0.0159 (0.0020)
α_K	0.418 (0.010)	δ_{13}	-0.104 (0.013)
α_M	0.178 (0.007)	δ_{23}	-0.0418 (0.0079)
β_1	0.0829 (0.0042)	ρ_{L1}	0.0275 (0.0079)
β_2	0.00865 (0.00253)	ρ_{L2}	-0.0221 (0.0046)
β_3	0.513 (0.033)	ρ_{L3}	-0.0375 (0.0244)
γ_{LL}	0.0594 (0.0240)	ρ_{K1}	-0.0217 (0.0089)
γ_{KK}	0.188602*	ρ_{K2}	0.0293 (0.0052)
γ_{MM}	0.0441 (0.0192)	ρ_{K3}	0.0239 (0.0270)
γ_{LK}	-0.102 (0.015)	ρ_{M1}	-0.00582 (0.00636)
γ_{LM}	0.0425 (0.0158)	ρ_{M2}	-0.00718 (0.00353)
γ_{KM}	-0.0866 (0.0147)	ρ_{M3}	0.0136 (0.0220)
δ_{11}	0.0301 (0.0056)	λ_1	-1.676 (0.332)
δ_{22}	0.0125 (0.0056)	λ_2	3.742 (0.732)
		λ_3	-0.327 (0.094)

Table 5-7 cont'd.

* The value of this parameter was preassigned. Unconstrained regression resulted in an own-price elasticity for capital which was slightly positive although insignificantly different from zero. The value of the parameter γ_{KK} was constrained so that it produced an own-price elasticity of capital as close as possible to that obtained for the aggregate output case, consistent with this value not being rejected by the data using a 5% significance level formal hypothesis test. A comparison of capital own-price elasticities in Tables 5-4 and 5-9 demonstrates the close similarity of the estimates.

Table 5-8

Summary Statistics - Three Output Cost Functions

Equation	R^2	D.W. Statistic
Cost Function	0.9992	1.27
Labour Share	0.9957	1.83
Capital Share	0.9912	1.57
Message Toll "Share"	0.6207	1.73
Other Toll "Share"	0.9900	0.88

Table 5-9

Factor Price Elasticities
(Evaluated at the Mean Observations)

	Labour	Capital	Materials
Labour	-0.482 (0.068)	0.137 (0.030)	0.603 (0.095)
Capital	0.193 (0.042)	-0.126*	-0.0348 (0.0884)
Materials	0.289 (0.046)	-0.0118 (0.0301)	-0.568 (0.116)

* There is no standard error associated with the capital own-price elasticity since γ_{KK} was preassigned. See footnote to Table 5-7 for details.

Table 5-10

Output and Technical Change Indicator Elasticities
(Evaluated at Mean Observations)

	Output			Technical Change Indicator	
	Q_1	Q_2	Q_3	A	S
Cost	0.104 (0.001)	0.0269 (0.0006)	0.552 (0.028)	-0.0391 (0.0116)	-0.0357 (0.0119)
Labour	0.183 (0.023)	-0.0369 (0.0133)	0.443 (0.079)	-0.238 (0.022)	-0.173 (0.059)
Capital	0.0593 (0.0183)	0.0870 (0.0109)	0.601 (0.060)	0.121 (0.010)	-0.183 (0.062)
Materials	0.0687 (0.0380)	-0.0164 (0.0211)	0.634 (0.134)	-0.094 (0.035)	-0.186 (0.061)

There is one peculiarity in the output elasticities with respect to other toll (Q_2). Labour and materials elasticities although very small are negative and the labour elasticity is significantly negative. It is unlikely that labour is a regressive input with respect to other toll output, as this result suggests.

Turning now to the technical change indicator elasticities, we see, from Table 5-10, the effects of the introduction of innovations. An increase in the percentage of phones with access to direct-distance dialing facilities is accompanied by declines in employment and materials usage and a slight increase in capital services demanded. On the other hand, an increase in the percentage of phones connected to central offices with modern switching facilities is accompanied by a decline in demand for all three factors of production.

The employment effects of innovative activity are clearly apparent in the results. A 1% increase in A from its mean value of 53.3% to 53.8% results in a reduction in employment of 0.24%. In addition, a 1% increase in S from its mean value of 19.8% to 20% results in a decline in employment of 0.17%. The aggregate employment effects of innovative activity are substantial. In the next chapter we analyse these effects in terms of their impact on the various categories of employment.

Finally we should comment on the lack of robustness of the division of efficiency gains between scale effects and technical change effects. We replicated the Fuss-Waverman (1977) capital service price technical change augmenting model with our revised data.[4] Within the last year Bell Canada has substantially revised several years (1971-72) other toll, directory advertising, and miscellaneous revenue constant dollar outputs and made smaller adjustments in the constant dollar local service revenue from 1969-75. In addition, Fuss and Waverman (1977) included indirect taxes in the materials input and had data only to 1975. These data changes were the only differences between the two estimations. The comparisons of relevant measures of the technology evaluated for the year 1967 are contained in Table 5-11. In our replication, the efficiency gains are due mainly to scale effects. For Fuss-Waverman, efficiency gains are due mainly to technical change. Clearly this lack of robustness suggests that more research effort must be devoted to data measurement particularly with respect to the definition of the output measures.

Table 5-11

Comparison of Measures of Technology for the Fuss-Waverman Model

	Fuss-Waverman (1977)	Denny-Fuss
rate of capital augmenting technical change	-0.0668	-0.0204
total cost elasticity	0.945	0.684

Chapter 6

An Empirical Analysis of the Employment Effects of Technical Change

6.1 Introduction

In this chapter we examine the effects of the introduction of innovations on the demand for labour disaggregated into four categories. For the years 1952-72, some data are available on seven types of labour employed by Bell Canada. The data include manhours worked and a wage rate. The seven types of labour for which disaggregated data are available are:

1) telephone operators
2) plant craftsmen
3) clerical workers
4) other non-supervisors
5) foremen and supervisors
6) executives
7) part-time workers .

The quality of the wage data was poor for labour categories 4, 5, 6 and 7. This low quality was due to the assumption made by Millen (1974) in constructing the data that wage rates of these four groups were proportional to one another during part of the time period. According to the Hicks aggregation theorem, we must either find a source of independent variation in the wages paid to these four categories or aggregate the categories, since we wish to analyse employment within a system of factor demand equations. We have chosen to aggregate the last four categories into a residual category which we label, somewhat loosely, as "white collar" employees. We have also made a number of adjustments to this data set. These adjustments are discussed in detail in the Data Appendix.

6.2 A Two-Stage Model of the Cost Structure

The disaggregation of labour into four categories means that we wish to analyse a cost structure with six inputs - a large number for econometric cost function estimation. Fuss (1977) has developed an econometric model to deal with the many input cases which we utilize in this chapter. The conceptual details are presented in the referenced publication. Here we present a brief outline of the model as it applies to our analysis.

