MEASURING THE IMPACT OF REGULATION
IN A DYNAMIC CONTEXT:
AN APPLICATION TO BELL CANADA

By

MICHEL PATRY

B.A.A., Ecole des Hautes Etudes Commerciales de Montréal, 1978
M.Sc., Ecole des Hautes Etudes Commerciales de Montréal, 1981

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

Department of Economics

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

November 1987

Department of Economics

The University of British Columbia
1956 Main Mall
Vancouver, Canada
V6T 1Y3

Date 1987.12.15

ABSTRACT

In this thesis, a model of producer behavior for a regulated utility that fully takes into account the dynamic nature of the capital accumulation process of the firm is developed and empirically implemented using recent data on Bell Canada. On the basis of this model of producer behavior, loss formulae that approximate the value of foregone output due to imperfect regulation in a dynamic context are derived and estimates of the deadweight loss in the case of Bell are provided.

The estimation results indicate the importance of dynamic elements, such as expectations and adjustment costs of investment, in modeling the behavior of Bell. They also suggest that rate of return regulation may have affected the investment decisions of the utility.

TABLE OF CONTENTS

LIST OF TABLES

ACKNOWLEDGEMENTS

This dissertation has benefitted immensely from the comments, advice, and encouragement of the members of my supervisory committee, Hugh Neary (Chairman), Margaret Slade, and Erwin Diewert. Each of them will immediately recognize the mark of his or her influence on this dissertation. I want to express my gratitude to them.

My studies at the University of British Columbia were made possible by the financial support of the Ecole des Hautes Etudes Commerciales de Montréal and of the Social Sciences and Humanities Research Council of Canada. The department of Economics of UBC and the Institut d'économie appliquée of the Ecole des HEC provided an excellent environment to study and undertake research in economics.

Finally, I would like to thank my parents for teaching me the value of education and for their support, and my wife, Carole Hennessey, for her help, unending support and love during all those years. Without her continued encouragement, this dissertation would not have been completed. It is to her that this dissertation is dedicated.

CHAPTER 1

INTRODUCTION

1.1 In the last decade or so the literature on the economics of regulation has become increasingly concerned with the critical evaluation of existing regulatory practices. Deregulation has become a political topic and some regulatory reforms have been undertaken in the United States and Great Britain, notably in the air transportation and telecommunications sectors. In Canada the restructuring of regulatory institutions has become an issue and studies on the eventual impact of deregulation have multiplied.

The growing disenchantment with the performance of the regulatory system in general has one of its roots in the perceived ineffectiveness of many regulatory regimes in fostering economic efficiency in the production and distribution of resources. As a result, the case for more market competition and for new methods of regulating business practices has gained in popularity.

But the task of choosing among various institutional frameworks supposes that one could actually achieve a delicate balance, since the costs of any system of regulation must be weighted against the costs associated with alternative regimes. As Demsetz (1969) warns, one must compare the actual or predicted performance of various existing or implementable schemes, rather than comparing the imperfect functioning of a given system to some theoretical optimum. The fact that a given set of institutions does not achieve a "first-best" allocation does not necessarily warrant its being therefore relinquished. This exercise, in turn, requires that policy-makers have some information about the impact of different regulatory practices on the behavior of enterprises, and about the relative costs and benefits of alternative regulatory schemes.

The provision of such information has not been the focus of most of the literature on regulation. This literature has largely concentrated on static (and sometimes dynamic) models of the behavior of regulated enterprises, seeking to determine whether the predicted behavior is "efficient" or not. The most studied type of regulation is the control of natural monopolies through "rate of return regulation". It is with this type of regulation that the present thesis is concerned. More precisely, the aim of this dissertation is the assessment of the impact of rate-regulation on the largest telecommunications enterprise in Canada, Bell Canada, in a dynamic context. The dynamic character of the analysis here is very important since rate-regulation is generally perceived as affecting the investment decisions of regulated firms, thus interfering with the enterprises' intertemporal allocation of resources.

1.2 The goals of this thesis are: (i) the development of a theoretical model of producer behavior for a regulated utility that takes fully into account the dynamic character of the capital accumulation process of the firm; (ii) the empirical application of the model of producer behavior to Bell Canada in order to determine the basic characteristics of the firm's production structure, to ascertain the importance of expectations and adjustment costs in the capital accumulation decisions of the company, and to identify the impact of regulation on the firm; (iii) the derivation of loss formulae that approximate the value of foregone output due to less than perfect (rate of return) regulation; and finally, (iv) the measurement of some losses due to regulation.

The theoretical and empirical literature on the regulation of natural monopolies is briefly reviewed, and the contribution this thesis makes is clarified in the following paragraphs.

1.3 Under rate of return regulation, a firm must submit its price schedule to a regulatory commission or board (the Canadian Radio-Television and Telecommunications Commission in the case of Bell Canada) for approval[1]. The commission is generally taken to set (or approve) prices that will provide the utility with a "fair rate of return" on its invested capital. More precisely, three quantities have to be determined by the regulatory authority: the rate base, the allowed rate of return and the allowed operating expenses. The rate base consists of the amount of capital actually embodied in the utility's plants, and is measured by the value of the firm's assets minus depreciation. The allowed rate of return is, in principle, the rate of return that the utility is permitted to earn on its rate base; this should enable the firm to attract new capital and should constitute a fair reward to investors. In practice, the determination of the allowed rate of return is one of the most complicated and controversial issues in the regulatory process. The allowed operating expenditures, finally, include all non-base-input costs that are deemed reasonable. Once these quantities are known to the regulators, the allowed rate of return is applied to the rate base and the allowed operating expenditures are added to this amount to obtain the firm's required revenues. A decision on a price vector that will generate these revenues is then arrived at.

The static equilibrium of this process has been captured in an abstract model of the regulated firm proposed by Averch and Johnson (1962). In their seminal article, the authors derived two important propositions: regulated utilities will overinvest in capital whenever the allowed rate of return exceeds the cost of capital to the utilities and, under the same circumstances, regulated monopolies will find it profitable to "invade" other markets and cross-subsidize some of their activities. Numerous extensions, specializations and criticisms of the Averch-Johnson ("A.-J.") model have been worked out subsequently and constitute an important literature. The first A.-J. proposition has been tested empirically a number of times but the jury is still out: a clear verdict has not yet been rendered because of conflicting evidence.

Takayama (1969), Zajac (1970, 1972), Baumol and Klevorick (1970), Sheshinski (1971), Bailey (1973) and McNicol (1973) developed, refined and corrected on a few points the original model of Averch and Johnson. But the fundamental A.-J. result, that is the incentive that a regulated firm may have to use more capital than a competitive (efficient) producer would use in producing the regulated firm's output remained. In order to prevent any misunderstanding it is worth insisting on the definition of overcapitalization this thesis adopts. Overcapitalization here means the incentive a regulated producer has to use more capital than it should to minimize its total production cost. It does not mean that the regulated enterprise uses more capital than an unregulated firm would in producing a different output vector.[2]

The static theory of the regulated monopolist was expanded when the duality of the model was developed by Fuss and Waverman (1977), Cowing (1978), Diewert (1981a) and Färe and Logan (1984). Sheshinski and Bailey also pioneered the welfare analysis of rate-regulation. But more will be said about this later.

1.4 The effect of uncertainty on the A.-J. model of firm behavior has been studied in papers by Perrakis (1976 a,b), Peles and Stein (1976), Das (1980), Bawa and Sibley (1980), Burnes, Montgomery and Quirk (1980) and Braeutigam and Quirk (1984). The model elaborated and estimated in this thesis does not include a stochastic demand side but it nevertheless retains some features of the models developed by these authors. In this thesis as in most of these papers, the firm, in maximizing the expected discounted value of its profits, has to make a decision on the level of its stock of capital that depends on the realizations of a number of variables whose values are not known with certainty at the decision point. Expectations thus need to be formed for some variables. The model of producer behavior presented in Chapter 2 overlooks this question altogether but the estimating model of Chapter 3 deals with it and introduces rational expectations in the estimation.

Since investment decisions generally affect a business' profitability for a long period of time, capital accumulation decisions are taken in a forward-looking fashion. Myopic behavioral models of the firm in which the capital stock is freely chosen in each period, as are all other inputs, may seriously fail to capture the essence of the decision-making process of the enterprise. The seriousness of the shortcomings of such static models depends mostly on the longevity of capital goods, on the role played by expectations in the decison-making process and on the existence of adjustment costs of investment.

Recent advances in the theory of the firm have focused on the dynamic elements that play a crucial role in the determination of a firm's investment policy. These issues are particularly relevant to the analysis of the behavior of regulated utilities since these firms are remarkably capital intensive and, principally , because a great deal of the debate about the efficiency of rate of return regulation has centered around the A.-J. overcapitalization result.

Major departures from the static theoretical model of a firm's behavior in a regulated environment can first be found in Joskow (1972, 1973, 1974) and Klevorick (1973) who stressed the importance of regulatory lags, hence introducing an element of dynamics into their analysis.

Adjustment costs of investment of the Lucas (1967), Treadway (1971) and Mortensen (1973) type were introduced in the theoretical model of the regulated firm by A. Marino (1978a, 1979), El-Hodiri and Takayama (1981), and Dechert (1984). This is a significant development since these costs have a direct impact on the investment decisions of the firm. Whereas El-Hodiri and Takayama and Dechert specified the producer's problem as that of the maximization of discounted profit subject to a series of regulatory constraints, Marino assumed that regulation only required that the discounted sum of profit does not exceed a given percentage of the discounted sum of capital cost. This is the working hypothesis that this thesis will make. Hence, the form taken by the regulatory constraint in this dissertation relaxes the hypothesis that regulation is binding in each and every period; rather the regulatory constraint is assumed to bind "on average" over a number of time periods[3]. While Marino and El-Hodiri and Takayama found that the regulated utility will invest more than an unregulated concern, Dechert demonstrated that such a result may or may not occur in the steady state depending on the importance of scale economies (hence on the concavity of the utility's revenue function). Notice however that those papers did not focus on the notion of overcapitalization retained in this thesis.

This thesis will show that a weak form of the original A.-J. effect holds in the presence of convex adjustment costs and under a regulatory constraint defined over the planning horizon of the firm (as in Marino , 1978a, 1979; and Gollop and Karlson, 1980) in a context of continuous planning by the firm: that is when capital is treated as a quasi-fixed input. Other propositions concerning the bounds on the Lagrange multiplier and other aspects of the behavior of a regulated monopolist are also derived.

Most of those theoretical developments have not however found their way into the empirical literature on regulated utilities; this literature has been cast primarily in a strict static framework. It is to this literature that the next section is dedicated.

1.5 The first attempts to test empirically the validity of the A.-J. model are in Spann (1974) and Courville (1974). Neither could reject the hypothesis of an A.-J. bias. Petersen (1975), Cowing (1978), Hayashi and Trapani (1978) and Pescatrice and Trapani (1980) also obtained results largely in favor of the A.-J. model, while Boyes (1976), Smithson (1978), Gollop and Karlson (1980), and Fuss and Waverman (1981) failed to confirm the basic propositions of the A.-J. model.

But these papers do not reproduce the same test time and again. On the contrary, the reader is presented with a wide diversity of estimation strategies and problem formulations. Each paper follows a different path to test the theory. For instance, while most studies estimated the cost function, Courville and Boyes aimed directly at the production function. All contributions, except those of Smithson and Gollop and Karlson, are based on static (long-run) models of the firm. And all, except Fuss and Waverman, deal with a cross-section of firms operating in the American electricity generation industry.

This thesis borrows from many of these contributions on some points and departs from all of them on others. Following Smithson and Gollop and Karlson, a dynamic approach is taken in this thesis. Smithson is the first who looked at capital accumulation in a non-static manner, doing so by introducing the assumption of a partial adjustment mechanism for all inputs in a basically static model. Gollop and Karlson, on the other hand, developed a dynamic, intertemporal model of choice which they estimated for thirty-nine utilities over a five-year period. In their model, it is the longevity of the capital goods that impels the firm to look farther ahead, and they specifically abstracted from uncertainty, lags in regulation or adjustment costs. In contrast, the estimated model of producer behavior in Chapter 3 is characterized by a forward-looking firm which has rational expectations about the realization of unknown variables and faces convex costs of adjustment. Lags in the adjustment process of (regulated) prices are also considered in the empirical analysis.

While previous empirical work has mostly centered on one single industry (with the ensuing risk that the evaluation of A.-J. models will be based on their applicability to one particular sector of the economy), the empirical model in this thesis is applied to the behavior of Bell Canada, which operates in the Canadian telecommunications industry. This thesis thus enlarges an already rich literature on the telecommunications industry in Canada[4], and complements in particular the study by Fuss and Waverman on the regulation of Bell. In contrast to what is done here, Fuss and Waverman used a static model of the firm and specified the regulatory constraint in such a way that it is assumed to be revised on a yearly basis. Finally, it should be pointed out that the estimated capital-accumulation equation of Chapter 3 transposes to a dynamic context the estimation strategy found in Pescatrice and Trapani (1980) and also suggested in Diewert (1981a).

1.6 Turning now to the welfare analysis of rate-regulation, one can go back to Wilcox (1966), Wein (1968) and Kahn (1968) for a preliminary qualitative assessment of the costs and benefits of regulation. Already contained in these papers is the idea that, even if monopoly is an "evil", it does not logically entail the desirability of regulation. And conversely, any costs found to be induced by regulation do not by themselves invalidate the institution. For as Schmalensee (1974) put it:

> "there are no shortcuts, rules of thumb, or general theorems that the analyst can employ; detailed quantitative forecasts must be generated."

Klevorick (1971) captured the essential ingredients of all welfare analysis of rate-regulation when he suggested that society's problem may be that of choosing an "optimal" fair rate of return which need not coincide with the utility's cost of capital. A similar result is due to Sheshinski (1971) who demonstrated that, in a one-consumer economy, some regulation is always worthwhile. Later, Callen, Matthewson and Mohring (1976) used the framework developed by Klevorick and Sheshinski to examine numerically the effect a rate of return constraint has on outputs, costs, capital intensity and welfare for various parameter values for Cobb-Douglas production and demand functions. Recently, Diewert (1981a) developed a producer price approach to measure the loss of efficiency due to regulation. His treatment, although partial-equilibrium in nature and restricted to the production sector of the economy alone, attempts to capture the general equilibrium impact of rate-regulation. This impact, as Bailey (1973) had pointed out, involves not only the loss of production efficiency within the regulated sector but also the loss in exchange efficiency: the loss of efficiency induced by the distortions between regulated and non regulated goods. Those sources of loss are taken into account by Diewert but the losses to consumers are ignored: distributional issues are not addressed in this framework.

This thesis will use the methodology developed by Diewert to develop one-sector and two-sector loss measures due to regulation and, by estimating the model of producer behavior developed in Chapters 2 and 3, it will provide estimates of the loss of output due to the inefficient regulation of Bell Canada. This is the first time that the deadweight loss of rate-regulation has been estimated using a model of welfare analysis. This thesis thus takes a step in the direction indicated by Schmalensee.

1.7 The plan of the dissertation is thus the following: a theoretical model of a regulated utility is developed in Chapter 2; a stochastic specification of this intertemporal model of producer behavior is provided in Chapter 3; the empirical results and their implications concerning the effect of regulation and the role played by the dynamic elements of the model are discussed in Chapter 4; and, finally, a welfare analysis based on a producer price approach to the measurement of the deadweight loss due to regulation is presented in Chapter 5.