A general cost function for the cost structure being modelled can be written as

$$C = C(w_1, w_2, w_3, w_4, P_K, P_M, Q, T) \tag{6.1}$$

where w_1 = wage rate of operators

w_2 = wage rate of plant craftsmen

w_3 = wage rate of clerical workers

w_4 = wage rate of white collar employees

P_K = user cost of capital services

P_M = price of materials

Q = output quantity

T = indicator of technical change

We assume that the cost function (6.1) can be written in the separable form

$$C = C(P_L(w_1,w_2,w_3,w_4,Q,T), P_K, P_M, Q, T) \tag{6.2}$$

The separability restriction implies that the partial elasticities of substitution between each labour type and capital or materials are identical. However, there can exist a variety of different substitution possibilities among labour types. The function

$$\hat{P}_L = P_L(w_1, w_2, w_3, w_4, Q, T) \tag{6.3}$$

is called an aggregator function, and estimation of this function yields an estimated wage rate for aggregate labour (L) . The aggregator function (6.3) is more general than the one proposed by Fuss (1977) in two ways. First, the function need not be of zero homogeneity in output. Second, the technical change indicator can affect the relative employment opportunities of the different labour categories, as well as the absolute level of aggregate employment.

According to the two-stage model a cost-minimizing firm is envisaged as choosing input levels in two stages. In the first stage, for a given level of output (Q) , the firm chooses the proportions of employment by labour categories in order to minimize the cost per unit ($\hat{P}_L$) of aggregate labour. In the second stage, also for a given level of output, the firm combines aggregate labour, capital, and materials to minimize the cost of production. The estimation of this second stage is identical to the estimation of the single output cost function carried out in Chapter 5. The only difference is that the actual aggregate wage series (P_L) is replaced by an estimated wage series $\hat{P}_L$, obtained by estimating the parameters of (6.3).

Equation (6.3) is one component of what is called the labour, "submodel" and can be represented by the translog approximation

$$\log \hat{P}_L = \beta_0 + \sum_i \beta_i \log w_i + \tfrac{1}{2} \sum_i \beta_{ii} (\log w_i)^2$$
$$+ \sum_{\substack{i\,j \\ i \neq j}}\sum \beta_{ij} \log w_i \log w_j + \sum_i \beta_{iQ} \log w_i \log Q$$
$$+ \sum \beta_{iT} \log w_i \log T \quad . \tag{6.4}$$

$$i = 1,\ldots 4$$

The remaining components of the labour sub-model can be obtained (by applying Shephard's Lemma to equation (6.4)) as

$$SL_i = \beta_i + \sum_j \beta_{ij} \log w_i + \beta_{iQ} \log Q + \beta_{iT} \log T \tag{6.5}$$

$$i = 1,\ldots 4$$

where SL_i is the cost share of labour type i in the total cost of labour. Since the cost shares sum to unity the following restrictions are placed on the parameters:

$$\sum_i \beta_i = 1 \ , \quad \sum_i \beta_{ij} = 0 \ , \quad \sum \beta_{iQ} = 0 \ , \quad \sum \beta_{iT} = 0 \quad . \tag{6.6}$$

In addition $\beta_{ij} = \beta_{ji}$ by the second order approximation property of the aggregator function (6.4). Finally once again one equation must be deleted in estimation.

The two-stage model is estimated as follows. First, the parameters of the sub-model are estimated using three of the share equations (6.5), and the estimated parameters are substituted into (6.4) to obtain the estimated aggregate price of labour series. The parameter β_0 can be set arbitrarily to zero to normalize the series since the estimated series is a price index. Second, using $\hat{P}_L$ in place of P_L the parameters of the aggregate model are estimated from the system of equations (5.2) and (5.3).

We begin the presentation of the empirical results with those pertaining to the second stage aggregate model. The technology indicator used was $T = e^A$, since A once again performed in a superior manner relative to the competing indicators at both stages of the two-stage model. The results are summarized in Tables 6-1 to 6-4, which correspond exactly to Table 5-2 to 5-5. The results are reasonably similar. Much of the differences in the factor price elasticities are attributable to the fact that with the different sample periods, the sample means at which these elasticities are calculated are different. There are somewhat more substantial differences in output and technical change indicator elasticities, a fact which illustrates the lack of robustness of these estimates. Nevertheless, the interpretive discussion in Chapter 5 applies to these results as well so that we will move immediately to a consideration of the labour sub-model. Tables 6-5 to 6-8 contain the results obtained by estimating the labour sub-model. Table 6-5 presents the parameter estimates while Table 6-6 presents the summary statistics. Factor price elasticities and output and technical change indicator elasticities are contained in Tables 6-7 and 6-8. It is important to note that these elasticities assume aggregate L as well as Q are held constant. The comparable elasticities with L optimally chosen and only Q held constant are presented in Tables 6-9 and 6-10. Finally, it should also be noted that we have only calculated the lower triangular portion of the price elasticities matrix. The missing elasticities are easily calculated using the formulae found in Fuss (1977).

Table 6-1

Parameter Estimates - Aggregate Inputs Stage of Two-Stage Model (standard errors in brackets)

Parameter	Estimate	Parameter	Estimate
α_o	6.45 (0.07)	γ_{MM}	0.105 (0.037)
α_Q	1.07 (0.13)	γ_{LQ}	-0.0346 (0.0058)
α_L	0.169 (0.005)	γ_{KQ}	0.0183 (0.0140)
α_K	0.575 (0.016)	γ_{MQ}	0.0163 (0.0136)
α_M	0.256 (0.015)	γ_{QQ}	0.0449 (0.1201)
γ_{LL}	0.0388 (0.0161)	β_{LT}	-0.0669 (0.0063)
γ_{LK}	0.00166 (0.01622)	β_{KT}	0.122 (0.021)
γ_{LM}	-0.0405 (0.0116)	β_{MT}	-0.0552 (0.0202)
γ_{KK}	0.0623 (0.0422)	β_T	-0.399 (0.190)
γ_{KM}	-0.0640 (0.0380)	β_{TT}	0.305 (0.258)
β_{TQ}	-0.525 (0.165)		

Table 6-2

Summary Statistics

Equation	R^2	D.W. Statistics
Cost Function	0.9993	1.44
Labour Share	0.9948	1.44
Capital Share	0.9734	1.60

Table 6-3

Factor Price Elasticities
(Evaluated at the Mean Observations)

	Labour	Capital	Materials
Labour	-0.533 (0.045)	0.362 (0.034)	0.119 (0.068)
Capital	0.477 (0.045)	-0.396 (0.089)	0.0935 (0.2250)
Materials	0.059 (0.032)	0.0334 (0.0803)	-0.212 (0.222)

Table 6-4

Output and Technical Change Indicator Elasticities
(Evalutated at the Mean Observations)

	Output	Technical Change Indicator
Cost	0.808 (0.022)	-0.0425 (0.0165)
Labour	0.712 (0.028)	-0.131 (0.019)
Capital	0.847 (0.026)	0.081 (0.017)
Materials	0.905 (0.094)	-0.198 (0.068)

Table 6-5

Parameter Estimates - Labour Sub-model
Stage of Two-Stage Model
(standard errors in brackets)

β_1	0.255 (0.014)	β_{1Q}	-0.0212 (0.0095)
β_2	0.199 (0.013)	β_{2Q}	-0.00591 (0.00928)
β_3	0.170 (0.008)	β_{3Q}	0.0146 (0.0060)
β_4	0.375 (0.020)	β_{4Q}	0.0125 (0.0135)
β_{11}	-0.0737 (0.0355)	β_{1T}	-0.144 (0.017)
β_{12}	0.102 (0.029)	β_{2T}	0.0353 (0.0167)
β_{13}	0.0534 (0.0174)	β_{3T}	-0.0154 (0.0104)
β_{14}	-0.0821 (0.0264)	β_{4T}	0.124 (0.025)
β_{22}	0.107 (0.032)	β_{33}	0.105 (0.033)
β_{23}	-0.174 (0.023)	β_{34}	0.0151 (0.0193)
β_{24}	-0.0353 (0.0282)	β_{44}	-0.00445 (0.04543)

Table 6-6

Summary Statistics

Equation	R^2	D.W. Statistics
Operators Share	0.9895	2.02
Plant Craftsmens Share	0.7182	1.12
Clerical Workers Share	0.6620	1.12

Table 6-7

Factor Price Elasticities (Aggregate L Constant)
(Evaluated at the Mean Observations)

	Operators	Plant Craftsmen	Clerical	White Collar
Operators	-1.169 (0.178)			
Plant Craftsmen	0.736 (0.144)	-0.299 (0.144)		
Clerical	0.528 (0.087)	-0.518 (0.102)	-0.335 (0.126)	
White Collar	0.828 (0.214)	0.158 (0.126)	0.0324 (0.1056)	-0.360 (0.135)

Table 6-8

Output and Technical Change Indicator
Elasticities (Aggregate L Constant)
(Evaluated at the Mean Observations)

	Output	Technical Change Indicator
Operators	-0.108 (0.048)	-0.352 (0.042)
Plant Craftsmen	-0.0285 (0.0422)	0.0658 (0.0359)
Clerical	0.0540 (0.0239)	-0.0373 (0.0198)
White Collar	0.0376 (0.0411)	0.176 (0.036)

From Tables 6-7 and 6-9, we can see that, of the labour subtypes, only the operators component exhibits elastic demand. All components are substitutes except for clerical workers and plant craftsmen which appear to be complements.

Tables 6-8 and 6-10 present the employment effects of increased output and the introduction of innovations as represented by access to direct-distance dialing facilities. Table 6-8 provides the relative employment effects while Table 6-10 provides the absolute effects. An increase in output leads to a decline in the relative employment of operators and plant craftsmen and an increase in the relative employment of clerical and white collar workers. By way of contrast, an increase in access to direct-distance dialing facilities is accompanied by a relative decline in operators and clerical workers and a relative increase in plant craftsmen and white collar employees. These results are apparent from an inspection of Table 6-8. Table 6-10 illustrates the effect of increased scale and innovative activity on absolute employment levels of the four categories. Larger scale production is characterized by a reduction in labour intensity, especially operator intensity. The results with respect to innovation are particularly striking. An increase in access to direct-distance dialing facilities is accompanied by absolute decline in the employment of operators and clerical workers and in the use of materials. It is also accompanied by increased employment of plant craftsmen and white collar workers, and increased installation of capital equipment. For example, from Table 6-10, we see that a one per cent point increase in the percentage of telephones with access to direct-distance dialing facilities from its mean

Table 6-9

Factor Price Elasticities (Aggregate L Optimally Chosen)
(Evaluated at the Mean Observations)

	Operators	Plant Craftsmen	Clerical	White Collar	Capital	Materials
Operators	-1.276				0.072	0.024
Plant Craftsmen	0.617	-0.418			0.081	0.027
Clerical	0.389	-0.657	-0.474		0.094	0.031
White Collar	0.660	-0.010	-0.136	-0.528	0.114	0.038

Table 6-10

Output and Technical Change Indicator
Elasticities (Aggregate L Optimally Chosen)
(Evaluated at the Mean Observations)

	Output	Technical Change Indicator
Operators	0.606	-0.861
Plant Craftsmen	0.685	0.027
Clerical	0.768	-0.190
White Collar	0.752	0.261
Capital	0.847	0.081
Materials	0.905	-0.198

value of 47% to 47½% is accompanied by a 0.85% decline in the employment level of operators. This very large effect graphically illustrates the substantial employment effects inherent in labour-saving innovative activity.

Chapter 7

The Contributions of Scale Economies, Non-Marginal Cost Pricing and Technical Change to Total Factor Productivity Growth

In this chapter we attempt to determine the relative importance of scale economies, non-marginal cost pricing, and technical change to total factor productivity growth as conventionally measured. For the case of a single output, only scale and shift due to technical change influence the conventional Divisia index. In the case of multiple outputs non-marginal cost pricing also becomes a determinant. To allocate the relative contributions we utilize the equations

$$\dot{TFP} = \dot{A} + (\varepsilon_{CQ}^{-1} - 1)\,\dot{F} \tag{4.10}$$

for the single output case, and a rearrangement of equation (4.26):

$$\dot{Q} - \dot{F} = \dot{TFP} = -\,\dot{B} - \sum_j \left(\varepsilon_{CQ_j} - \frac{P_j Q_j}{R} \right) \dot{Q}_j \tag{7.1}$$

for the multiple output case. The required cost elasticities are computed from the relevant cost functions estimated in Chapter 5. Tables 7-1 and 7-2 present the results of the allocation exercise. These results represent the dividing up of $\dot{TFP}$ which appears in column 1 of Table 3-3. It can be seen from Tables 7-1 and 7-2 that efficiency gains due to the exploitation of scale economies and the existence of non-marginal cost pricing practices appear to dominate cost savings due to the introduction of direct-distance dialing and modern switching facilities in $\dot{TFP}$. This result is especially striking in the 1963-66 and post 1970 period. However, the answer is not quite so simple. Since the technology cannot be specified as homothetic with respect to outputs and subject to Hicks neutral

Table 7-1

Analysis of the Growth of Total Factor Productivity
Aggregate Output Case

Period	Growth of Total Factor Productivity $\dot{TFP}$	Relative Importance of Contributors to Growth of Total Factor Productivity	
		Technical Change	Scale Economies
1952-57	1.4%	33%	67%
1958-62	3.0%	50%	50%
1963-66	3.1%	9%	91%
1967-70	4.7%	29%	71%
1971-76	4.5%	-2%	102%

Table 7-2

Analysis of the Growth of Total Factor Productivity
Multiple Output Case

Period	Growth of Total Factor Productivity $\dot{TFP}$	Relative Importance of Contributors to Growth of Total Factor Productivity: Technical Change	Scale Economies and Non-Marginal Cost Pricing
1952-57	1.4%	29%	71%
1958-62	3.0%	44%	56%
1963-66	3.1%	0	100%
1967-70	4.7%	19%	81%
1971-76	4.5%	4%	96%

technical change (see the tests in Table 5-6), scale and technical change interact to create efficiency gains. For example, technical change is estimated to have the effect of increasing the returns to larger scale over what they would have been in the absence of technical change, since $\frac{\partial^2 \log C}{\partial \log Q \, \partial \log A}$ and $\frac{\partial^2 \log C}{\partial \log Q \, \partial \log S}$ are both negative. Some of the contribution of scale in Tables 7-1 and 7-2 is in fact due to scale-augmenting technical change. Further analysis is necessary in order to obtain a full interpretation of the allocation procedure underlying Tables 7-1 and 7-2.