NOTES TO CHAPTER 1

1. See Waverman (1982).

2. Many authors do compare the capital stock used by a regulated producer to that employed by an unregulated firm that does not necessarily produce the same output level. The confusion created by the varying usages of "overcapitalization" in the literature is apparent in the Presman and Carol (1971), El-Hodiri and Takayama (1973) and Presman and Carol (1973) exchange of views. Sheshinski (1971) and Marino (1978, 1979) also seem to adopt the second view of overcapitalization.

3. Gollop and Karlson (1980) also used a similar specification for the regulatory constraint.

4. See Breslaw and Smith (1982b), Denny et al. (1981a), Fuss and Waverman (1977, 1981), Kiss et al. (1981) and Bernstein (1986, 1987).

CHAPTER 2

A DYNAMIC MODEL OF A RATE-REGULATED FIRM

2.0 INTRODUCTION

A very general intertemporal profit maximization model of a rate-regulated monopoly is developed in this chapter. An informal description of the model is given in this introduction and a formal presentation follows in section 2.1. The remainder of the chapter deals with specific results pertaining to the effect of regulation on the capital accumulation and output decisions of the firm.

The model of producer behavior used here belongs to the family of "dynamic temporary equilibrium" or "intertemporal profit maximization with quasi-fixed inputs" models. Hicks (1939, ch. 15) was the first to use such a model. Malinvaud (1953), Dorfman, Samuelson and Solow (1958), and Diewert (1977) have developed Hicks' approach further. In Hicks (1939), producers are assumed in every period to make production plans, specifying the input-output quantities they plan to trade over the following t'-period planning horizon (t', the horizon length, is a behavioral parameter treated as exogenous). The particular feature of these plans is that they include the stocks of capital that remain with the firms all through the planning horizon 1, 2, ..., t'. The stream of revenues expected by each firm consists of the net revenues (profit) associated with each period of the horizon and the value of the stocks left in t'. These stocks are distinguished from the flow variables on the basis that there are well defined market clearing prices for every flow variable in each period, whereas no such prices exist for the stocks. In other words, the levels of the stocks at the beginning of each period constrain the producers for the length of the period, so that stocks are fixed in the short-run. These stocks can, however, be varied in the long-run since producers can use them more or less intensively and speed up or slow down their depreciation by upgrading (investment activities) or maintaining them (maintenance and repair activities). Hence the "quasi-fixed" nature of these inputs. To maximize their profits, producers will choose a particular time path for these stocks.

The temporary nature of the model comes from the fact that producers plan for t' periods but carry out their buying and selling decisions for period one only. At the end of period one, they can change their expectations about future business conditions and adjust stocks in consequence. Clearly, however, they cannot change the level of the stocks they have inherited from last period's decisions and which are this period's beginning stock levels. The dynamic aspect of this model is clear: since no period is self-contained, the decisions taken in "t" will affect next-period possibilities, and in turn depend on period "t-1" decisions as well as on price expectations for the future.

The existence of flow variables having well defined prices is not difficult to accept. On the other hand, what do stocks consist of? Hicks (1939) refers to "plant size" but Diewert (1981b) and Diewert and Lewis (1982) suggest these stocks may include: (i) inventories of goods in process; (ii) bolted down units of various types and vintages of capital stocks (as opposed to uninstalled pieces of capital which can be thought of as flow variables); and (iii) various reserves of renewable or unrenewable resources. As noted above, stocks are firm-specific assets that have no well-defined market price.

The model is thus fairly general for it endogenizes the depreciation rate of the stocks, allows for adjustment costs in varying the stock levels and encompasses the "vintage" models of investment. If the depreciation rate is assumed fixed and exogenous and "vintages" are ignored, it reduces to a Jorgensonian model of investment with (possibly) adjustment costs.

To fix notation and background, suppose there are I outputs y_i (i = 1, ..., I), J variable inputs x_j (j = 1, ..., J), and N types of stocks or capital goods (which can theoretically be distinguished according to their vintages and other characteristics) s_n (n = 1, ..., N). Let y^t, x^t and s^t be the I, J and N dimensional column vectors[1] of outputs, inputs and stocks in period t. Also define the J-dimensional (column) vector of prices for the flow inputs in period t: $w^t \equiv (w_1^t, \ldots, w_J^t)^T$, the N-dimensional vector of regulatory (excess return) variables $e^t \equiv (e_1^t, \ldots, e_N^t)^T$ and the inverse demand functions in t,
$\varphi^t(y^t) \equiv (\varphi_1^t(y^t), \ldots, \varphi_I^t(y^t))^T \equiv p^t \equiv (p_1^t, \ldots, p_I^t)^T$ where $\varphi_i^t(y^t)$ is the i^{th} output price[2] in period t. It is further assumed that $x^t \geq 0_J$, $y^t \geq 0_I$, $s^t \geq 0_N$, $w^t >> 0_J$, $\varphi^t(y^t) \equiv p^t >> 0_I$ and that: $\nabla_y \varphi^t(y^t) = (\nabla_y \varphi_1^t(y^t), \ldots, \nabla_y \varphi_I^t(y^t))^T$, with $\nabla_y \varphi_i^t(y^t) \equiv [\partial\varphi_i^t / \partial y_1^t, \ldots, \partial\varphi_i^t / \partial y_i^t, \ldots, \partial\varphi_i^t / \partial y_I^t]^T$ exist. Finally, $\{x^t\}$, $\{y^t\}$, $\{s^t\}$ and $\{e^t\}$ refer to the sequences of vectors $(x^1, x^2, \ldots, x^{t'})$, and so on; and denote the <u>row vectors</u> $(x^{1T}, x^{2T}, \ldots, x^{t'T})$, $(y^{1T}, y^{2T}, \ldots, y^{t'T})$, $(s^{1T}, s^{2T}, \ldots, s^{t'T})$ and $(e^{1T}, e^{2T}, \ldots, e^{t'T})$ by x^T, y^T, s^T, and e^T respectively (recall that x^T is the transpose of x; hence x, y, s, and e are column vectors).

Following Malinvaud (1953), Diewert (1981 b, c), and Diewert and Lewis (1982), write the one period technology set[3] of the firm as $S^R \equiv \{(y, x, s^0, s^1)\}$ where $s^0 \geq 0_N$ is the beginning of the period and $s^1 \geq 0_N$ is the end of the period stock vector. S^R, which could be indexed according to time, describes the set of tradeoffs open to the firm: it can, given s^0, produce more outputs or use less inputs at the cost of depleting or running down s^1 or, on the other hand, it can use more x to produce less y and obtain a larger end-period stock of capital s^1. See Malinvaud (1953) for more detail.

For given output levels y, stocks s^0 and s^1 and for $w >> 0_J$, let the one period variable cost function C(t) be defined by:

$$C(y, w, s^0, s^1) \equiv \begin{cases} \min \{w \cdot x: (y, x, s^0, s^1) \in S^R\} \\ \text{if there is such a vector in } S^R; \\ \\ \infty, \text{ otherwise.} \end{cases} \quad \ldots(2.1)$$

C(t) is a variable cost function with factors (s^0, s^1) fixed in the short-run. It is conceptually similar to the variable profit function discussed by Diewert (1981b) and Diewert and Lewis (1982). It follows that the usual properties of a variable cost function apply. In particular, it can be shown that $C(y, w, s^0, s^1)$ is a concave and positively linearly homogeneous function in w for fixed (s^0, s^1)[4]; and if differentiable, Shephard's lemma implies:

$$x(y, w, s^0, s^1) = \nabla_w C(y, w, s^0, s^1), \qquad \ldots(2.2)$$

where $x(y, w, s^0, s^1)$ is the vector of conditional demand functions which minimize $C(\cdot)$ given the vector (y, w, s^0, s^1), and $\nabla_w C(y, w, s^0, s^1) \equiv [\partial C/\partial w_1, \partial C/\partial w_2, \ldots, \partial C/\partial w_J]^T$.

A formal model of a regulated monopolist facing the one period technology sets $\{S_t^R\}$ and planning for t' period is developed in the next section.

2.1 SOME RESULTS ON THE BEHAVIOR OF A REGULATED FIRM IN A DYNAMIC CONTEXT WITH QUASI-FIXED INPUTS

In this section, an intertemporal model for a multiple-output, multiple-input monopolist regulated through an intertemporal rate of return constraint is developed. It is assumed that:

(A1) the firm wants to maximize its net present value and chooses a plan for the choice variables x^t, y^t, s^t accordingly.

In each period the enterprise is supposed to plan for the following t' periods. That is, there is continual planning revision, with t' as the (finite) length of the planning horizon (see Hicks, 1939; Diewert, 1981b). This section will consider the non-stochastic version of the model only. A stochastic specification is provided in Chapter 3.

The monopolist is facing three types of constraint: (i) the firm must choose (x^t, y^t, s^t) that are feasible given S_t^R; (ii) it faces a common-carrier obligation which means that it must service all comers at the regulated price; and (iii) it is limited to (x^t, y^t, s^t) that provide it with at most a fair (or allowed) rate of return on its capital stock. Formally translated, these constraints imply:

$$(x^t, y^t, s^t) \in S_t^R, \qquad \ldots(2.3)$$

$$p^t = \varphi^t(y^t), \qquad \ldots(2.4)$$

$$D(\pi) \leq f(x, y, s, e), \qquad \ldots(2.5)$$

where $D(\pi)$ is the discounted sum of profits and $f(y, x, s, e)$ is the regulatory constraint function.

To specify the form of rate-regulation, the following functional form for f is imposed:

(A2) $f(y^T, x^T, s^T, e^T) = \Sigma_{t=1}^{t'} R(0, t)\ e^t\ \ s^{t-1}$; $e^t \geq 0$,

...(2.6)

where R(0,t) is the present value in period zero of a dollar in period t, $e^t = (e_1^t, e_2^t, \ldots, e_n^t, \ldots, e_N^t)^T$ is the vector of excess return on the various components of the capital stock, and the allowed excess return which is assumed non negative by definition applies to the stocks at the beginning of each period. (2.6) corresponds to the "cycle constraint" specified in Marino (1978, 1979) and closely resembles the constraint specification of Gollop and Karlson (1981).[5] The import of (A2) is that regulation constrains the firm to earn, over some horizon, no more than an allowed return on its capital. But this allowed return is not less than the utility's cost of capital. The excess return on capital, e, is thus positive or nil.

Writing the producer's problem using the one period variable cost function and (2.3)-(2.6), the regulated monopolist behaves as if solving:

$$\max_{\{y^t\},\{s^t\}} (1-\hat{u})\ \{\Sigma_{t=1}^{t'}\ R(0,t)\ [\ \varphi^t(y^t)y^t - C(y^t,w^t,s^{t-1},s^t\ )\ ]$$

$$+\ R(0,t')\ Q\ s^{t'}\} + \hat{u}\ [\ \ \Sigma_{t=1}^{t'}\ R(0,t)\ e^t\ s^{t-1}], \quad \ldots(2.7)$$

where $\hat{u}$ is the Lagrange multiplier associated with the regulatory constraint and Q is the scrap value of stocks at t'.

It will prove useful to introduce in the analysis the possibility that the firm indulges in some "rate-base padding" or "gold-plating" activities. To do so it is convenient to define the following quantities:

$$R \equiv [R(0,1),\ R(0,2),\ \ldots,\ R(0,t')]\ ; \qquad \ldots(2.8a)$$

$$V(y,R) \equiv \Sigma_{t=1}^{t'}\ R(0,t)\ \varphi^t(y^t)\ y^t\ ; \qquad \ldots(2.8b)$$

$$\tilde{C}(y,\ w,\ s,\ R) \equiv \Sigma_{t=1}^{t'}\ [R(0,t)\ C(t)] - R(0,t')\ s^{t'}Q\ ; \qquad \ldots(2.8c)$$

$$z^t \equiv (z_1^t\ ,\ z_2^t\ ,\ \ldots,\ z_j^t,\ \ldots,\ z_J^t\ )^T \geq 0_J\ ; \qquad \ldots(2.8d)$$

$$v^t \equiv (\ v_1^t\ ,\ v_2^t\ ,\ \ldots,\ v_n^t\ ,\ \ldots,\ v_N^t\ )^T \geq 0_N\ ; \qquad \ldots(2.8e)$$

$$z\ \equiv (z^{1T}\ ,\ z^{2T}\ ,\ \ldots,\ z^{t'T}\ )^T\ ; \qquad \ldots(2.8f)$$

$$v\ \equiv (\ v^{1T}\ ,\ v^{2T}\ ,\ \ldots,\ v^{t'T}\ )^T\ . \qquad \ldots(2.8g)$$

Respectively, (2.8) describes a discount factor vector, discounted total revenues, discounted total costs minus the market scrap values of the final period stocks, vectors of <u>unused</u> (from a productive point of view) units of variable inputs (z) and vectors of <u>unused</u> units of capital stocks (v).

To deal with the possibility that the utility may find it advantageous to buy unused factors of production in order to manipulate the regulatory process, (2.7) can temporarily be modified in the following way:

$$\max_{\substack{\{y^t\},\ \{s^t\} \\ \{z^t\},\ \{v^t\}}} \quad L' = (1-u)\ [V(y,R) - \tilde{C}(y,\ w,\ s,\ R)$$

$$- \Sigma_{t=1}^{t'} R(0,t)\ (w^t\ z^t) - G(v,R)]$$

$$+ u\ \Sigma_{t=1}^{t'}\ R(0,t)\ e^{t}(s^{t-1} + v^{t-1}),$$

$$y^t \geq 0,\quad s^t \geq 0,\quad z^t \geq 0,\quad v^t \geq 0,\ u \geq 0\ ; \qquad \text{...(2.9)}$$

where G(v,R) is the discounted cost of buying and installing unused capital stocks. These unproductive units of capital can be conceived of as slack variables. And the degree of slack, which may vary according to time and type of capital, is measured here by $[\ v_n^t\ /\ (s_n^t + v_n^t\ )\ ]$. If the optimal level of slack is zero, there is no rate-padding, gold-plating or X-inefficiency going on. On the contrary, if

[v_n^t / (s_n^t + v_n^t)] is positive, it is because the utility is wasting resources.

Assume that:

(A3) every function in (2.7) and (2.9) is once continuously differentiable;

and that

(A4) $(\partial G/\partial v_n^t) > 0$.