Chapter 8

Conclusions and Suggestions for Future Research

In this project we have measured the rate of productivity growth for Bell Canada and developed a framework within which this productivity growth can be interpreted. While on the surface Bell Canada's productivity growth rate appeared impressive, this fact does not necessarily mean technical progress was similarly impressive. Problems in output measurement, the effects of scale economies, and non-marginal cost pricing practices combined to cause total factor productivity growth to overstate the efficiency gains due to innovative activity. While the above statement appears to us to be correct qualitatively, a definitive quantitative disaggregation of the components of the productivity index has eluded us. We feel that the bulk of the difficulty lies in the way in which current revenues are decomposed into prices and quantities in the offical Bell Canada data set. We recommend that future research effort be devoted to the conceptualization and measurement of telecommunications service outputs.

In this project we have also demonstrated ways in which the effects of particular innovations can be incorporated into econometric estimation of the characteristics of Bell Canada's technology. Within this framework the employment effects of the diffusion of new technology was analysed. The increases in telephones connected to direct-distance dialing facilities and modern switching facilities were both accompanied by reductions in the employment intensity of production. For particular labour categories, increases in access to DDD facilities resulted in employment losses for operators and clerical workers and employment gains for plant craftsmen and white collar workers. The employment effects of innovative activity were substantial. An especially striking effect was the reduction in employment opportunities for operators.

The results derived from econometric estimation depend importantly on the specification of the technical change indicators used to measure the diffusion of innovations. We have made a start at a careful introduction of these indicators. Clearly, more research needs to be done in specifying and measuring indicators of shifts in the production function.

The role of regulation has not been explored in any detail. We have provided a formula (in Chapter 4) which can be used to assess the effect of rate of return regulation on measured total factor productivity growth. We have not provided an empirical estimate of the effect due to the lack of a correct series on the allowed rate of return. Such a series needs to be calculated both for productivity analysis and econometric estimation. This calculation should also be a subject of future research.

Finally, there are larger issues related to regulation which can be built on the analysis contained in this project report. For example, what is the effect of regulation on technical change, particularly on the rate of diffusion of innovations? How can regulatory authorities use measured total factor productivity indices to provide incentives for regulated firms to accelerate efficiency gains? These and similar questions linking productivity and innovative activity are natural avenues for exploration when the analysis begun in this project is extended in future research efforts.

DATA APPENDIX

I. Bell Canada Data

A. Revisions to the Materials Series

Table III of the Memorandum on Productivity and Bell Canada Productivity shows current and constant dollar quantities for materials and for indirect taxes. Both Fuss and Waverman and Corbo have aggregated the constant dollar quantities of materials and taxes to form a new constant dollar series. Corbo adds on the quantity of uncollectibles to form the series that he calls materials. Consequently, the materials variable is a combinations of bad debts, non-income taxes and materials.

To avoid the incorrect treatment of bad debts and non-income taxes, we have eliminated these components from the materials series. Consequently, our new materials series is simply the current and constant dollar series labelled "cost of materials, services, rent and supplies" in Table III.

The information on indirect taxes in the Memorandum does not permit one to allocate the indirect taxes to the pertinent outputs and inputs. Data in the Bell Canada Annual Charts will permit such an allocation. On pages 313-14, there is a complete breakdown of the taxes other than income. The allocation of these taxes was roughly determined. Labour expenses were increased by the indirect taxes in columns 3, 4 and 5 of p. 313 and columns 1 and 2 of p. 314. The net revenue from production was decreased by the Ontario gross receipts tax in column 7 of p. 314. The remainder of the indirect taxes were allocated to capital.

These changes increase the prices of capital and labour, and reduce the price of aggregate output. The constant dollar quantities of these variables are not changed. For materials, both the price and the quantity are changed.

Uncollectibles are subtracted from total revenue. This does not lower the output but does lower the price. Theoretically, this would be correct if all bad debts were anticipated. Since the magnitude of the change in the price level is very small, no significant errors are likely to arise from this change.

In Table A.1, total revenues (col. 2) and costs (col. 3) are shown for Bell Canada after the adjustment for indirect taxes formerly included in materials. The first column shows the unadjusted total revenue figures as an example of the magnitude of the change relative to column 2.

B. Basic Output and Input Data

The major source of information on inputs and outputs is the Memorandum on Productivity and Bell Canada Productivity. Data in this Memorandum have been updated and revised to 1976 in Bell Canada's response to the National Anti-Poverty Organization's request for information before the CRTC. Unless otherwise noted all data on inputs and outputs are taken from these sources.

Output prices and constant dollar quantities for six outputs are shown in Tables A.2 and A.3. The output quantities are not affected by our revision to materials. For convenience the output price indexes are

TABLE A.1

Revenues and Costs for Bell Canada, 1952-76

(millions of dollars)

	Total Revenue* Unadjusted	Total Revenue	Total Cost**
1952	184.842	182.335	171.828
1953	202.358	199.538	186.955
1954	219.889	216.934	205.207
1955	245.325	242.046	230.417
1956	274.565	270.858	262.387
1957	303.929	299.276	292.931
1958	329.975	324.687	321.702
1959	377.904	371.698	347.910
1960	406.578	399.712	371.491
1961	435.271	427.066	391.480
1962	472.981	463.891	420.953
1963	505.139	495.430	454.427
1964	544.837	534.078	480.096
1965	595.827	584.218	521.012
1966	648.093	635.274	580.757
1967	705.599	691.256	635.852
1968	761.810	746.095	696.533
1969	846.234	829.234	796.883
1970	942.887	924.766	884.179
1971	1023.09	1002.45	999.744
1972	1129.48	1109.05	1124.25
1973	1279.71	1247.96	1274.41
1974	1446.38	1411.28	1499.21
1975	1674.88	1634.03	1728.48
1976	1912.68	1865.88	1978.68

* See text for description of the adjustment for indirect taxes.
** Includes capital services evaluated at the user cost of capital.