Padding (holding unused capital) is therefore not costless by definition of G(v,R). As a result, a solution ($\overset{*}{y}$, $\overset{*}{s}$, $\overset{*}{z}$, $\overset{*}{v}$, $\overset{*}{u}$) to (2.9), if it exists, must satisfy the following necessary (first-order) Kuhn-Tucker conditions[6]:

<u>Conditions M</u>

$$y_i^t \begin{cases} (1-\overset{*}{u})\ [\ \partial V/\partial y_i^t - \partial\tilde{C}/\partial y_i^t\ ] \le 0, & \ldots(2.10a) \\ (1-\overset{*}{u})\ \overset{*}{y}{}_i^t\ [\ \partial V/\partial y_i^t - \partial\tilde{C}/\partial y_i^t\ ] = 0, & \ldots(2.10b) \\ :\ (i = 1, \ldots, I) \text{ and } (t = 1, \ldots, t'). & \end{cases}$$

$$s_n^t \begin{cases} (1-\overset{*}{u})\ [\ -\partial\tilde{C}/\partial s_n^t\ ] + \overset{*}{u}\ R(0,t+1)\ e_n^{t+1} \le 0, & \ldots(2.10c) \\ (1-\overset{*}{u})\ \overset{*}{s}{}_n^t\ [\ -\partial\tilde{C}/\partial s_n^t\ ] + \overset{*}{s}{}_n^t\ \overset{*}{u}\ R(0,t+1)\ e_n^{t+1} = 0, & \ldots(2.10d) \\ :\ (n = 1, \ldots, N) \text{ and } (t = 1, \ldots, t'-1). & \end{cases}$$

$$s_n^{t'} \begin{cases} (1-\overset{*}{u})\ [\ -\partial\tilde{C}/\partial \overset{*}{s}{}_n^{t'}\ ] \le 0, & \ldots(2.10e) \\ (1-\overset{*}{u})\ \overset{*}{s}{}_n^{t'}\ [\ -\partial\tilde{C}/\partial \overset{*}{s}{}_n^{t'}\ ] = 0, & \ldots(2.10f) \\ :\ n = 1, \ldots, N. & \end{cases}$$

$$z_j^t \begin{cases} (1-\overset{*}{u})\ [\ -R(0,t)\ w_j^t\ ] \le 0, & \ldots(2.10g) \\ (1-\overset{*}{u})\ \overset{*}{z}{}_j^t\ [\ -R(0,t)\ w_j^t\ ] = 0, & \ldots(2.10h) \\ :\ (j = 1, \ldots, J) \text{ and } (t = 1, \ldots, t'). & \end{cases}$$

$$v_n^t \begin{cases} (1-\overset{*}{u})\ [-\partial G/\partial v_n^t\ ] + \overset{*}{u}\ R(0,t+1)\ e_n^{t+1} \leq 0, & \ldots(2.10i) \\ (1-\overset{*}{u})\ \overset{*}{v}{}_n^t\ [\ -\partial G/\partial v_n^t\ ] + \overset{*}{v}{}_n^t\ \overset{*}{u}\ R(0,t+1)\ e_n^{t+1} = 0, & \\ :\ (n = 1,\ \ldots,\ N) \text{ and } (t = 1,\ \ldots,\ t'-1). & \ldots(2.10j) \end{cases}$$

$$v_n^{t'} \begin{cases} (1-\overset{*}{u})\ [\ -\partial G/\partial v_n^{t'}\ ]\ \leq 0, & \ldots(2.10k) \\ (1-\overset{*}{u})\ \overset{*}{v}{}_n^{t'} [\ -\partial G/\partial v_n^{t'}\ ] = 0, & \ldots(2.10l) \\ :(\ n = 1,\ \ldots,\ N). & \end{cases}$$

$$u \begin{cases} [\ -V(\overset{*}{y},R) + \tilde{C}(\overset{*}{y},\ w,\ \overset{*}{s},\ R) + \Sigma_{t=1}^{t'} R(0,t)\ (w^t\ \overset{*}{z}{}^t\ ) & \\ +\ G(\overset{*}{z},R) + \Sigma_{t=1}^{t'} R(0,t)\ e^t\ (\ \overset{*}{s}{}^{t-1} + \overset{*}{v}{}^{t-1})]\ \geq 0; & \ldots(2.10m) \\ \overset{*}{u}\ [\ -V(\overset{*}{y},R) + \tilde{C}(\overset{*}{y},\ w,\ \overset{*}{s},\ R) + \Sigma_t^{t'} R(0,t)\ (w^t\ z^t\ ) & \\ +\ G(\overset{*}{z},R) + \Sigma_t^{t'} R(0,t)\ e^t\ (\overset{*}{s}{}^{t-1} + \overset{*}{v}{}^{t-1}\ )\ ] = 0; & \ldots(2.10n) \end{cases}$$

$$\overset{*}{u} \geq 0; \quad \overset{*}{y}{}_i^t \geq 0; \quad \overset{*}{s}{}_n^t \geq 0; \quad \overset{*}{z}{}_j^t \geq 0; \quad \overset{*}{v}{}_n^t \geq 0. \qquad \ldots(2.10o)$$

Conditions M are similar to those in Marino (1978), in which idle factors of production are not allowed, and parallel those in Bailey (1973) who dealt with a purely static problem.

Establishing bounds for $\overset{*}{u}$ is important since this Lagrange multiplier plays a key role in the interpretation of the first-order conditions (2.10) and, in particular, in assessing the impact of regulation on the firm. But the endogeneity of u renders other proofs on its bounds inappropriate. Hence the results in Bailey (1973), Marino (1978) and Diewert (1981a) do not necessarily extend to this context. Thus the first proposition derived from Conditions M establishes bounds on $\overset{*}{u}$.

<u>Proposition 2.1</u> Assuming G(v,R) is an increasing function of v (hence using (A4)), $0 \le \overset{*}{u} < 1$ if at least one $e_n^t > 0$. In general,

$$\overset{*}{u} \le \underset{\{n,t\}}{\text{Min}} \{(\partial G/\partial v_n^t)/[(\partial G/\partial v_n^t) + \hat{e}_n^{t+1}]\},$$

where $\hat{e}_n^t = R(0,t)\, e_n^t$.

<u>Proof</u> Using (2.10i): $(1-\overset{*}{u})\,[\partial G/\partial v_n^t] \ge \overset{*}{u}\,\hat{e}_n^{t+1}$, and using (2.10o): $\overset{*}{u} \ge 0$. Thus,

$$0 \le \overset{*}{u} \le \frac{[\partial G/\partial v_n^t]}{[\partial G/\partial v_n^t] + \hat{e}_n^{t+1}} < 1 \quad \text{if } \hat{e}^{t+1} > 0.$$

Q.E.D.

Notice that proving Proposition 2.1 makes explicit use of the assumption $(\partial G/\partial v_n^t) > 0$.

The following proposition will prove useful when the issue of overcapitalization is considered. It establishes in a straightforward manner a sign restriction on $[\partial\tilde{C}/\partial s_n^t]$, for all n. Recall that, for convenience, $\hat{e}^t = R(0,t)\, e^t$.

<u>Proposition 2.2</u> $\nabla_{s^t}\tilde{C}(\overset{*}{y}, w, \overset{*}{s}, R) \equiv [\partial\tilde{C}/\partial s_1^t, \ldots, \partial\tilde{C}/\partial s_N^t] \geq 0_N$ for $t = 1, \ldots, t'-1$, and $e_n^t > 0$.

<u>Proof</u> Using (2.10c) and Proposition 2.1:

$$\overset{*}{u}\, \hat{e}^{t+1} \leq (1 - \overset{*}{u})\ \nabla_{s^t}\tilde{C}(\overset{*}{y}, w, \overset{*}{s}, R);$$

rearranging, using (A2) and Proposition 2.1 again gives:

$$\nabla_{s^t}\tilde{C}(\overset{*}{y}, w, \overset{*}{s}, R) \geq \overset{*}{u}\,(1 - \overset{*}{u})^{-1}\, \hat{e}^{t+1} \geq 0_N.$$

To see how this result helps in determining the impact of regulation on the capital accumulation decisions of the firm, consider the first-order condition (2.10d). Were $\overset{*}{u} = 0$, so that the firm is ineffectively regulated, then $\partial\tilde{C}/\partial s_n^t = 0$, and the efficient (cost-minimizing) producer chooses to increase s_n^t up to the point where the marginal cost of doing so is just offset by the marginal gains an increase in s_n^t will bring in (t+1) through reduced variable costs. Remember that increasing the stock level in t means a more intensive usage of variable inputs or the buying of more flow variables while, at the same time, it will reduce the variable cost of producing any output level next period. By contrast, when $\overset{*}{u} > 0$ the firm is effectively regulated and Proposition 2.2 implies that $\partial\tilde{C}/\partial s_n^t \geq 0$. Thus, the regulated producer increases s_n^t up to the point where a marginal positive change in this stock pushes up today's variable costs more than it reduces tomorrow's. A common assumption in the literature is that $\tilde{C}(y, w, s, R)$ is convex in s (see Marino, 1979; El-Hodiri and Takayama, 1981). Then clearly stocks are built up in t more than they would be under efficient production circumstances. Proposition 2.4 below will formalize this line of thought.

Before that, the optimal level of slack is shown to be zero. Proposition 2.3 is based on the following assumption, which should appear quite realistic after the above discussion:

$$\text{(A5)}\quad \nabla_{s^t}\tilde{C}(y, w, s, R) << \nabla_{v^t}G(v,R), \text{ for all } y,s.$$

That is, the increase in total costs brought about by a per-unit increase in a component of s is smaller than the incremental cost associated with a per-unit increase in a component of v. The reason is intuitive. Augmenting the level of the productive factor s_n^t contributes to reduce variable costs in the future, ceteris paribus. On the other hand, increasing the level of unused stock v_n^t implies immediate additional costs but no gain in the future by definition of v_n^t.

<u>Proposition 2.3</u> Assuming (A1), (A5), $\overset{*}{y}^t \gg 0$, $\overset{*}{s}^t \gg 0_N$ and $e^t \gg 0$ for all t, then the optimal level of slack is zero. Hence, $\overset{*}{z}^t = 0_J$ and $\overset{*}{v}^t = 0_N$ for all t.

<u>Proof</u> (2.10d) and (2.10i) yield, given $\overset{*}{s}^t \gg 0_N$:

$$(1-\overset{*}{u})\ [-\nabla_{s^t}\tilde{C}(\overset{*}{y},\ w,\ \overset{*}{s},\ R)] + \overset{*}{u}\ \hat{e}^{t+1} = 0_N \geq$$

$$(1-\overset{*}{u})\ [-\nabla_{v^t}G(v,R)] + \overset{*}{u}\ \hat{e}^{t+1}.$$

Using (A5), $(1-\overset{*}{u})[-\nabla_{v^t}G(v,R)] + \overset{*}{u}\hat{e}^{t+1} \ll 0_N$.

And from (2.10j), it follows that $\overset{*}{v}^t = 0_N$ for all $t < t'$. For $t = t'$, (2.10e) and (2.10k) together with the assumption above imply (2.10k) holds as a strict inequality.

And, by (2.10l), $\overset{*}{v}^{t'} = 0_N$. $\overset{*}{z}^t = 0_J$, for all t, follows from (2.10h), Proposition 2.1 and $w_J^t \gg 0_J$.

<u>Q.E.D.</u>

This proof extends to the dynamic context the important result originally due to Bailey (1973) in the static case about the irrelevance of X-inefficiency, rate-base padding, etc... under realistic assumptions. An immediate implication of Proposition 1.3 is that regulated producers can be taken to operate on their production frontier. This fact is important and makes it possible in the next chapters to focus on the allocative efficiency costs of regulation and to neglect resource costs due to technical inefficiency per-se. It should be remembered, however, that this result crucially depends upon (A1). The common belief in the presence of rate-padding and gold-plating may be compatible with other objective functions.

Using this result, and assuming an interior solution obtains, the first-order conditions (2.10) can be rewritten as the following set of necessary conditions associated with the solution to problem (2.7):

$$R(0,t)(1-\overset{*}{u})[\varphi^t(\overset{*}{y}) + \nabla_y\varphi^t(\overset{*}{y})\ \overset{*}{y}^t - \nabla_y C(\overset{*}{y}^t,\ w^t,\ \overset{*}{s}^{t-1},\ \overset{*}{s}^t)] = 0_I,$$

$$t = 1, \ldots, t'; \qquad \ldots(2.11a)$$

$$(1-\overset{*}{u})\ [\ R(0,t)\ (-\nabla_{s^t} C(\overset{*}{y}^t,\ w^t,\ \overset{*}{s}^{t-1},\ \overset{*}{s}^t) + R(0,t+1)$$

$$(-\nabla_{s^t} C(\overset{*}{y}^{t+1},\ w^{t+1},\ \overset{*}{s}^t,\ \overset{*}{s}^{t+1}))] + \overset{*}{u}\ R(0,t+1)\ e^{t+1} = 0\ ,$$

$$t = 1, \ldots, t'-1; \qquad \ldots(2.11b)$$

$$(1-\overset{*}{u})\ [R(0,t')\ (-\nabla_{s^{t'}}C(\overset{*}{y}^{t'},\ w^{t'},\ \overset{*}{s}^{t'-1},\ \overset{*}{s}^{t'})\ +\ Q]\ =\ 0_N. \qquad \text{...(2.11c)}$$

Now define:

$$m^t \equiv m\ (\overset{*}{y}^t)\ \equiv\ -\nabla_y\varphi^t(\overset{*}{y}^t)\ \overset{*}{y}^t\ ,\ t = 1,\ \ldots,\ t'; \qquad \text{...(2.12a)}$$

$$\mu^t \equiv [\overset{*}{u}\ R(0,t+1)\ e^{t+1}/(1-\overset{*}{u})]\ \geq\ 0_N. \qquad \text{...(2.12b)}$$

Substituting (2.12) into (2.11) yields the following set of necessary conditions when $\overset{*}{s}^t >> 0_N$, $\overset{*}{y}^t >> 0_I$.

<u>Conditions R:</u>

$$(1-\overset{*}{u})\ R(0,t)\ [\overset{*}{p}^t - m^t - \nabla_y C(\overset{*}{y}^t\ ,\ w^t,\ \overset{*}{s}^{t-1},\ \overset{*}{s}^t)]\ =\ 0_I,$$

$$t = 1,\ \ldots,\ t'; \qquad \text{...(2.13a)}$$

$$[R(0,t)\ (-\nabla_{s^t}C(\overset{*}{y}^t,\ w^t,\ \overset{*}{s}^{t-1},\ \overset{*}{s}^t))\ +\ R(0,t+1)\ (-\nabla_{s^t}C(\overset{*}{y}^{t+1},$$

$$w^{t+1},\ \overset{*}{s}^t,\ \overset{*}{s}^{t+1}))]\ +\ \mu^t\ =\ 0_N,\ t = 1,\ \ldots,\ t'; \qquad \text{...(2.13b)}$$

$$(1-\overset{*}{u})\ [R(0,t')\ (-\nabla_{s^{t'}}C(\overset{*}{y}^{t'},\ w^t,\ \overset{*}{s}^{t'-1},\ \overset{*}{s}^{t'})\ +\ Q)]\ =\ 0_N. \qquad \text{...(2.13c)}$$

These "Conditions R" have a nice economic interpretation. A regulated firm constrained by a fair rate of return ceiling on its profits will pick a vector of outputs such that marginal cost is less than price. If m^t is thought of as a markup vector in period t, (2.13a) emphasizes that non-zero m^t leads the firm to act as if it were a competitive firm facing prices $(\overset{*}{p}^t - m^t)$ instead of $\overset{*}{p}^t$. Thus, intuition suggests that a regulated firm will produce "too little output". A similar reasoning applies to (2.13b): instead of choosing $\{s^t\}$ that minimizes the cost of producing $\{\overset{*}{y}^t\}$ at $\{w^t\}$, the firm's behavior implies it chooses the end-period stocks in t in such a way that the marginal cost of adding one unit of capital at the end of t is larger than the incremental savings an additional unit will bring in (t+1): the firm "overshoots" the optimal level of stocks. In general, then, intuition suggests that "too much" capital will be used by a regulated firm.