TABLE A.2

Output Price Indices, 1952-76

(1967 = 100)

	LOCAL	INTRA	TRANS	USO	Other Toll	Miscellaneous
1952	92.40	106.05	109.19	94.46	97.61	69.78
1953	93.30	106.05	112.26	94.46	100.14	69.82
1954	93.30	106.05	114.10	94.46	101.67	69.74
1955	93.30	106.05	114.10	94.46	101.67	73.20
1956	93.30	106.05	114.10	93.83	101.67	75.13
1957	93.30	106.05	114.10	91.45	101.67	77.93
1958	93.90	107.26	114.10	91.45	101.67	80.32
1959	100.00	113.31	113.64	91.45	101.67	86.03
1960	100.00	113.31	112.69	100.44	101.67	88.89
1961	100.00	111.81	109.56	102.34	101.67	89.25
1962	100.00	104.32	105.92	102.34	101.79	90.77
1963	100.00	104.32	104.10	102.34	101.92	97.50
1964	100.00	104.32	103.14	102.34	101.80	98.14
1965	100.00	104.32	102.18	102.34	101.39	98.79
1966	100.00	100.72	100.36	102.34	100.06	99.42
1967	100.00	100.00	100.00	100.00	100.00	100.00
1968	100.00	98.78	99.90	100.00	99.90	101.54
1969	100.30	99.22	99.65	100.47	101.66	105.99
1970	101.60	110.93	99.65	100.63	101.60	106.86
1971	105.60	113.41	99.65	100.63	104.00	111.49
1972	108.60	115.79	99.62	100.63	104.57	122.53
1973	111.60	119.25	99.45	100.63	107.36	133.33
1974	114.00	121.35	99.45	100.63	110.68	152.68
1975	119.60	124.16	105.40	106.78	115.84	169.29
1976	127.00	130.13	113.74	114.16	124.46	187.03

TABLE A.3

Output Quantities, Constant 1967 Dollars 1952-76

	LOCAL	INTRA	TRANS	USO	Other Toll	Misc-ellaneous
1952	126.40	45.20	2.10	6.10	1.70	14.90
1953	137.00	48.30	2.40	6.90	2.30	16.90
1954	148.00	51.70	2.60	7.90	2.90	19.50
1955	162.90	57.50	4.80	8.80	4.30	19.40
1956	181.70	64.00	5.70	10.40	6.30	19.30
1957	200.60	68.20	6.50	12.90	7.80	22.20
1958	216.60	70.10	7.50	14.20	9.30	25.40
1959	233.60	75.40	8.70	16.30	10.50	27.20
1960	250.90	78.80	9.50	17.30	12.50	28.80
1961	269.50	84.90	10.60	16.50	14.70	30.70
1962	289.60	100.10	12.10	17.90	18.00	32.50
1963	308.70	104.40	13.40	19.90	21.60	32.00
1964	325.00	112.50	14.80	24.30	30.20	32.20
1965	350.80	125.30	16.40	28.70	34.90	33.20
1966	380.70	137.00	19.60	34.70	40.00	34.40
1967	410.00	152.80	22.10	39.00	45.10	36.60
1968	437.60	164.70	25.30	42.70	54.10	38.90
1969	471.40	187.20	29.30	49.60	63.40	41.70
1970	504.30	198.70	32.00	55.60	72.80	45.20
1971	538.00	203.70	35.00	59.80	77.30	43.50
1972	579.80	220.90	42.60	71.30	90.90	28.40
1973	625.50	246.90	51.60	89.80	108.00	22.20
1974	679.40	277.20	64.30	104.20	119.70	22.40
1975	734.30	308.90	76.90	120.80	138.20	25.40
1976	779.70	332.40	81.60	129.00	156.70	29.30

given in unrevised form. This is because other researchers may wish to alter our procedure. The price indexes that we used differ by only a single scalar in each year. In order to obtain our price indexes, multiply the individual indexes in Table A.2 by the ratio of Total Revenue (Table A.1, col. 2) to Unadjusted Total Revenue (Table A.1, col. 1).

The outputs are constant dollar local service revenue (LOCAL), toll message revenue within Bell Canada (INTRA), toll message revenue within Canada and outside of Bell Canada (TRANS), toll message revenue on calls to U.S. and Overseas (USO), Other non-message toll and Miscellaneous. The last category is a combination of Directory Advertising, Rents and other residual revenue sources. The sharp discontinuity in this series is created by the formation in 1971 of a separate corporation to handle directory advertising. We have made minor adjustments to this series in 1971-72 to smooth the break.

The annual observations on the prices and quantities of capital, labour and material inputs are given in Table A.4. The quantity of capital is the constant dollar net stock shown in Table 7, column 3 of the Bell response to the NAPO inquiry (NAPO). The labour quantity is the weighted man-hours (in millions) from Table 6 of the same source. Materials in constant dollars is from Table 3, col. 2 of the same source.

The price of capital services is the same as that used by Fuss and Waverman. It is the sum of an expected real rate of interest of six per cent plus the rate of economic depreciation all multiplied by the Bell Canada telephone price index. The depreciation rate is defined as the ratio of constant dollar economic depreciation (NAPO, Table 4, col. 3) to the stock of capital (NAPO, Table 7, col. 3). The Telephone plant price index is given in NAPO, Table 8 col. 2.

TABLE A.4

Prices and Quantities of Inputs, 1952-76

Quantities (millions)

	Capital[a]	Labour[b]	Materials[a]
1952	626.60	44.90	38.70
1953	690.40	46.10	41.60
1954	764.90	48.20	46.50
1955	871.30	51.90	53.30
1956	989.90	55.70	62.40
1957	1127.10	57.80	62.90
1958	1280.00	57.60	69.20
1959	1429.50	56.50	72.90
1960	1579.10	54.60	76.10
1961	1721.90	52.40	79.40
1962	1860.10	52.30	85.10
1963	2004.00	53.50	89.70
1964	2150.40	54.40	89.80
1965	2283.60	55.80	98.00
1966	2431.20	57.50	101.90
1967	2585.60	56.60	98.70
1968	2734.00	55.50	103.90
1969	2886.00	56.60	123.80
1970	3054.80	57.80	123.10
1971	3190.40	58.10	146.50
1972	3334.90	57.50	147.60
1973	3493.00	60.40	149.90
1974	3653.50	63.90	151.70
1975	3808.90	64.10	149.10
1976	3978.90	67.30	159.60

contd ...