In order to gain a better understanding of this latter phenomenon, imagine that a competitive or efficient firm is asked to produce the outputs chosen by the regulated firm, $\{\overset{*}{y}^t\}$, and the last period stock vectors, $\overset{*}{s}^{t'}$. The capital stocks that would solve the efficient producer's problem, say $\{\bar{s}^t\}$, would satisfy:

$$\underset{\{s^t\}}{\mathrm{Min}_t} \ \Sigma_{t=1}^{t'-1} R(0,t)\, C(\overset{*}{y}^t, w^t, s^{t-1}, s^t). \qquad \ldots(2.14)$$

The necessary first-order conditions for this problem are:

$$R(0,t)\ \nabla_{s^t} C(\overset{*}{y}^t, w^t, \bar{s}^{t-1}, \bar{s}^{t}) + R(0,t+1)\ \nabla_{s^t} C(\overset{*}{y}^{t+1}, w^{t+1}, \bar{s}^{t}, \bar{s}^{t+1}) = 0_N\ ,\ t = 1, \ldots, t'-1. \qquad \ldots(2.15)$$

These are also sufficient if the matrix of second order derivatives of (2.15) with respect to ($\bar{s}^1, \ldots, \bar{s}^{t'-1}$) is positive definite at $\{\bar{s}^t\}$. Denote this matrix by H. But a stronger characterization is necessary to obtain a clear overcapitalization result. Therefore, assume that

(A6) $C(\overset{*}{y}^t, w^t, s^{t-1}, s^t)$ is convex in the stocks $(\bar{s}^{t-1}, \bar{s}^{t})$,

and consider the system of equations (2.16) in $(\overset{*}{y}, w, s, \tau, \mu)$:

$$R(0,t)\ \nabla_{s^t} C(\overset{*}{y}^t, w^t, s^{t-1}, s^{t}) + R(0,t+1)\ \nabla_{s^t} C(\overset{*}{y}^{t+1}, w^{t+1}, s^{t}, s^{t+1}) + \tau\ \mu^t = 0_N\ ,\ \ t = 1, \ldots, t'-1. \qquad \ldots(2.16)$$

When $\tau = 1$, (2.16) is equivalent to (2.13b) and when $\tau = 0$, it reduces to (2.15). Therefore, as τ increases from 0 to 1, (2.16) transforms the first-order conditions for an efficient firm into the "distorted" first-order conditions

(2.13b)[7]. Now, by (A6), H is positive definite. The nonsingularity of H allows one to use the implicit function theorem to express the s-solution to (2.16) as functions of the (given) variables $\overset{*}{y}$, w, μ, τ (hence taking μ as a parameter vector) in a close neighborhood of $\{\bar{s}^t\}$. The question of interest regarding the use of capital is whether[8] $s(\overset{*}{y}, w, \mu, 0) < s(\overset{*}{y}, w, \mu, 1)$. Proposition 2.4 demonstrates that this is the case for s_n^t if the following extra assumption is made:

(A7) let $\mu_n^t > 0$ and $\mu_m^\Theta = 0$, for all $\Theta \neq t$ and $m \neq n$.

<u>Proposition 2.4</u> If (A6) and (A7) hold, and treating μ as a vector of parameters, then the introduction of rate-regulation will lead to overcapitalization in s_n^t if $e_n^{t+1} > 0$.

<u>Proof</u> Let E_n^t be a ((t'x N) - N) row vector with zeroes everywhere except in the ((t-1)N + n)th place and $[\mu]^T \otimes E_n^t$ be the Kronecker product. Then, $[\partial s_n^t/\partial \tau] = [\mu]^T \otimes E_n^t H^{-1}$, where H^{-1} is the inverse of H and is positive definite by (A6). Since μ_n^t is positive by (A7), the sign of the above derivative is positive. Now, using the mean value

theorem:

$$s_n^t(1) - s_n^t(0) = [\,\partial s_n^t(a)/\partial\tau\,] > 0,$$

where $a \in [0,1]$.

Q.E.D.

2.2 CONCLUDING REMARKS

This concludes the brief exploration of the dynamics of the model of producer behavior introduced in this chapter. The necessary conditions for a profit maximizing position were derived and shown to be distinct from that of an efficient firm (conditions R).

Four propositions were derived concerning (i) bounds on the Lagrange multiplier, (ii) bounds on the first-order conditions, (iii) the use of unproductive units of capital stocks and flow services (which were shown never to be profitable) and (iv) an A.-J. effect.

NOTES TO CHAPTER 2

1. Notation: x^T means the transpose of vector x. w x, where both w and x are vectors, is the dot product: $w\,x = \Sigma_j\, w_j\, x_j$. And $w >> 0_J$ means $w_j > 0$ for all j while $w > 0_J$ means $w_j \geq 0$ for all j but $w_j > 0$ for some j.

2. Notice that this formulation allows for interdependent demand functions since the i^{th} inverse demand function $\varphi_i^t(y^t)$ has the whole y^t vector for argument.

3. For the remainder of this section, time superscripts will be omitted.

4. It can also be shown that, in general, C(t) is nonincreasing in the components of s^0 and nondecreasing in the components of s^1 if S^R satisfies free disposal in the stocks. See Diewert and Lewis (1982) for the proof in the context of a profit function.

5. This is a very particular way of specifying the regulatory constraint. Most authors use a period-by-period constraint. This last hypothesis appears unrealistic for it implies a continuous adjustment in the regulatory process. In addition, (A2) is the most tractable specification for estimation purposes and for convenience is maintained through this theoretical section. See Gollop and Karlson (1981) for a theoretical development of a shorter period constraint; note that they move to a specification like (A2) for estimation purposes.

6. By (A2) and (A4), $[\, e_n^{t+1} + (\partial G/\partial v_n^t)] > 0$, for all n and t and $w_j^t > 0$, for all t and j. Thus the Fromovitz-Mangasarian constraint qualification is met and conditions (2.10) are necessary.

7. μ^t is interpretable as a regulation-induced distortion in the shadow value of capital perceived by the firm. Treat this as a parameter. Then for any $\tau \in [0,1]$ equation (2.16) is the relevant first-order condition for a firm to minimize cost when perceiving a shadow value that includes the distortion $\tau\mu^t$.

8. Let $\mu^T = (\mu^{1T}, \ldots, \mu^{t'-1\,T})$.

CHAPTER 3

REGULATION AND FIRM BEHAVIOR: AN ECONOMETRIC MODEL FOR BELL CANADA

3.0 INTRODUCTION

In this chapter, econometric models of the behavior of Bell Canada are presented. The object of the empirical implementation of these models is manyfold. In the first place, it will provide an econometric foundation to the model of producer behavior developed in Chapter 2. Secondly, it will generate additional information on the production structure of Bell Canada. Thirdly, the empirical results will help to ascertain the importance of dynamics and the impact of regulation on the utility's decisions. Finally, the estimated models will allow the computation of the loss of output due to less than perfect regulation.

Bell is the most important enterprise in the Canadian telephone industry. It operates in all of Ontario and Quebec as well as in other parts of eastern Canada and accounts for roughly 60% of the whole industry's output, labor force and equipment. Considered a "natural monopoly" by the federal government, the enterprise is regulated by the Canadian Radio-Television and Telecommunications Commission (CRTC) through a procedure which closely resembles the regulatory framework analyzed in the first chapter of this thesis [1].

Because of its sheer importance in terms of employment, output, etc... and because of the recent debate[2] concerning the structure of regulation in this particular industry, the Canadian telephone sector appears to be an ideal candidate to implement empirically the model of Chapter 2 and evaluate the loss measures to be developed in Chapter 5. The selection of Bell Canada is justified by two criteria: its importance and the fact that reliable, firm-specific, and not typically "accounting" data are available for nearly a thirty-year period.

The cost structure of Bell Canada has often been investigated with rather sophisticated econometric methods. But, as was pointed out in the Introduction, none of the published studies has yet incorporated the two essentially dynamic aspects of the capital accumulation process that are expectations and the presence of adjustment costs in a model of a regulated firm. Until very recently, all empirical studies of Bell's behavior and technology have postulated a static framework in which capital is a variable factor of production and prices are known with certainty to the utility. Examples are Kiss et al. (1981), Fuss and Waverman (1977, 1981), Denny et al. (1981a), and Breslaw and Smith (1982b, 1983).

Also, all but one study abstracts from any effect regulation might have had on the firm's decisions. Fuss and Waverman (1981) attempt to incorporate the effect of regulation through an "A.-J. effect" and to this end develop a very comprehensive model of a rate-regulated firm. But their empirical estimation of both a short-run and a long-run version of this model performed "poorly", in the words of the authors (see p. X and pp.136-141) though a standard profit-maximizing model led to very good results. Multicollinearity was suspected by the authors as the primary factor responsible for the disappointing empirical results (see bottom of p. 141).

More recently Bernstein (1986, 1987) estimated one-output and two-output dynamic systems of input demand equations for Bell Canada that are characterized by rational expectations and convex costs of adjustment (but ignoring regulation). This contributes somewhat to bridging the gaps in the literature.

This thesis departs from those studies, and more generally from the existing literature on the estimation of the technology of regulated monopolies, in the following ways: (i) regulation is allowed to have an impact on the investment and output decisions of Bell in a model that incorporates three essentially dynamic features: rational expectations, convex adjustment costs and lagged adjustments of prices to their desired levels; (ii) the regulatory constraint is specified in a slightly different way than in most theoretical or empirical work; and, (iii) two distinct measures of the user cost of capital are used in the estimation in order to check the robustness of the results.

Two basic models are actually developed and estimated, each using two different capital cost variables. The first is a constrained model of profit-maximization in which Bell does not control the prices and levels of its outputs and the second is a profit-maximization model in which one output is endogenously determined. Both models, it should be noted, allow the identification of all the relevant parameters necessary to accomplish the purposes of the empirical work defined in the first paragraph of this chapter. Moreover, since profit-maximization implies cost-minimization, there is one main advantage and one major drawback to maintaining the hypothesis of endogenous output. On the positive side, the added first-order condition may produce a gain in efficiency in terms of parameter estimates but, on the other hand, biased estimates may result if the utility is cost minimizing but not profit maximizing with respect to some of its outputs.

The latter possibility is probably remote for a standard business operation but not for Bell. In fact, it is a matter of debate whether the utility really does control all of its prices and outputs. Since it is generally admitted that the prices of "local services" are set by regulators, the output levels of these services can then safely be regarded as exogenous to the firm since Bell has the "common carrier" obligation to service all comers at the regulated prices. Toll prices, on the other hand, can be regarded as determined by the firm and approved by regulators, or as merely influenced by the utility and basically exogenous to it. Fuss and Waverman (1977, 1981) have argued for the former hypothesis and built static models based on it. Kiss et al. (1981) and Bernstein (1986, 1987) have opted for the second alternative. Since it is very difficult to determine which is the best alternative a priori, both models are estimated and the likelihood of the hypotheses is judged by the overall performance of the estimated models.

The structure of each model, its stochastic specification, as well as the estimation strategy are presented in the next two sections. A data section closes this chapter. The empirical results are presented and discussed in Chapter 4.

3.1 A MODEL OF PROFIT-MAXIMIZATION WITH EXOGENOUS OUTPUTS

In this two-output, three-input model of Bell Canada, the prices and levels of the local and toll outputs are assumed exogenous to the decision making process of the firm. The model developed here captures many dynamic aspects of the capital accumulation process that are absent from most of the literature. It also takes into account the impact of regulation and, by using a flexible functional form, imposes as few a-priori restrictions on the data as possible. But a number of simplifying assumptions must still be made. These and the essential characteristics of the estimated intertemporal model of producer behavior are outlined below.

(A8) The producer is assumed to choose, in each period, a plan (that is, a vector of optimal levels for all the decision variables) that maximizes the net present value of the stream of profits associated with it.

This is in accordance with the Hicks-Malinvaud-Diewert framework of Chapter 2. Generally, however, the producer will carry on the execution of that plan only for the first period since a new plan will be drawn next period that takes into account all the information then available.

(A9) This maximization is constrained by a ceiling on the net present value of profits imposed by the CRTC. This constraint is known with certainty to the utility and does not change with the passage of time.

The intertemporal regulatory constraint thus takes the form it has in Chapter 2, which is consistent with Marino (1978a, 1979) and Gollop and Karlson (1980).

(A10) Bell's outputs are aggregated into two variables: local output and toll output.

Although a much finer disaggregation of output revenues is available for Bell, econometric tractability requires that a few aggregates be defined. Econometric studies of Bell Canada have alternatively used specifications with one, two or three outputs. Multicollinearity problems would render the estimation of a three-output restricted cost function probably very arduous since the output variables are highly collinear and, together with the technological change proxy and the capital stock, would put the number of highly correlated variables appearing on the right-hand side to five.

(A11) Labor and materials are considered variable inputs, i.e. inputs whose levels are being chosen in each period given a complete knowledge of current prices. No costs beyond the purchase price of the inputs are incurred when the firm adjusts the levels of these inputs.

(A12) A capital aggregate is assumed to exist for Bell; it is treated as a quasi-fixed input with an exogenously determined rate of decay.

Hence any regulation induced effect on the use of capital is hypothesised to affect the investment pattern directly since the firm does not control the real rate of decay of its capital. This, of course, is a strong but standard assumption[3].

Using the notation of Chapter 2, (A12) implies that $s^1 = s^0(1-\delta) + I^1$, where s^0 is the beginning of the period stock level, s^1 the end of the period level, δ the rate of depreciation or decay of the stock and I is gross investment. A large number of production processes are compatible with (A11)-(A12): the level of output in any period t can be made to depend on s^0, or on s^1, for example; one can consider the existence of external or internal adjustment costs defined either over net or gross investment; and there may exist delays in the installation of the investment goods; etc... The specification chosen in this section is thus only one of a host of sensible representations of the technology set S^R. Clearly, there are many specifications along the above lines that are possible and that might be tested against the data. Some experimentation was actually done but there is no guarantee that the adopted specification is the most appropriate.

In particular, it is assumed that:

(A13) the capital goods installed in any period become immediately productive.

This means that Bell inherits in period t a stock of capital from period t-1 and combines this stock with the net investment in the stock accruing in year t to obtain its productive capital stock, K^t, that will determine together with the variable inputs utilized the output production levels in t. There are no delivery lags or gestation period but,

(A14) the accumulation or decumulation of the stock of capital is assumed to be subject to convex costs of adjustment. Furthermore, these costs are assumed to be strongly separable from the rest of the technology; that is, the cost-minimizing variable-input demands are independent of the level of adjustment costs.

This assumption is made for the sake of econometric tractability. Other specifications were tried but proved inferior[4]. The origins of those adjustment costs can be either: (i) the costs associated with the reorganization of production, retooling and retraining implied by the installation of the new equipment (in which case these costs are "internal" to the firm) or, (ii) the costs associated with the need to raise new capital, or with the higher prices paid when the firm orders large quantities of capital goods (in which case these costs are said to be "external" to the firm). The latter source of costs is more in line with the separability of those costs from the rest of the technology.

To complete the characterization of the model two more assumptions have to be made:

(A15) Bell is assumed to be price-taker in all input markets , and

(A16) the levels of both toll and local output prices are assumed to be exogenously determined by the regulatory commission.

The nomenclature of the variables entering this model of producer behavior is given in Table 3.1, a complete description of all variables used in the econometric work is given in section 3.3, below, and in Appendix A.