Table A.4 continued

Prices

	Capital	Labour	Materials
1952	.107104	1.69303	.741602
1953	.104903	1.81627	.740384
1954	.103069	1.89562	,752688
1955	.100474	1.97639	.756097
1956	.101772	2.02233	.785256
1957	.106881	2.11185	.801272
1958	.107180	2.22591	.813584
1959	.108826	2.33527	.828532
1960	.108809	2.48666	.839685
1961	.108405	2.63202	.842569
1962	.110074	2.74387	.854289
1963	.112139	2.83471	.869565
1964	.112478	2.90667	.891982
1965	.115471	2.99505	.920408
1966	.122637	3.21050	.961727
1967	.131990	3.46077	1.00000
1968	.139274	3.75600	1.03272
1969	.150062	4.07077	1.07754
1970	.158857	4.50004	1.12754
1971	.169790	4.94917	1.16382
1972	.185697	5.64473	1.22222
1973	.203335	6.02574	1.33422
1974	.231050	6.61295	1.53263
1975	.259583	7.57487	1.70490
1976	.281448	8.33328	1.86717

(a) Materials is a constant 1967 dollar quantity with a price index 1967 = 1.00. Capital is a constant 1967 dollar quantity with an unnormalized service price.

(b) Labour is a weighted man-hours quantity and a dollar per man-hour price.

The price of labour is the implicit price derived by dividing the quantity of labour into the total employee expense, (Bell Chart Book, p. 317, col. 1). The price of materials is the implicit price calculated by dividing current dollar materials (NAPO, Table 3, col. 1) by constant materials (NAPO, Table 3, col. 2).

C. Cost Shares

The cost shares for capital, labour and materials are given in Table A.5. Bell Canada has steadily reduced the share of labour costs from a high of 44 per cent to the current 28 per cent. Predominantly, the shift was to a larger share of capital.

TABLE A.5

Cost Shares of Inputs, Bell Canada, 1952-76

(percentages)

	Labour	Capital	Materials
1952	44.24	39.06	16.70
1953	44.79	38.74	16.47
1954	44.52	38.42	17.06
1955	44.52	37.99	17.49
1956	42.93	38.39	18.67
1957	41.67	41.12	17.20
1958	39.85	42.64	17.50
1959	37.92	44.71	17.36
1960	36.55	46.25	17.20
1961	35.23	47.68	17.09
1962	34.09	48.64	17.27
1963	33.37	49.46	17.16
1964	32.94	50.38	16.68
1965	32.08	50.61	17.31
1966	31.79	51.34	16.87
1967	30.81	53.67	15.52
1968	29.92	54.67	15.40
1969	28.91	54.35	16.74
1970	29.42	54.88	15.70
1971	28.76	54.18	17.05
1972	28.87	55.08	16.05
1973	28.56	55.75	15.69
1974	28.19	56.30	15.50
1975	28.09	57.20	14.71
1976	28.34	56.60	15.06

D. Disaggregated Labour - 1952-72

Data for this period for seven types of labour are available from Millen (1974). His Table A-22 gives price indexes for these seven types from 1952-72. The labour types are:

1. Telephone Operators
2. Plant Craftsmen
3. Clerical Non-Supervisors
4. Other Non-Supervisors
5. Foremen and Supervisors
6. Executive and Staff
7. Part-Time and Occasional

Millen's price indexes are weighted for quality and deflated by the price of output. We have calculated an unweighted, undeflated price index for each labour category using the following method. Define,

w_i^m - Millen's price index for labour type i (Millen, Table A-22)

L_i - unweighted man-hours of labour input of type i

s_i - Millen's implicit weight for labour type i

p - aggregate price index of Bell output (Millen, Table A-20)

$s_i \cdot L_i$ - Millen's weighted man-hours for labour type i (Millen, Table A-17)

We observe the variables, w_i^m, s_iL_i and L_i. Calculate the weights $s_i = s_iL_i/L_i$. The new price index for labour type i, w_i, is

$$w_i = w_i^m * s_i * p$$

Unfortunately, the basic information underlying Millen's construction of disaggregated wage data is too weak to support econometric estimation of demand functions for seven types of labour. To establish this conclusion requires some careful comments.

In Appendix C, Table 2, there is an error. The column totals for D and E are inconsistent with the disaggregated rows for these same columns. The sum of rows one to six and row eight equals 233,273 for column C and 74,222 for column D. This implies that column E must change to 3.143 from 3.209. Table 4 in Appendix C must also be revised. The adjustment factor is not 1.0608 but is 1.0831. Without this adjustment the sum of the disaggregated labour costs in 1967 does not equal the aggregate employee compensation in 1967. With the error corrected, for 1967 the total labour cost is consistent but this is not true for other years.

Millen's disaggregated wage series imply that the sum of the labour costs of all types equals $79.54 million in 1952 and $285.59 million in 1972. The actual total labour costs were $75.33 million and $317.85 million. The adjustment mentioned in the previous paragraph will raise Millen's data by a factor of 1.02102 to $81.21 million and $291.59 million. Since the underlying man-hours data are identical for all these calculations it must be the wage rate data that cause the errors. Millen's data simply does not rise fast enough throughout the period. With the adjustment for 1967, total labour costs are consistent for that one year but in earlier and later years problems arise.

It is possible to isolate two major problems in the data construction. These do not explain all the inconsistencies but eliminate a large portion.

We will first discuss the problems and then state our procedure. In the construction of the disaggregated wage data, Millen assumed that the ratio of total compensation to total wage payments was a constant across all categories of labour for all years. "The implied assumption is that the ratio of employee expense to basic wages is the same for all types of labour in all years", [Millen, p. 102]. This is factually wrong and will prevent the sum of disaggregated labour costs from equalling aggregate labour costs unless a separate constraint on total labour costs is introduced. It is not. For example, the Bell Canada Chart Book indicates that from 1952-67, total employee expenses were roughly 107% of wage payments expensed. This percentage rose to 117% by 1976. Millen's disaggregated wage data do not capture this upward trend after 1967. His assumption is that there is no trend.

There is an error in the calculation of the wage rates for some labour types from 1952-66. Millen (p. 102) states, "During this period it was assumed that the price of other labour inputs moved by the same percentage as the price index for aggregate labour input". 'Other labour inputs' refers to all categories aside from operators, plant craftsmen and clerical workers. Since these latter categories had average wage increases below the overall average wage increases, the 'other labour inputs' must have had increases that were above the average. Millen's procedure of using the overall average increase results in the wages of other labour inputs being too high in 1952 and subsequent years. This would help to explain the observed excess of Millen's total labour costs over actual total compensation in the years prior to 1967.

It is not possible to simply correct these faults and construct disaggregated wage rates that are consistent with the observed total employee compensation. Consistency must be enforced in the construction of the data which is what we have done.

Before specifying our methods, it should be clear that Millen's basic sources do not provide sufficient information to usefully distinguish relative wage changes amongst the four categories: Other Non-Supervisors, Foremen and Supervisors, Executive and Staff, and Part-Time and Occasional. For the years 1952-67, Millen applied the same growth rate to all categories. This implies that the relative prices of these labour types do not change. In fact Millen's data show some relative price changes but this must be an error.

Our procedure is to reconstruct data for the four other categories listed in the paragraph above for the years 1952-67. This is done by calculating the average increase in wages for these <u>four</u> types. Note that Millen used the average increase for <u>all</u> types. The average increase for the four types is applied to the 1967 wage data for each type to construct the series back to 1952.