TABLE 3.1

NOMENCLATURE OF THE VARIABLES

IN THE CONSTRAINED MAXIMIZATION MODEL

Y_L^t	local output quantity
Y_T^t	toll output quantity
L^t	labor input quantity
M^t	materials input quantity
K^t	capital stock
P_L^t	price of local output
P_T^t	price of toll output
w^t	price of labor
m^t	price of materials
v_i^t	user cost of capital (i=1,2)
u	Lagrange multiplier
e_i^t	allowed excess return on K^t
$R(\tau,t)$	present value in τ of one \$ in t
E_τ	expectations taken in τ
S^t	firm's technology set in t
F^t	proxy for technological change
$\hat{w}^t$	w^t / m^t
c^t	$\hat{w}^t L^t + M^t = C^t / m^t$

(A8)-(A16) imply that Bell attempts, in any year τ, to solve the following problem:

$$\underset{\{K^t\}}{\text{Max}}\ E_\tau \Sigma_\tau^{t'} (1-u)\ R(\tau,t)\ \{\ p_L^t\ y_L^t + p_T^t\ y_T^t - C(y_L^t, y_T^t, w^t, m^t, K^t, F^t)$$

$$- v^t K^t - 0.5\ B\ (K^t - K^{t-1})^2\ \} + (1-u)\ R(\tau,t')\ K^{t'} Q^{t'}$$

$$+ u\ \{\ \Sigma_{t=1}^{t'}\ R(\tau,t)\ e^t\ K^{t-1}\ \}, \qquad \ldots(3.1)$$

where B is a cost of adjustment parameter and u is the Lagrange multiplier associated with the utility's regulatory constraint[5]. Notice that adjustment costs are defined over net investment and assumed to be strongly separable from the rest of the technology. A more general specification with internal adjustment costs could be conceived but, unless a-priori restrictions are imposed on the estimation, this introduces too many parameters (see note 4). The restricted cost function appearing in (3.1), C(t), is found by solving the following constrained minimization problem:

$$\underset{L^t,\ M^t}{\text{Min}}\ \{\ w^t\ L^t + m^t\ M^t\ :\ (y_L^t, y_T^t, L^t, M^t, K^t) \in S^t\ \}, \qquad \ldots(3.2)$$

where S^t is the technology set of the firm in year t. The "shifts" occuring in the technology are captured by the technological change proxy F^t in (3.1). The restricted cost function $C(t) \equiv C(\ y_L^t\ , y_T^t\ ,\ w^t\ ,\ m^t\ , K^t\ ,\ F^t\ )$ is monotonically nondecreasing in the input prices and the outputs, nonincreasing in K^t, linearly homogeneous and concave in the input prices (w,m). The cost function is also assumed to be twice continuously differentiable with respect to its arguments.

C(t) thus "solves" the firm's problem of choosing the level of the variable inputs in each period t given the price vector (w,m), the output levels and the stock of capital. This solution, however, is not independent of the dynamic elements in the producer's problem since it depends on K^t. In fact, assumption (A11) allows the producer's problem to be broken down into two stages: the first stage is that of the short-run problem of choosing the levels of the variable inputs, whereas the second stage corresponds to the long-run optimization problem described by (3.1).

The maximization of (3.1) and Shephard's lemma yields the following first-order conditions at any year τ:

$$L^\tau = \partial C(\tau)/\partial w^\tau, \qquad \ldots(3.3)$$

$$M^\tau = \partial C(\tau)/\partial m^\tau, \qquad \ldots(3.4)$$

$$(1-u)\ \{-\partial C(\tau)/\partial K^\tau - v^\tau - B(K^\tau - K^{\tau-1})\} +$$

$$E_\tau\{(1-u)\ R(\tau,\tau+1)\ B(K^{\tau+1} - K^\tau)\} + u\ R(\tau,t+1)\ e^{\tau+1} = 0$$

$$\ldots(3.5)$$

$$(1-u)\ \{-\partial C(t')/\partial K^{t'} - v^{t'} - B(K^{t'} - K^{t'-1})\} + Q^{t'} = 0 \ . \qquad \ldots(3.6)$$

Where $Q^{t'}$ stands for the scrap value of the firm's stock of capital at the end of period t', hence (3.6) is an end-point condition. In addition to the regularity conditions on C(t), a sufficient condition for a constrained optimum implied by (3.3)-(3.6) is that $(\partial^2 C/\partial K^2) > 0$ and $B > 0$ or, more generally, that the objective function in (3.1) be concave in K.

One way of looking at (3.3)-(3.6) is to consider these equations as determining the optimal paths for $\{L^t, M^t, K^t\}$ given all future prices and output levels and to try to solve for these paths. By assuming that all input prices and output levels are known with certainty and expected to remain static over time (actually the hypothesis of stationary expectations with respect to relative prices is sufficient: this implies that all prices and the discount rate change at a constant rate) and by using specific functional forms (such as a quadratic cost function; see Berndt, Morrison and Watkins, (1981)) one can solve explicitly the optimal control problem for the inputs trajectories[6]. In such a case, the long-run solution is characterized by the equilibrium condition that the capital stock remains constant from period to period. Once an expression for the long-run (steady state) capital stock K^{**} is obtained, an approximation to the capital accumulation equation in the neighborhood of K^{**} can be derived and estimated.

An alternative way of looking at (3.3)-(3.5) is suggested in the papers by Pindyck and Rotemberg (1983a, b) and consists in treating the first-order conditions as estimating equations. Notice that these equations hold necessarily at every period τ even if the producer plans ahead up to period t' but realizes its plan for only one period. Therefore, foregoing an explicit solution for the optimal trajectories, one can look at (3.3)-(3.5) as regression equations once an operational definition of E_{τ} is given: that is, once an expectations formation process is posited. This avenue offers the possibility of retaining both the generality of flexible functional forms and the rational expectations hypothesis (RE).

Experimentation with both a normalized quadratic restricted cost function (as in Denny, Fuss and Waverman, 1981b), and with a restricted translog cost function (as in Pindyck and Rotemberg, 1983b) led to the selection of the second functional form. Therefore, the following restricted translog cost function normalized by the price of materials is specified in which c is total variable cost normalized by the price of materials and $\hat{w}$ is the normalized price of labor:

$$\ln c^\tau = \alpha_{00} + \alpha_{01}\ln \hat{w}^\tau + \alpha_{02}\ln y_L^\tau + \alpha_{03}\ln y_T^\tau + \alpha_{04}\ln K^\tau + \alpha_{05} F^\tau + 0.5 [\alpha_{11} (\ln \hat{w}^\tau)^2 + \alpha_{22}(\ln y_L^\tau)^2 + \alpha_{33} (\ln y_T^\tau)^2 + \alpha_{44} (\ln K^\tau)^2] + \alpha_{12}\ln \hat{w}^\tau \ln y_L^\tau + \alpha_{13} \ln \hat{w}^\tau \ln y_T^\tau + \alpha_{14} \ln \hat{w}^\tau \ln K^\tau + \alpha_{15} \ln \hat{w}^\tau F^\tau + \alpha_{23} \ln y_L^\tau \ln y_T^\tau + \alpha_{24} \ln y_L^\tau \ln K^\tau + \alpha_{25} \ln y_L^\tau F^\tau + \alpha_{34} \ln y_T^\tau \ln K^\tau + \alpha_{35} \ln y_T^\tau F^\tau + \alpha_{45} \ln K^\tau F^\tau. \quad ...(3.7)$$

With this specification, the estimated first-order condition (3.3) can be expressed as in (3.8), while the capital accumulation equation (3.5) can be rewritten as (3.9).

$$(\hat{w}^\tau L^\tau)/c^\tau = \alpha_{01} + \alpha_{11}\ln \hat{w}^\tau + \alpha_{12} \ln y_L^\tau + \alpha_{13} \ln y_T^\tau + \alpha_{14} \ln K^\tau + \alpha_{15} F^\tau. \quad ...(3.8)$$

$$0 = [\alpha_{04} + \alpha_{14} \ln \hat{w}^\tau + \alpha_{24} \ln y_L^\tau + \alpha_{34} \ln y_T^\tau + \alpha_{44} \ln K^\tau + \alpha_{45} F^\tau] (c^\tau/ K^\tau) + v^\tau + B(K^\tau - K^{\tau-1}) - R(\tau, \tau+1) E_\tau [B(K^{\tau+1}- K^\tau) + \beta e^{\tau+1}], \quad ...(3.9)$$

where $\beta = u/(1-u)$ is an estimated parameter. u is thus treated as a parameter, as in Spann (1974), Courville (1974), Boyes (1976), Pescatrice and Trapani (1980) and Gollop and Karlson (1980). A more appropriate specification would be a "rolling constraint" that was fully consistent with the form of regulatory constraint used in (A2), Chapter 2. This would require estimation of one regulatory parameter per period. The data however proved unable to yield convincing estimates when more than one such parameter was used.

Before discussing the estimation strategy and the nature of the expectations formation process, note that the hypothesis of linear homogeneity of C(t) in the input prices is maintained through the normalization rule in (3.7) as is the assumption that C(t) has a symmetric Hessian matrix of price derivatives. But the monotonicity and curvature conditions are not imposed and can be checked at all observation points. Also notice that the demand for materials is replaced in the estimation by equation (3.7), the translog cost function, to avoid singularity of the residuals covariance matrix.

(3.7) and (3.8) correspond to the first stage of the producer's problem and involve variables whose values are known with certainty in τ. This is not the case for equation (3.9) since expectations need to be taken. This last condition simply says that the net effect on profit of an extra unit of capital is zero. This net effect is made up of four components: the savings in variable costs resulting from an additional unit of capital, the current cost of adjustment, the expected savings in future adjustment costs discounted to τ, and the contribution to allowed excess profits an additional unit of capital makes. To estimate equations of this sort while maintaining the RE hypothesis, Hansen (1982) and Hansen and Singleton (1982) suggest a generalized method of moments estimator. Their idea consists in using an instrumental variables procedure that minimizes the correlation between any variable known at τ and the residuals of (3.9). These residuals, which can be interpreted as expectational errors, are computed using the actual values of $K^{\tau+1}$ on the left-hand side. Moreover, as shown in Hansen (1982), if these residuals are assumed to be homoscedastic, the procedure reduces to nonlinear three-stage least squares.

The estimation strategy thus consists, as in Pindyck and Rotemberg (1983a, b), in using nonlinear three-stage least squares to estimate the system of equations (3.7)-(3.9) with $K^{\tau+1}$ as the dependent variable in the capital accumulation equation.[7] As pointed out in Pindyck and Rotemberg (1983b), using any variable known at τ as instrument could be justified only if equations (3.7) and

(3.8) held exactly, without errors. For if these equations contain error terms because of technological shocks, measurement or optimization errors, these error terms are likely to be correlated with some variables in the capital accumulation equation. Hence, as is suggested in Pindyck and Rotemberg (1983b), the conditioning set does not include current variables appearing in the cost, labor share or capital accumulation equation.

The set of chosen instruments include: the lagged (by one period) values of $\hat{w}$, p_L, L, M, y_L, and q (the price of investment goods). The endogenous variables in the system of estimating equations are C^t, K^t, $(K^t - K^{t-1})$ and e^t. The nonlinear algorithm of SHAZAM (version 5.1) is used to generate estimates of the parameters in (3.7)-(3.9) once intruments have been substituted for the endogenous variables in the system. A convergence criterion of 0.00001 is employed to produce the final results.

The inclusion of e^t in the set of endogenous variables deserves further discussion. Even if this variable is theoretically exogenous, it cannot be treated as such in the empirical investigation for the following reasons. As will be made clearer in the data section at the end of this chapter, e^t is defined for estimation purposes as the difference between the firm's actual return on capital and its cost of capital. Since realized profits are definitely endogenous, so is the actual return on capital and hence e^t. It is possible to construct an exogenous indicator of the firm's "allowed return" on capital by using the level of profits approved by the regulators in rate cases. This solution is adopted in Fuss and Waverman (1981) in their static model of a regulated utility.

However, the level of profits approved by the regulatory commission does not appear to reflect truly the real permissiveness or stringency of the regulators' control, nor does the latter solution preclude the possibility that the firm influences the commission in its setting of the allowed rate of return[8]. Since this thesis takes a long-run view of the regulatory constraint and assumes that the profit ceiling is defined over a long horizon, the actual level of Bell's profitability over this horizon seems to correspond more closely to what regulation allows the firm to earn. Moreover, the allowed rate of return used in Fuss and Waverman does not appear to be binding: the utility sometimes earns more, sometimes less than the set rate of return. Finally, note that the practice of using the actual return on capital as a proxy for the allowed return is common in the empirical literature on regulation and can be found, among others, in Courville (1974), Spann (1974), Hayashi and Trapani (1976), Pescatrice and Trapani (1980), Gollop and

Karlson (1980), Cowing (1980) and Nelson and Wohar (1983). Therefore, to minimize the risk of an endogeneity bias it is decided to instrument for e^t.

Now, appending jointly normally zero-mean random terms to each equation, and labeling these $(u_C, u_L, u_K)^t$, the following error structure is posited:

$$
\text{(A17)} \quad \begin{cases} \operatorname{cov}(u_i^t, u_j^t) = \sigma_{ij}, & i,j = c, L, K; \\ \operatorname{cov}(u_i^t, u_j^{t-1}) = 0, & i,j = c, L, K. \end{cases}
$$

Also recall that u_K is interpreted as an expectational error whereas u_C and u_L are seen as representing optimization or measurement errors but <u>not</u> errors in expectations. Notice that the parameter estimates will be consistent even if the assumption of an homoscedastic error structure is violated, although the standard errors of the parameters will then be invalid.

Finally, two measures of the user cost of capital and, as a result, two different excess return variables are alternatively used in the estimation. This step is taken to check the robustness of the results to the construction of the cost of capital variable. These variables are defined in detail in section 3.3.

3.2 A MODEL OF PROFIT-MAXIMIZATION WITH ENDOGENOUS OUTPUT

The model of producer behavior described in 3.1 can be transformed into a model in which the firm is a price-setter by adding a transformed first-order condition to the estimating equations, as shown in Fuss and Waverman (1977) in a static context. Basically, the following hypothesis is substituted for (A16):

(A18) local price and output are exogenous to the firm but the price and quantity of toll output are chosen by Bell so as to maximize its expected profits.

This is the behavioral assumption underlying the papers by Denny et al. (1981a, b) and Fuss and Waverman (1977, 1981). Under this hypothesis, Bell's constrained objective function becomes:

$$\begin{aligned} \operatorname*{Max}_{\{Y_T^t,\ K^t\}} \quad & E_\tau \ (1-u) \ \Sigma_\tau^{t'} \ R\ (\tau,t) \ \{ \ p_L^t \ Y_L^t + \ \varphi \ (Y_T^t) \ Y_T^t \\ & - C(t) - v^t \ K^t - \ B(K^t - K^{t-1} \ )^2 \ \} \ + \\ & (1-u) \ R(\tau,t') \ Q \ K^{t'} + \\ & u \ \{ \ \Sigma_{t=1}^{t'} \ R\ (\tau,t) \ e^t \ K^{t-1} \ \}, \qquad \ldots(3.10) \end{aligned}$$

where $\varphi(y_T^t)$ is the inverse demand function for Bell's toll output. The necessary condition for a maximum of profits associated with the choice of the optimal toll output level can be written as[9]:

$$(p_T^\tau \ y_T^\tau \ )/ \ C^\tau = (b_1 \ /(1+b_1) \ ) \ [\ \alpha_{03} + \ \alpha_{13} \ \ln^\tau \hat{w}$$

$$+ \alpha_{23} \ \ln y_L^\tau + \alpha_{33} \ \ln y_T^\tau + \alpha_{34} \ K^\tau$$

$$+ \alpha_{36} \ F^\tau \ ], \qquad \ldots(3.11)$$

in which b_1 is the toll output elasticity of demand. By choosing a suitable specification for the demand for toll output, a system of five equations is obtained in place of the previous system of three estimating equations.

Numerous attempts at estimating this system were made. In most cases, the regularity conditions on the cost function were violated and the second-order conditions for a maximum of profit failed to be met. More specifically, marginal cost was found to decrease more rapidly than marginal revenue almost everywhere. This was the case in over twenty estimated models. To determine if equation (3.11) is indeed the source of those irregularities, the system of equations (3.7), (3.8) and (3.11) was estimated: this imposes the profit-maximizing condition but ignores both regulation and adjustment costs. Again, the results were disappointing. Because of the very poor results no parametric test of output endogeneity was done here.

In comparison, Fuss and Waverman (1981) obtained very good results under an identical maintained hypothesis. However, there are many major differences between their studies and this one: Fuss and Waverman use three outputs instead of two, they treat capital as a variable input, use a specification in which technical progress is an output-augmenting process and estimate a hybrid translog variable cost function in which the output variables are modified by the Box-Cox transformation. Finally, they ignore regulation and adjustment costs.

Those considerations aside, it may also be that the dynamic character of the cost function used here did not "mesh" very well with the static formulation of the output determining equation. One particularly strong aspect of the hypothesis contained in (3.11) is the implication that toll prices are adjusted continously so that the desired equality between marginal revenue and marginal cost is obtained at each observation point. Even with yearly observations, this may be an unrealistic assumption since rate hearings are held at irregular intervals and hardly once a year. Moreover, this assumption implies that the price adjustments demanded by Bell are systematically granted.

A specification in which prices adjust slowly to the desired level may therefore more closely reflect the sluggish way in which Bell can have its toll price adjusted. Above all, such a specification can shed some light onto the plausibility of the profit-maximization hypothesis.

A simple, and ad-hoc, process of adjustment is the following variant of a Koyck partial adjustment model for the price of toll services:

$$p_T^t = p_T^{t-1} + \Theta\ (\overset{*}{p}{}_T^t - p_T^{t-1}), \qquad \text{...(3.12)}$$

where $\overset{*}{p}{}_T^t$ is the optimal (or desired) price level in year t. If $\Theta = 1$, full adjustment occurs every year and $p_T^t = \overset{*}{p}{}_T^t$: the first-order condition (3.11) then obtains. In contrast, for $0 < \Theta < 1$, Bell gets only Θ% of its desired adjustment in any given year. The utility's rule for choosing y_T, analogous to (3.11), but considering the fact that p_T^t may be different from $\overset{*}{p}{}_T^t$ is:

$$(p_T^\tau\ y_T^\tau)/C^\tau = (\ \Theta\ b_1/(1 + b_1))\ S_y \ + \ (1-\Theta)\ ((p_T^{\tau-1}\ y_T^\tau\ )/\ C^\tau\ ), \qquad \text{...(3.13)}$$

where $S_y = [\ \partial \ln C\ (\tau)/\partial \ln\ y_T^t\ ]$. As a result, estimating (3.13), which has (3.11) as a special case, makes it possible to test the hypothesis of instantaneous price adjustment against that of partial adjustment. Since the elasticity of the demand for toll output enters the above first-order condition, it is preferable to complete the system of estimating equations by the demand for toll services. The double-log[10] specification is chosen for the demand function:

$$\ln y_T^\tau = b_0 + b_1 \ln (p_T^\tau / CPI^\tau) + b_2 \ln RPC^\tau, \qquad ...(3.14)$$

where CPI^τ is the consumer price index and RPC^τ the real per-capita income in Bell's territory.

The estimated model of producer behavior with endogenous output consists of equations (3.7), (3.8), (3.9), (3.13) and (3.14). The method of estimation is nonlinear three-stage least squares and the set of instruments described in 3.1 is employed (notice however that y_T^τ is now an endogenous variable).

The first-order conditions (3.5) and (3.13) are also sufficient if the profit function in (3.10) is concave in the choice variables (that condition ensures that the constraint is convex). These conditions, along with the regularity conditions on $C(\tau)$ are checked at each observation point. Both versions of the capital cost variables are again used in the estimation.

3.3 DATA SECTION

The precise procedure for constructing the data series used to estimate the models in 3.1 and 3.2 is outlined in Appendix A and the final output and input price and quantity series are reported in Appendix B. This section gives the definitions of all the variables along with summary statistics on the data.

The principal source of the data is a recent submission to the Canadian Radio-Television and Telecommunications Commission (CRTC) by Bell Canada. The data are annual, covering the period 1952-1980. The two output variables are measured in millions of constant 1976 dollar revenues. The output price variables are Divisia indexes of all local and toll categories of revenues normalized to 1.0 in 1976. The quantity of labor is millions of manhours and the average hourly wage rate is used as the price of labor. The quantity of materials is measured as the constant 1976 dollar value of expenditures on materials, services, rents and supplies. And the price of materials is given by an implicit price index, normalized to 1.0 in 1976.

The quantity of capital is the constant 1976 dollar total average net stock of capital at reproduction cost. The determination of the user cost of capital services (or cost of capital) for a firm is not straightforward. This is because the cost of capital is an opportunity cost and a forward-looking concept (Kolbe et al., 1984): investors look at the expected (marginal) return on their investments and compare this return to the expected return on foregone investments. This definition of the cost of capital implies that historic values about a firm's policy, riskiness, capital structure, etc... may be irrelevant for inferring the cost of capital of a marginal investment in the firm. The case of regulated enterprises is even more complex because it may prove very difficult to ascertain the level of risk of a regulated concern.

Moreover, in the context of this research, the measurement of the user cost of capital turns out to be crucial since one of the important propositions of Chapter 2 implies that effective regulation may induce overcapitalization by the regulated firms. This proposition can be tested against the data only if a measure of the excess return on capital is available. But this excess return variable is defined as the difference between the allowed return on capital and the cost of capital. Therefore, any measurement error involved in the computations of either or both of those two volatile variables will immediately affect the chosen measure of the excess return on capital and possibly bias the estimated parameters. The wide diversity of results that were obtained by different researchers while trying to test the overcapitalization effect in a static framework in the U.S. electric utility industry, for instance, may in part be attributable to the choice of different measures for the cost of capital and for the (gross) excess return on capital services.

While following the mainstream procedure for estimating the cost of capital, this thesis takes two precautionary steps against the possible bias induced by the choice of a particular user cost variable. First, the user cost formula retained does take into account the specific effects of the fiscal regime, the existence of accelerated depreciation for tax purposes, the presence of a ceiling constraint on the actual return to capital and the fact that capital funds are raised from many sources. Secondly, two slightly different measures of the cost of capital services are derived using the two most common procedures for computing the cost of equity capital: the discounted cash flow method (DCF) and the capital asset pricing model (CAPM) method. These two user cost of capital variables are then used alternatively in the econometric estimation in order to test the robustness of the estimation to the choice of a particular capital cost measure.

Most user cost of capital formulae are in the tradition developed by Christensen and Jorgenson (1969). The procedure adopted in this thesis lies in the same tradition but is based on a model of Boadway and Bruce (1979) in which a consumer maximizes utility over an intertemporal consumption stream. This maximization is constrained by the consumer's ability to borrow and the firm's ability to generate distributable profits. Fuss and Waverman (1981) have adapted this model to the case of a regulated firm, and this thesis further modifies their suggested measures of the cost of capital and of the excess returns earned.

Fuss and Waverman's user cost of capital services is given by:

$$v^i = q(\Theta c_B + c_E^i \frac{(1-\Theta)}{(1-t)} + \delta) - (\alpha-\delta) \frac{g\ t\ q}{(1-t)(\alpha+g)}, \quad i=1,2 \qquad \ldots(3.15)$$

where q is the asset price of capital, Θ the fraction of the firm's capital financed by debt, δ the economic depreciation rate, α the accelerated depreciation rate, t the tax rate on corporate income, g the treasury bond rate which is used as a proxy for the personal borrowing rate, c_B is the cost of debt, and c_E^i is the cost of equity capital. This latter can be computed in two ways, with c_E^1 using the CAPM method and c_E^2 using the DCF method. Notice that (3.15) defines a «gross» user cost of capital, and that c_B and c_E^i are accordingly after tax percentages. An implicit assumption contained in

(3.15) is that marginal investments do not alter the capital structure of the firm. This is a standard assumption although it may not be warranted. Lastly, note that Fuss and Waverman use exclusively a DCF method to compute (3.15), and that their specification of the DCF model is different from the specification in this thesis in some minor respects. The two methods are described in greater details in the Appendix. Insofar as the procedures may ignore the effects of capital gains (or losses) due to appreciation of prices of capital assets Bell Canada owns, and of any neglected relevant investment tax credits, the overall effect would be to over-estimate the user cost of capital and under-estimate the excess return. The resulting bias would favor rejection of the A.-J. hypothesis. Note also that use of the CAPM model may not be warranted in the case of rate-regulation (see for example Brennan and Schwartz, 1982).

The formula given in Fuss and Waverman for the allowed gross return on capital is:

$$s = q\ (\theta\ c_B + s_E \frac{(1-\theta)}{(1-t)} + \delta\ ), \qquad \ldots(3.16)$$

where s_E is the allowed (gross) rate of return on equity. s_E is assumed to be equal to the actual rate of return on equity. This solution is also adopted by Spann (1974), Gollop and Karlson (1980), Pescatrice and Trapani (1980), Hayashi and Trapani (1976), Cowing (1978) and Nelson and

Wohar (1983) among others. This is consistent with the assumptions that regulation is binding and that the firm maximizes its profits. It also implies that regulators allow the firm to earn a given rate of return when they do not react.

Finally, the allowed (gross) excess return on capital services can be obtained from (3.15) and (3.16):

$$e^i = (s-v^i) = q\,[\,(s - c^i)\,(1-\Theta)\,/\,(1-t)\,] + (\alpha - \delta)\,[\,(\,q\,t\,g\,)\,/\,(1 - t)\,(\alpha + g)]. \quad \ldots(3.17)$$

Summary statistics on all variables appear in Table 3.2. The values of v^1, v^2 and s can be found in Table 3.3. Table 3.4 lists the e^i values. Cursory examination of those tables reveals that, in general, $s_E > c_E^i$ and thus $e^i > 0$. This is consistent with the assumptions of Chapters 2 and 3 and opens the possibility of an A.-J. bias: hence that $u > 0$. Notice however that $e^i < 0$ in 1980 (using c_E^1) and in 1973, 74, 76, 77 and 1979 (using c_E^2). Although these occurences are few, they are somewhat inconsistent with the theorizing in this thesis. Interestingly, Fuss and Waverman (1981) remark that regulation seems to have tightened for Bell during the seventies: the relatively

TABLE 3.2

BELL DATA SET:

SUMMARY STATISTICS

(1952-1980)

Variable Name	Mean	Standard Deviation	Minimum	Maximum
y_L	0.62175 E+03	0.33356 E+03	0.19429 E+03	0.12837 E+04
p_L	0.85624	0.15998	0.71803	1.3205
y_T	0.43369 E+03	0.35352 E+03	75.968	0.12560 E+04
p_T	0.88829	0.11059	0.79112	1.1936
L	58.693	6.63800	49.000	76.200
w	4.9294	3.5350	1.7087	14.140
M	0.19809 E+03	95.460	69.019	0.39935 E+03
m	0.69356	0.26624	0.44626	1.4010
K	0.43509 E+04	0.20972 E+04	0.12902 E+04	0.80055 E+04
v^1	0.10523	0.067605	0.045261	0.30311
v^2	0.11490	0.065915	0.058846	0.27418
e^1	0.015941	0.011781	-0.020947	0.039687
e^2	0.006271	0.005078	-0.004383	0.013815

TABLE 3.3

GROSS USER COST OF CAPITAL

AND ALLOWED RETURN ON

CAPITAL FOR BELL: 1952-1980

Year	v^1	v^2	s
1952	0.0480	0.0754	0.0785
1953	0.0500	0.0725	0.0727
1954	0.0458	0.0630	0.0718
1955	0.0453	0.0588	0.0692
1956	0.0533	0.0599	0.0691
1957	0.0593	0.0615	0.0682
1958	0.0541	0.0640	0.0693
1959	0.0711	0.0720	0.0774
1960	0.0621	0.0698	0.0779
1961	0.0615	0.0673	0.0786
1962	0.0692	0.0730	0.0800
1963	0.0671	0.0692	0.0807
1964	0.0693	0.0174	0.0830
1965	0.0714	0.0740	0.0879
1966	0.0865	0.0792	0.0864
1967	0.0782	0.0849	0.0963
1968	0.0922	0.0922	0.1032
1969	0.1052	0.0976	0.1090
1970	0.1033	0.1106	0.1187
1971	0.0912	0.1146	0.1228
1972	0.0992	0.1297	0.1350
1973	0.1145	0.1426	0.1423
1974	0.1405	0.1567	0.1533
1975	0.1534	0.1865	0.1931
1976	0.1915	0.2061	0.2018
1977	0.1912	0.2108	0.2080
1978	0.2150	0.2297	0.2327
1979	0.2651	0.2675	0.2655
1980	0.3031	0.2742	0.2822
MEAN	0.1052	0.1149	0.1211

TABLE 3.4

EXCESS ALLOWED RETURN ON CAPITAL

FOR BELL: 1952-1980

YEAR	e^1	e^2
1952	0.0305	0.0313
1953	0.0227	0.0003
1954	0.0260	0.0088
1955	0.0240	0.0104
1956	0.0158	0.0091
1957	0.0090	0.0068
1958	0.0151	0.0052
1959	0.0063	0.0055
1960	0.0158	0.0081
1961	0.0171	0.0113
1962	0.0103	0.0092
1963	0.0136	0.0114
1964	0.0136	0.0115
1965	0.0165	0.0138
1966	0.0058	0.0072
1967	0.0181	0.0113
1968	0.0110	0.0110
1969	0.0037	0.0113
1970	0.0153	0.0098
1971	0.0317	0.0082
1972	0.0357	0.0053
1973	0.0278	-0.0002
1974	0.0128	-0.0034
1975	0.0397	0.0066
1976	0.0103	-0.0044
1977	0.0169	-0.0027
1978	0.0177	0.0030
1979	0.0004	-0.0020
1980	-0.0209	0.0086
MEAN	0.0159	0.0063

small and sometimes negative values for e^i during this period seem to support this conjecture.

Finally, an indicator of technological change has to be defined. Many measures of technological change exist for Bell Canada. Common indicators are the percentage of phones with access to direct distance dialing (A), the percentage of toll calls using direct distance dialing (DDD), the percentage of phones connected to offices with "modern" switching equipment (S), and various combinations of these three indicators (Kiss et al., 1981, provide a list of four of those indicators). In addition, Fuss and Waverman experiment with a capital-augmenting indicator whereas Denny et al. (1981a) and Fuss and Waverman (1981) use output-augmenting indicators. These take the form: $X\ e^{az}$ where X is output or capital, z is one of the above indicators and a is an estimated parameter. Studies of the US Bell system have also employed indices based on past research and development expenditures.

As pointed out in Denny et al. (1981a) and in Bernstein (1987), it is widely believed that the single most important technological innovation of the last thirty years occured in the sixties and consisted in the development of modern switching equipment (electronic switchboards, etc...) and the introduction of direct-distance dialing facilities.