To enforce consistency in total labour costs, we have simply adjusted all wage series by a constant in each year. Therefore in each year the sum of the disaggregated wage costs equals the observed total employee expense.

The prices of the four labour types used in our estimation are shown in Table A.6. The first three categories are self-explanatory. Given the difficulties with Millen's data construction, we have aggregated the last four categories in our list of seven and labelled it "all others" in

Table A.6. For the benefit of those who might desire the data, Table A.7 gives the disaggregated price data for the four categories which we have aggregated. Tables A.8-10 are updated versions of Millen's Tables A.16, A.17 and A.22 respectively. Unfortunately, the last table has not been extended to 1976.

TABLE A.6

Disaggregate Price Indexes for Four Labour Categories Used in Labour Sub-Model*

	Telephone Operators	Plant Craftsmen	Clerical	All Others
1952	1.296	1.879	1.490	0.418
	1.359	1.967	1.553	0.472
	1.426	2.003	1.592	0.494
1955	1.479	2.020	1.606	0.525
	1.517	2.034	1.638	0.530
	1.620	2.122	1.738	0.541
	1.720	2.250	1.852	0.580
	1.803	2.524	1.948	0.629
1960	1.875	2.567	2.026	0.690
	1.952	2.699	2.098	0.757
	1.976	2.690	2.147	0.815
	2.008	2.872	2.191	0.835
	2.056	2.930	2.245	0.858
1965	2.051	3.040	2.328	0.875
	2.105	3.138	2.381	0.919
	2.272	3.420	2.578	1.000
	2.460	3.787	2.790	1.096
	2.676	4.186	3.045	1.177
1970	3.027	4.706	3.382	1.287
	3.796	5.335	3.828	1.376
1972	4.180	5.961	4.211	1.553

* Columns one to three are in dollars per unweighted man-hour. Column four is a price index, 1967 = 1.00.

TABLE A.7

Disaggregated Price Indexes for Other Labour Categories*

	Other Non-Supervisors	Foremen and Supervisors	Executives and Staff	Part-Time
1952	1.378	1.985	2.654	1.405
	1.568	2.242	2.985	1.584
	1.639	2.367	3.084	1.661
1955	1.735	2.547	3.248	1.763
	1.753	2.581	3.261	1.788
	1.777	2.647	3.324	1.832
	1.912	2.832	3.555	1.967
	2.103	3.080	3.834	2.077
1960	2.325	3.384	4.184	2.262
	2.536	3.714	4.606	2.482
	2.719	4.036	4.964	2.622
	2.768	4.129	5.110	2.682
	2.831	4.204	5.265	2.831
1965	2.901	4.300	5.394	2.771
	3.035	4.536	5.657	2.934
	3.322	4.899	6.147	3.212
	3.652	5.330	6.680	3.776
	3.924	5.714	7.141	4.205
1970	4.267	6.203	7.835	4.704
	4.486	6.513	8.477	5.228
1972	5.062	7.349	9.565	5.961

* Each series is in dollars per man-hour

TABLE A.8

Man-Hours Worked (Excluding Construction)

(Millions)

Year	Telephone Operators	Plant Craftsmen	Clerical Non-Supervisors	Other Non-Supervisors	Foremen and Supervisors	Executive and Staff	Part-Time and Occasional	Total
1952	18.317	8.304	7.770	4.065	5.503	2.946	1.494	48.399
1953	17.730	8.604	8.139	4.214	5.704	3.080	1.508	48.979
1954	18.967	9.167	9.080	4.478	5.124	3.336	1.625	51.777
1955	19.978	10.613	10.279	4.962	4.725	3.700	1.819	56.076
1956	19.616	11.762	11.658	5.754	5.217	4.175	2.061	60.243
1957	19.788	12.106	12.159	6.462	5.482	4.487	2.095	62.579
1958	18.022	12.493	12.015	6.617	5.337	4.645	2.125	61.254
1959	15.505	12.282	11.165	6.090	5.560	4.608	2.342	57.552
1960	13.938	11.922	10.844	5.739	5.424	4.802	2.385	55.054
1961	12.212	11.543	10.311	5.608	5.181	4.820	2.117	51.792
1962	12.190	11.162	10.496	5.677	4.957	4.986	2.129	51.597
1963	12.797	11.620	10.978	5.817	4.899	5.086	1.992	53.189
1964	12.711	11.960	11.463	5.948	4.609	5.457	1.940	54.088
1965	12.428	12.925	11.544	6.119	4.455	5.947	2.084	55.502
1966	13.139	13.108	12.447	6.662	4.607	6.312	2.034	58.309
1967	12.362	12.902	11.828	6.517	4.908	6.227	1.836	56.580
1968	11.741	12.432	11.370	6.294	4.800	6.143	1.781	54.561
1969	11.846	12.620	11.734	6.422	4.707	6.363	1.843	55.535
1970	11.303	12.829	11.704	6.780	4.867	6.833	1.817	56.133
1971	10.226	12.866	11.407	6.884	4.760	7.162	1.661	55.166
1972	10.076	12.501	11.445	7.080	4.865	7.516	1.642	55.125
1973	10.295	13.083	12.043	7.606	5.088	7.984	1.746	57.845
1974	10.126	14.432	12.893	8.143	5.286	8.702	1.986	61.568
1975	9.337	14.669	13.059	8.177	5.141	9.005	1.958	61.346
1976	9.291	16.134	13.630	8.259	5.618	9.418	1.916	64.766

TABLE A.9

Weighted Man-Hours Worked (Excluding Construction)

(Millions)

Year	Telephone Operators	Plant Craftsmen	Clerical Non-Supervisors	Other Non-Supervisors	Foremen and Supervisors	Executive and Staff	Part-Time and Occasional	Total
1952	12.092	8.373	5.959	3.917	7.639	5.483	1.463	44.926
1953	11.783	8.817	6.248	4.094	7.926	5.714	1.475	46.059
1954	12.714	9.350	6.896	4.344	7.180	6.112	1.593	48.188
1955	13.518	10.681	7.751	4.782	6.684	6.697	1.775	51.889
1956	13.218	11.499	8.683	5.492	7.333	7.438	1.999	55.661
1957	13.280	11.668	9.017	6.110	7.721	7.966	2.035	57.798
1958	12.220	12.209	9.016	6.300	7.526	8.252	2.074	57.596
1959	10.709	12.959	8.517	5.938	7.941	8.217	2.248	56.529
1960	9.704	12.340	8.287	5.658	7.782	8.547	2.278	54.597
1961	8.551	12.168	7.935	5.548	7.507	8.690	2.043	52.442
1962	8.451	11.862	8.076	5.601	7.260	9.011	2.019	52.279
1963	8.720	12.313	8.450	5.714	7.179	9.254	1.889	53.518
1964	8.605	12.549	8.825	5.855	6.737	10.022	1.834	54.427
1965	8.400	13.233	8.847	6.006	6.481	10.886	1.946	55.799
1966	8.777	12.948	9.370	6.434	6.650	11.399	1.892	57.470
1967	8.281	12.892	8.962	6.362	7.067	11.286	1.727	56.578
1968	7.928	12.744	8.707	6.221	6.924	11.204	1.761	55.488
1969	8.029	13.031	8.993	6.333	6.760	11.573	1.879	56.598
1970	7.730	13.266	9.023	6.665	6.956	12.340	1.855	57.835
1971	7.067	13.257	8.795	6.740	7.050	12.788	1.701	57.398
1972	6.998	12.928	8.821	6.912	6.895	13.308	1.684	57.546
1973	7.131	13.506	9.272	7.414	7.169	14.071	1.812	60.375
1974	6.971	14.571	9.788	7.880	7.350	15.225	2.069	63.854
1975	6.451	14.763	9.944	7.967	7.161	15.823	2.040	64.149
1976	6.431	16.157	10.385	8.073	7.782	16.514	1.997	67.337