All the above mentioned technological change indicators reflect this pattern. After some experimentation, two indices were singled out for use in all the estimations in this thesis. These are: the percentage of phones with access to direct distance dialing (A), this is used by Fuss and Waverman (1981); and one of the technological indicators in Kiss et al. (1981) defined as:

$$T2 = FNEW\ [\ h\ PDH + (1-h)\ A\ ], \qquad \ldots(3.18)$$

where FNEW is defined as one plus the percentage of crossbar and electronic central offices, PDH is the percentage of dial phones and $h = (\ y_L \ /\ (y_L + y_T)\ )$.

The series defined by (24) ends in 1978. A regression of known values on a constant and a time trend gave an R^2 of .997 . The fitted values of the proxy variable for 1979 and 1980 were added to the series to complete it.

NOTES TO CHAPTER 3

1. See Waverman (1982) and Green (1980).

2. See Chapter 5 of Economic Council of Canada (1981).

3. See Epstein and Denny (1980) for a short-run model of producer behavior in which the real rate of depreciation is endogenously determined.

4. Alternate specifications in which costs of adjustment were made to depend (linearly or logarithmically) on input prices were used in the estimation but proved unsatisfactory: the regularity conditions on the cost function, including the sign restrictions on the adjustment cost coefficients, were generally violated. Also notice that the chosen specification is consistent with the often imposed restriction that marginal adjustment costs vanish when net investment is zero.

5. As in Chapter 2, the initial level of the capital stock is given.

6. See Gould (1968), Brechling (1975) and Berndt, Fuss and Waverman (1980). Berndt, Morrisson and Watkins (1981) review the literature on the estimation of dynamic factor demands.

7. Specifically, taking $K^{\tau+1}$ to the L.H.S. and rewriting equation (3.9) gives the actual estimating equation:

$$K^{\tau+1} = [B\ R(\tau,\tau+1)]^{-1} \{[\alpha_{04} + \alpha_{14} \ln \hat{w}^{\tau} + \alpha_{24} \ln y_L^{\tau} + \alpha_{34} \ln y_T^{\tau} + \alpha_{44} \ln K^{\tau} + \alpha_{45} F^{\tau}][C^{\tau}/ K^{\tau}] + v^{\tau} + B(K^{\tau} - K^{\tau-1}) + B\ R(\tau,\tau+1)\ K^{\tau}\} - (\beta/B)e^{\tau+1}. \quad \ldots(3.9')$$

8. See Waverman (1982) on the rate-setting process in the case of Bell Canada and the factors having an impact on the regulatory outcome. Notice that some variables that appear to play a significant role in the determination of the allowed rate of return are indeed controlled by the utility.

9. Equation (3.11) is derived as follows: let $S_y = \partial \ln C/\partial \ln y_T$ and $C' = \partial C/\partial y_T$, then marginal revenue is given by

$$MR = p_T \left(1 + (1/b_1) \right) = C' = S_y \, (C/Y_T). \qquad \ldots(1)$$

Hence:

$$p_T \, ((b_1 + 1)/b_1) = S_y \, (C/y_T), \qquad \ldots(2)$$

and,

$$(p_T \, y_T/C) = (b_1/(1+b_1)) \, S_y. \qquad \ldots(3)$$

Now consider the unrestricted and unnormalized variable translog cost function (where time superscripts have been omitted for simplicity):

$$\begin{aligned}
\ln C = {} & a_{00} + a_{01} \ln w + a_{02} \ln m + a_{03} \ln y_L + a_{04} \ln y_T \\
& a_{05} \ln K + a_{06} F + 0.5 \, [a_{11} (\ln w)^2 + a_{22} (\ln m)^2 + \\
& a_{33} (\ln y_L)^2 + a_{44} (\ln y_T)^2 + a_{55} (\ln K)^2] + \\
& a_{12} \ln w \ln m + a_{13} \ln w \ln y_L + a_{14} \ln w \ln y_T + \\
& a_{15} \ln w \ln K + a_{16} \ln w \, F + a_{23} \ln m \ln y_L + \\
& a_{24} \ln m \ln y_T + a_{25} \ln m \ln K + a_{26} \ln m \, F + \\
& a_{34} \ln y_L \ln y_T + a_{35} \ln y_L \ln K + a_{36} \ln y_L \, F + \\
& a_{45} \ln y_T \ln K + a_{46} \ln y_T \, F + a_{56} \ln K \, F. \qquad \ldots(4)
\end{aligned}$$

Notice that the symmetry assumption is the only condition imposed on (4). The linear homogeneity of the cost function in input prices implies:

$$a_{01} + a_{02} = 1, \qquad \text{...(5)}$$

$$a_{11} + a_{12} = a_{22} + a_{12} = 0, \qquad \text{...(6)}$$

$$\Sigma_i \, a_{ij} = 0, \; i=1,2 \text{ and } j=3,4,5,6. \qquad \text{...(7)}$$

Using (4), the elasticity of variable costs to toll output can be defined as:

$$S_Y = a_{04} + a_{14} \ln w + a_{24} \ln m + a_{34} \ln y_L + a_{44} \ln y_T$$

$$+ a_{45} \ln K + a_{46} F . \qquad \text{...(8)}$$

When the linear homogeneity assumption (7) is imposed, (8) becomes:

$$S_Y = a_{04} + a_{14} \ln (w/m) + a_{34} \ln y_L + a_{44} \ln y_T$$

$$+ a_{45} \ln K + a_{46} F. \qquad \text{...(9)}$$

Substituting (9) into (3) and renumbering the coefficients yields equation (3.11) in the text.

10. Other specifications for the demand for toll output were tried but proved inferior to this one. In particular, a specification in which the number of households in Bell's territory is included led to non statistically significant price and income elasticities. A specification that allows for a lag in consumers' response to price changes was also rejected when the hypothesis of no lags in response could not be statistically rejected. Most empirical studies of Bell's demands utilize a double-log functional form. Dobell (1972), Denny et al. (1981a) and Fuss and Waverman (1981) are cases in point. Experimentation with a semi-log specification for the inverse demand function lead to disappointing results.

CHAPTER 4

ESTIMATION RESULTS

4.0 INTRODUCTION

Parameter estimates, for the two models of producer behavior of Chapter 3 and using the two alternative measures for the user cost of capital, are presented and discussed in 4.1 through 4.3 . The sample period is 1953-1979 in all cases. The first and last observation of the data set have to be dropped because of the use of lagged and lead values of the capital stock in the capital accumulation equation. In general, the estimation results do not prove very sensitive to the choice between A and T2, the two technical change proxies. When discrepancies occured, they are reported. The best results, based on the value of the likelihood function and the regularity conditions on C(t), are chosen for each model. As a result, the percentage of phones with access to direct distance dialing (A) is used in the estimation of the exogenous output models while the index T2, defined in 3.3, is used in the estimated models with endogenous output.

4.1 EMPIRICAL RESULTS FOR THE CONSTRAINED MAXIMIZATION MODEL WITH EXOGENOUS OUTPUTS

The estimated coefficients for the constrained model of profit-maximization described by the set of equations (3.7)-(3.9), in Chapter 3, are shown in Table 4.1 , and the goodness-of-fit statistics are reported in Table 4.2 . Note that non-normalized data have been used in the estimation. Examination of Tables 4.1 and 4.2 reveals that the estimated models fit the data rather well. Most parameters are significant and the variance of the dependent variables is well explained by the regression equations. The Durbin-Watson statistics indicate that autocorrelation of the residuals does not seem to be a problem, except perhaps in the capital accumulation equation when v_1 is used.

In addition, B, the adjustment cost parameter, is statistically significant in both versions of the model. This signifies that Bell is not in long-run equilibrium. Since $\beta = u/(1-u)$, the implied values for the Lagrange multiplier are 0.44 and 0.8. Although the hypothesis that the first value is zero cannot be rejected, the second value is statistically significant and does fall within the theoretical range for u. This means that the hypothesis that regulation distorts the investment decisions of Bell cannot

TABLE 4.1

PARAMETER ESTIMATES: MODEL WITH EXOGENOUS OUTPUTS

	v_1 (CAPM)		v_2 (DCF)	
	coef.	st. dev.	coef.	st.dev.
α_{00}	46.559	50.322	-40.671	4.4980
α_{01}	1.0343	0.2449	1.0326	0.0819
α_{02}	-155.26	62.320	-28.462	3.2006
α_{03}	63.380	30.736	4.4007	0.7286
α_{04}	63.960	15.937	30.074	3.4050
α_{05}	3.7625	5.5830	-4.5250	1.2659
α_{11}	-0.0109	0.0303	-0.0430	0.0057
α_{22}	86.985	26.903	22.661	2.8498
α_{33}	18.768	7.3618	2.8738	0.4049
α_{44}	-1.1978	1.3502	-0.3976	0.2102
α_{12}	0.1418	0.1372	0.2012	0.0394
α_{13}	-0.0122	0.0527	-0.0209	0.0137
α_{14}	-0.1381	0.0758	-0.1705	0.0280
α_{15}	-0.0499	0.0298	-0.0447	0.0159
α_{23}	-40.253	14.119	-7.8379	1.0452
α_{24}	-18.287	3.9493	-7.9155	1.0921
α_{25}	-15.625	5.4697	-5.8876	0.7598
α_{34}	9.6543	2.4202	3.4489	0.5713
α_{35}	4.8227	2.3586	0.7348	0.2060
α_{45}	8.0345	2.1755	4.4706	0.6248
B	0.0012	0.0003	0.0005	0.0001
β	0.7748	1.3319	5.3166	1.0664

TABLE 4.2

SUMMARY STATISTICS FOR THE MODEL WITH EXOGENOUS OUTPUTS

	v1	
	R^2	D.W.
cost equation	0.9964	1.6841
labor share equation	0.8764	1.6253
capital accumulation equation	0.9992	0.8236

Log of the likelihood function: 11.76

	v_2	
	R^2	D.W.
cost equation	0.9957	1.6209
labor share equation	0.8715	1.7295
capital accumulation equation	0.9993	1.2859

Log of the likelihood function: 15.50

be rejected when v_2 is used.

The monotonicity and curvature properties on the cost function as well as the (sufficient) second-order conditions for a maximum of profit are checked and reported on in Table 4.3.

The estimated cost function appears well-behaved at most observation points; it describes the behavior of Bell Canada satisfactorily except for the pattern of the marginal cost of local output over a few years.

The concavity of the objective function in the capital stock is sufficient for a maximum of profit characterized by the estimated first-order conditions. This concavity condition is verified and found to hold everywhere.

Also note from the last tables that the v_2-specification provides the more satisfactory results: the maximized likelihood function is greater, failures in the monotonicity and curvature conditions scarcer and the residuals exhibit more evidence of randomness in the capital accumulation equation.

TABLE 4.3

MONOTONICITY AND CURVATURE PROPERTIES ON THE COST FUNCTION: MODEL WITH EXOGENOUS OUTPUTS

	v_1	v_2
Monotonicity conditions:		
capital	24/27	25/27
local ouput	17/27	21/27
toll output	17/27	27/27
labor share	27/27	27/27
Curvature properties:		
concavity in input prices	27/27	27/27
sufficient conditions for a maximum of profit	27/27	27/27

Additional information on the technology of Bell Canada and the properties of the estimated equilibrium is provided in Table 4.4. It can be shown by totally differentiating the normalized cost function that the desired factor price elasticities are:

$$E_{LL} = [\ \alpha_{11} / S_L\ ] - [\ 1 - S_L\ ], \qquad ...(4.1)$$

$$E_{LM} = -E_{LL}, \qquad ...(4.2)$$

$$E_{MM} = [\ \alpha_{11} / (1 - S_L)\ ] - S_L, \qquad ...(4.3)$$

$$E_{ML} = -E_{MM}\ , \qquad ...(4.4)$$

where E_{ij} is the cross-elasticity of the demand of the i^{th} factor with respect to the price of the j^{th} factor ($i,j = L, M$), and $S_L = (\ \partial \ln C\ / \partial \ln w)$ is the share of labor in variable costs. Hence S_L is the elasticity of variable costs with respect to the price of labor. The elasticity of variable costs to local and toll outputs are defined in a similar way.

The scale elasticity is defined as the growth in total output as all inputs are scaled up at a common rate. This elasticity can be shown to be the inverse of the effect of output growth on the growth of total costs. Caves, Christensen and Swanson (1981) demonstrate that in the case of a restricted cost function the scale elasticity is given by:

$$SE = [\ 1 - S_K\ ] \ / \ \Sigma_i \ S_i \ , \qquad \ldots(4.5)$$

where S_K is the elasticity of variable costs to capital and S_i is the elasticity of variable costs to output i.

Finally, the time shift in the variable cost function is given by:

$$\partial \ln C/\partial t = [\ \partial \ln C/\partial F\ ]\ [\partial F/\partial t]. \qquad \ldots(4.6)$$

The last expression is evaluated holding all variables other than F, the technological change proxy, constant at their mean value. The meaning of (4.6) is immediate: it represents the average annual rate at which the variable cost function is "shifting" through time because of technological change.

One interesting feature of Table 4.4 is the low sensitivity of the estimated characteristics of Bell's technology to the user cost specification. Moreover, the data contained in this table generally confirm other studies' findings. As in Bernstein (1986,1987), who also used a restricted cost function approach, and in Fuss and Waverman (1981) and Kiss et al. (1981), who used a static approach, the variable factor demands seem quite price inelastic[1].

TABLE 4.4

SUMMARY STATISTICS ON BELL'S TECHNOLOGY: AVERAGE VALUES

	V_1	V_2
Elasticity of variable costs with respect to:		
local output	0.66	0.51
toll output	0.50	0.46
capital	-0.89	-0.77
Scale elasticity	1.63	1.82
Shift in the variable cost function	-0.0269	-0.0239
Own elasticity of input demand:		
labor (E_{LL})	-0.35	-0.39
materials (E_{MM})	-0.70	-0.79

The estimated values for the technological shift in the cost function and the scale elasticity are extremely sensitive to the econometric specification, as noted in Fuss and Waverman (1981; p.117) and Denny et al. (1981a). The first of these studies reviews previous estimations of the scale elasticity of Bell and finds a wide range of values, from 0.94 to 1.47 (all estimates derived from long-run models of the utility). Bernstein (1986,1987) arrives at values ranging from 1.13 to 1.84 in a one-output model and averaging 1.5 in a two-output model. Kiss et al. (1981) report estimates in the range 1.22-1.75 based upon the estimation of more than twenty one-two-and three-output models. In general then, the values found in Table 4.4 seem in line with those in the literature.

As for the estimated "average downward shift" in the cost function, it suggests that technological change alone is responsible for an annual average reduction in variable costs of something like 2%. Using a very different specification for technological change[2], Bernstein (1987) finds an average value of 1.7%, a figure very close to the present result.

Finally, the reported results outperform those obtained when the alternative technological change proxy, T2, is used. The maximized likelihood values are greater in both the v_1 and v_2 versions of the model (the values with T2 are 9.46 and 10.90); the regularity conditions on the cost function are violated less often than when T2 is utilised; otherwise, there are no significant differences between the estimated properties of the cost function. In particular, the conclusions concerning the adjustment costs and regulatory parameters are upheld.