TABLE A.10

Price Indexes for Disaggregate Labour Inputs

Year	Telephone Operators	Plant Craftsmen	Clerical Non-Supervisors	Other Non-Supervisors	Foremen and Supervisors	Executive and Staff	Part-Time and Occasional	Total
1952	2.016	1.913	1.994	1.744	1.734	1.739	1.750	1.782
1953	2.092	1.963	2.069	1.864	1.855	1.859	1.871	1.905
1954	2.180	2.013	2.149	1.947	1.936	1.940	1.953	1.989
1955	2.230	2.048	2.173	2.015	2.004	2.008	2.022	2.059
1956	2.288	2.114	2.235	2.055	2.044	2.048	2.063	2.100
1957	2.440	2.225	2.369	2.147	2.135	2.139	2.154	2.194
1958	2.542	2.307	2.474	2.249	2.237	2.241	2.257	2.298
1959	2.475	2.267	2.420	2.230	2.218	2.223	2.238	2.279
1960	2.542	2.341	2.502	2.358	2.345	2.350	2.367	2.410
1961	2.629	2.415	2.571	2.501	2.487	2.493	2.510	2.556
1962	2.727	2.528	2.670	2.648	2.633	2.639	2.657	2.706
1963	2.817	2.591	2.722	2.724	2.709	2.715	2.734	2.783
1964	2.917	2.682	2.801	2.793	2.778	2.784	2.908	2.854
1965	2.917	2.855	2.920	2.879	2.864	2.870	2.890	2.943
1966	3.085	3.110	3.097	3.077	3.061	3.067	3.088	3.145
1967	3.320	3.350	3.331	3.331	3.313	3.320	3.343	3.404
1968	2.957	3.586	3.537	3.514	3.476	3.483	3.632	3.698
1969	3.817	3.919	3.841	3.778	3.740	3.728	3.916	3.988
1970	4.092	4.208	4.506	3.978	3.967	3.976	4.223	4.299
1971	4.698	4.428	4.246	4.047	4.184	4.193	4.509	4.590
1972	4.999	4.787	4.538	4.328	4.499	4.509	4.851	4.939

II. Construction of the Direct-Distance Dialing Access Indicator

We define the access technological change indicator (A) as the percentage of telephones with access to direct-distance dialing facilities. Data on A are available only since 1962, so a series must be constructed for the 1952-61 period. We do have available for the complete 1952-76 period a data series on the percentage of toll calls completed by direct-distance dialing (DDD). The problem is to link the two series and use the linkage to forecast the missing data on A.

We begin by assuming that long-distance callers learn over time the advantages of using the DDD facilities that are available. We model this learning process by specifying a logistics learning curve relationship between DDD and A of the form

$$DDD = A \cdot B(t) \qquad (A.1)$$

where t is time. B(t) represents the learning process and is specified as

$$B(t) = 1/(1+e^{\alpha+\beta t}) \qquad (A.2)$$

Note that $0 < B(t) < 1$, and B(t) represents the utilization rate of available direct-distance dialing facilities. Equation (A.1) can be rearranged to yield

$$A = DDD \cdot (1+e^{\alpha+\beta t}) \qquad (A.3)$$

Equation (A.3) was estimated for the period 1962-77. The results are presented in Table A-11. The estimates of α and β were used in equation (A.3) to forecast the values of A for the period 1952-61. These values appear in column 2 of Table 5-1 of the Report.

TABLE A-11

Results of Estimating Logistic Relationship
Between A and DDD

Parameter Estimates	R^2	D.W. Statistics
α: 2.88 (0.17)	0.91	0.59
β: -0.236 (0.012)		

FOOTNOTES

Chapter 1

1. For an explanation of this effect see Averch and Johnson (1962).

Chapter 3

1. This is derived in May and Denny (1979). Behavioural assumptions of some kind must be made to derive any results. For this particular one, the input markets must be competitive. An error will occur if for example, Northern Electric supplies Bell Canada at non-competitive prices.
2. These particular weights depend on the assumption that output is produced with constant returns to scale. Alternative weights may be calculated in other cases. The basic relationship remains unchanged.
3. Laspeyres aggregation is the method underlying Olley's total factor productivity measures discussed in section 3.3.
4. It should be noted that our index uses gross outputs, not real value-added as output measures and consequently includes material inputs as factors of production. This procedure is often not followed and it will render casual comparisons with productivity measures based on real value-added such as Olley's measures difficult.

Chapter 4

1. The effect of non-marginal cost pricing can also be analysed in the single output case. In that case equation (4.21) becomes

$$- B = \dot{TFP} + \left[\frac{MC \cdot Q}{C} - \frac{P \cdot Q}{R}\right] \dot{Q}$$

which is the single output counterpart to (4.27). We have left the effects of departures from marginal cost pricing to the multiple output case since interesting issues such as cross-subsidization can be explored.

2. In this section we consider the case of a single output. The multiple output case is completely analogous and easily derived.

3. For the multiproduct case, equation (4.37) becomes

$$- B = \left\{ \sum_j \varepsilon_{CQ_j} \dot{Q}_j - \dot{F} \right\} - \left\{ \lambda \left[S_L \dot{w} + S_M \dot{m} + \left(\frac{sK}{C}\right) \dot{s} \right] \right\} .$$

4. Note that in the multiproduct case this result would only be true under marginal cost pricing.

Chapter 5

1. These include number 5 crossbar, electronic and SP1.

2. In Chapter 2, we discussed the possibility of developing output measures based on messages. Incorporation of these measures into the estimation of the cost structure is a natural avenue for future research.

3. In the estimation of the three output model, this specification provided the most satisfactory results. In fact, in comparison with the general second order translog expansion of $C(w,r,m,Q_1,Q_2,Q_3,T)$, where T is any one of the four technical change indicators, the model specified in the text was superior, using a goodness-of-fit criterion, even though it contains three fewer parameters. The maximized likelihood function was higher and the residuals exhibited more evidence of randomness.

4. This model performed considerably worse than the three output model reported in detail in the report.

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