4.2 EMPIRICAL RESULTS FOR THE CONSTRAINED MAXIMIZATION MODEL WITH ENDOGENOUS OUTPUT

The estimation results pertaining to the set of equations (3.7)-(3.9) and (3.13),(3.14) are presented in Tables 4.5 to 4.7. The goodness-of-fit statistics and the high percentage of significant parameters in both the v_1 and v_2 versions of the model indicate that in this case also the estimated model fits the data rather well.

The major conclusions arrived at in the last section regarding the effect of regulation and the importance of adjustment costs receive further empirical support. The estimated adjustment costs parameter is again statistically significant in both the v_1 and v_2 versions of the model and similar in magnitude to that of 4.1. The regulatory parameter is statistically significant at the 0.1 and 0.025

levels of confidence depending on whether v_1 or v_2 is used in the estimation. The implied Lagrange multiplier values are 0.71 and 0.88, well within the theoretical range. The estimated Θ value, which tells of the speed of the toll price adjustment process, is highly significant in both versions of the model and close to 0.6, meaning that Bell obtains on average 60% of its desired price adjustment in any given year.

Together, those observations on B, β and Θ strongly suggest that both dynamics (on the cost and demand sides) and regulation are important in modelling a regulated utility like Bell.

In order to ascertain the relevance of lagged price response, a likelihood-ratio test is performed and the results are tabulated in Table 4.8. The test consists in estimating each version of the model twice, once imposing the constraint that Θ equals one (instantaneous adjustment of toll prices) and then freely estimating Θ. Theil (1971, p.397) demonstrates that:

$$-2\ [\ \mathrm{Ln}\ (H_0) - \mathrm{Ln}\ (H_1)\ ], \qquad \ldots(4.7)$$

TABLE 4.5

PARAMETER ESTIMATES: MODEL WITH ENDOGENOUS OUTPUTS

v_1 (CAPM)

	coef.	st. dev.		coef.	st. dev.
α_{00}	-69.555	10.116	Θ	0.5970	0.0611
α_{01}	1.1183	0.1751	b_0	-6.5609	1.3428
α_{02}	-14.208	7.4742	b_1	-1.3631	0.1643
α_{03}	-0.1191	0.1320	b_2	1.1840	0.1499
α_{04}	32.152	7.7635			
α_{05}	-0.2920	0.0450			
α_{11}	-0.0930	0.0535			
α_{22}	9.7729	3.0046			
α_{33}	0.0007	0.0283			
α_{44}	-1.9309	2.9237			
α_{12}	0.2418	0.0823			
α_{13}	0.0067	0.0309			
α_{14}	-0.2143	0.0505			
α_{15}	-0.0008	0.0005			
α_{23}	0.0015	0.0588			
α_{24}	-4.4188	2.8414			
α_{25}	-0.1123	0.0244			
α_{34}	0.0233	0.0298			
α_{35}	0.0013	0.0005			
α_{45}	0.1199	0.0230			
B	0.0015	0.0005			
β	2.4867	1.5553			

TABLE 4.6

PARAMETER ESTIMATES: MODEL WITH ENDOGENOUS OUTPUTS

v_2 (DCF)

	coef.	st. dev.		coef.	st. dev.
α_{00}	-66.693	7.2798	θ	0.6050	0.0944
α_{01}	1.1684	0.1754	b_0	-7.4573	1.4547
α_{02}	-10.756	3.3824	b_1	-1.2395	0.1833
α_{03}	-0.0280	0.1007	b_2	1.2833	0.1622
α_{04}	28.756	3.8823			
α_{05}	-0.2950	0.0360			
α_{11}	-0.1095	0.0449			
α_{22}	11.717	1.5907			
α_{33}	-0.0023	0.0381			
α_{44}	-0.0381	1.0121			
α_{12}	0.2064	0.0575			
α_{13}	0.0300	0.0166			
α_{14}	-0.2062	0.0468			
α_{15}	-0.0008	0.0005			
α_{23}	-0.0096	0.0795			
α_{24}	-6.3278	1.0914			
α_{25}	-0.1094	0.0179			
α_{34}	0.0133	0.0429			
α_{35}	0.0010	0.0007			
α_{45}	0.1182	0.0170			
B	0.0012	0.0003			
β	7.0552	2.4224			

TABLE 4.7

SUMMARY STATISTICS FOR THE MODEL WITH ENDOGENOUS OUTPUTS

	V_1	
	R^2	D.W.
cost equation	0.9958	1.9423
labor share equation	0.8611	1.8108
capital accumulation equation	0.9824	1.4947
toll output equation	0.9987	0.7975
toll demand equation	0.9723	1.9180

Log of the likelihood function: 133.23

	V_2	
	R^2	D.W.
cost equation	0.9956	1.7999
labor share equation	0.8536	1.7395
capital accumulation equation	0.9831	1.4668
toll output equation	0.9990	1.1699
toll demand equation	0.9718	1.9518

Log of the likelihood function: 133.10

follows a Chi-square distribution with r degrees of freedom where r is the number of restrictions imposed, H_0 is the value of the likelihood function under the null hypothesis and H_1 is the corresponding value when the constraint is relaxed.

The hypothesis of instantaneous price adjustment can be rejected in both versions of the model at the 0.01 level of confidence. This finding suggests that the failures in estimating the standard profit-maximizing model with endogenous output may be ascribable to the unrealism of the assumption of full price adjustment in one period. However, this conclusion, and the results of this model in general, must be interpreted with some caution in view of the ad-hoc nature of the posited adjustment process. Although it seems reasonable and is easily implemented econometrically, the lagged price response formulation is not fully rationalized by an underlying (constrained) optimizing behavior on the part of the utility. Therefeore, a lagged price response is estimated but not really explained.

Nevertheless, this last effort at introducing an additional dynamic element in the modelling of a regulated utility does indicate that the imposition of static conditions for the choice of the output level may lead to a

TABLE 4.8

LIKELIHOOD RATIO TEST ON Θ

Test H_0:	d.f.	Chi-square value (0.05)	Chi-square value (0.01)	Computed value	Decision
			v_1		
Θ = 1	1	3.84	6.63	11.93	Reject
			v_2		
Θ = 1	1	3.84	6.63	8.48	Reject

Note: the maximized likelihood values under the null hypothesis are 127.25 and 128.86 respectively.

mispecification problem, just as does the hypothesis that there are no marginal adjustment costs when the stock of capital is adjusted in any period.

The information contained in Tables 4.5-4.7 attests that the estimated demand equation for toll output fits the data very well. As required by profit-maximization, the demand for toll output is price elastic. Moreover, as can be seen in Table 4.9, the estimated elasticities corroborate the findings of past studies.

Tables 4.10 and 4.11 summarize the implications of the estimated model for Bell's behavior and production structure.

TABLE 4.9

ESTIMATED LONG-RUN TOLL ELASTICITY OF DEMAND FOR BELL, VARIOUS STUDIES

Source	Elasticity value
Breslaw and Smith (1982)	
chosen range for sensitivity analysis	-1.2 to -1.8
Fuss and Waverman (1981)	
"competitive toll"	-1.39
"monopoly toll"	-2.05
Denny et al. (1981a)	
"competitive toll"	-1.44
"monopoly toll"	-1.64
Dobell et al. (1972)	
residential demand	-1.2
business demand	-1.3
This dissertation	
v_1	-1.36
v_2	-1.24

TABLE 4.10

MONOTONICITY AND CURVATURE PROPERTIES ON THE COST FUNCTION: MODEL WITH ENDOGENOUS OUTPUTS

	v_1	v_2
Monotonicity conditions:		
capital	22/27	21/27
local output	21/27	21/27
toll output	27/27	27/27
labor share	27/27	27/27
Curvature properties:		
concavity in input prices	27/27	27/27
sufficient conditions for a maximum of profit	13/27	21/27

TABLE 4.11

SUMMARY STATISTICS ON

BELL'S TECHNOLOGY:

AVERAGE VALUES

	v_1	v_2
Elasticity of variable costs with respect to:		
local output	0.80	0.86
toll output	0.21	0.15
capital	-0.69	-0.66
Scale elasticity	1.67	1.64
Shift in the variable cost function	-0.01	-0.01
Own elasticity of input demand:		
labor (E_{LL})	-0.47	-0.50
materials (E_{MM})	-0.95	-1.00

Overall, the estimated cost function displays the desired properties. Although they are met less overwhelmingly than in the exogenous outputs case, the monotonicity conditions on the cost function are found to hold at a large majority of observation points. The behavior of the cost elasticity with respect to local output is again perverse over the same six-year period as previously; similarly, monotonicity of costs in the level of capital stock fails in the first years of the sample. On the other hand, the toll output and labor share monotonicity conditions, and the concavity of the cost function in input prices, hold everywhere. The concavity of the objective function in toll output and capital is checked at each observation point. This would make the estimated necessary conditions also sufficient for a maximum of profit. This indeed is the case at about one half and two-thirds of the years in the sample[3]. In addition, the marginal revenue function is found declining more rapidly than the marginal cost function everywhere. The opposite result held for the estimation of a standard profit-maximizing model ($\Theta = 1$), thus violating a necessary second-order condition. This is additional evidence for the fruitfulness of the dynamic-demand approach.

Now comparing the values in Table 4.11 to those in 4.4, one striking fact to emerge is that many estimated features of Bell's technology are not very sensitive to the objective function specification. For instance, the scale elasticity and the input demand elasticities show little variation (although the latter appear somewhat more elastic in the endogenous output case). Likewise for the elasticity of costs with respect to the stock of capital, which goes to -0.7 from -0.8 or -0.9. In contrast, the elasticities of cost with respect to toll and local outputs and the estimated time-shift in the cost function are affected. The differences between the two estimated models are greatest for the toll elasticity of costs. The estimated marginal cost of toll output is, on the whole, half what it was in 4.1 while that of local output is some thirty percent higher. Moreover, in the endogenous output case, the marginal cost of toll output is almost constant over the twenty-seven year period covered by the estimation: it slowly climbs from a value of 0.2 in 1953, with an output price of 0.83, to 0.33 in 1979, when the price of toll output reaches 1.17 .

4.3 CONCLUDING REMARKS ON THE ESTIMATION

A few remarks are in order before concluding the analysis of the empirical results. First, it appears that the overall performance of the estimation is satisfactory although it could be improved on a few points. For instance, it is still unclear why the local output monotonicity conditions fail to obtain in a few years. One possible explanation lies in the high correlation that exists between the local output quantity and the technological change proxies. In both the exogenous and endogenous-output cases, the coefficient on the cross-term in local output and the proxy for technological change is negative, and is large in absolute value when compared to that on toll output and the proxy. It may be that the chosen proxies, being more closely correlated to the growth in local output than in toll output, ascribe more of the reduction in costs to local output than a "perfect" index would, thus weighting down the elasticity of costs to local output. This point draws attention to the way in which technical change enters the estimation. There are many plausible specifications for capturing the effect of technical change and other specifications may produce better results.

The sensitivity of the results to the choice of a particular proxy is another interesting issue that has been mostly ignored in this work. While the exogenous output model was successfully estimated with two distinct technical change proxies that generated similar results, the estimation of the endogenous output model using the percentage of phones with access to direct distance dialing proved much inferior to that with the alternative technical change indicator, T2. For this reason the results corresponding to the first specification are not discussed in 4.2. Further attempts at estimating this latter model may yet lead to a better fit because the models estimated are highly nonlinear. Thus, there is a possibility that the obtained estimates corresponded to a local rather than a global maximum. Incidentally, it should be pointed out that all reported results were checked by re-estimating the models with different sets of starting values for the parameters, to ensure that convergence was to a global maximum of the likelihood function.

Second, note that in general the v_1 and v_2 specifications lead to the same qualitative conclusions concerning the importance of regulation, adjustment costs, lags, etc... although some parameter values are sensitive to the user cost specification, as was pointed out in the discussion of the results.

Finally, the exogenous output model, and particularly its v_2-specification, is singled out as the best description of Bell's behavior. This conclusion is based on the overall performance of the estimation, on the fact that the sufficient conditions for optimization are met globally and lastly, on theoretical grounds: the profit-maximization model with lagged price adjustments is to be seen as a first approximation to a dynamic decision rule for output choice that has not been thoroughly investigated. This does not mean that the empirical results in 4.2 are unreliable. It simply reflects the greater confidence this author has in the robustness and applicability of the first model of cost minimization.

NOTES TO CHAPTER 4

1. Fuss and Waverman (1981) estimate the labor demand elasticity and the materials demand elasticity at -0.437 and -0.371, but impose a zero capital demand elasticity on the estimation. Without this restriction, they obtain a positive, but non significant, (long-run) capital demand elasticity. This may result from a mispecification of the producer's problem that ignores both the existence of adjustment costs and regulation. Denny et al. (1981a) also obtain a positive demand price elasticity for capital of 0.019 in a very similar model. In Fuss and Waverman (1977), however. the the long-run capital demand price elasticity is estimated at -0.671.

2. In Bernstein (1987), the technological change proxy is a binary variable which takes the value 1 between 1958 and 1971, the years in which most innovations were introduced at Bell. This allows the author to obtain very satisfying empirical results but leaves open the question of the reasonableness of this specification which implies that costs decreased at once in 1958 and, more troubling, increased at once at the end of the period because of technological change.

3. Incidentally, the concavity of the objective function is sufficient but not necessary for a maximum of profit. Hence the estimated set of first-order conditions could still result from maximizing behavior even if concavity globally failed.

CHAPTER 5

A PRODUCER PRICES APPROACH TO MEASURING THE LOSS OF OUTPUT DUE TO IMPERFECT REGULATION IN A DYNAMIC ENVIRONMENT

5.0 INTRODUCTION

Measuring the waste of resources induced by regulation is necessary because present regulatory regimes do not succeed in implementing an optimal allocation of resources. The purpose of this chapter is to derive approximations to the deadweight loss of regulation. This loss is the cost imposed on society by the deviations from the desired allocation of resources that are brought about by the process of regulation in a dynamic context. Losses in efficiency, following Debreu (1951), are of three kinds: (a) the waste of resources due to the underutilization or underemployment of the factors of production of society; (b) the efficiency loss due to the failures, on the part of producers, to obtain the maximal output from a given set of utilized resources; and, (c) the loss in efficiency when inputs and outputs are not allocated in a way that maximizes a certain notion of welfare, such as the Pareto criterion.

The first type of waste can be ascribed to the economic institutions of a society and to the management of certain macro-variables and is ignored in this thesis. The second type is closely related to the notion of X-inefficiency or operations "off" the production frontier. As shown in Proposition 2.3, such misuse of resources is never profitable under rate of return regulation as long as profit maximization is a maintained hypothesis. Hence this kind of resource cost will also be ignored in the remainder of this thesis. This leaves the third kind of resource cost, usually called "allocative inefficiency". This misallocation of resources, which is the focus of this chapter, occurs whenever different producers or consumers face different prices for the same goods or whenever the private and social prices differ.

The measurement of this last type of resource cost has received considerable attention in the past and focused primarily on the distortions induced by taxation and monopolistic pricing. There are basically two methodologies for the measurement of waste: general and partial equilibrium. Hotelling (1938), Hicks (1978), Boiteux (1951), Debreu(1951), Allais(1973) and Diewert (1981e) present theoretical general equilibrium analyses. In recent years many attempts have been made to implement econometrically general equilibrium models of the economy and to compute deadweight losses. Shoven and Whalley (1984) survey the literaure on applied general equilibrium models. Harris and Cox (1983) is a recent application of this methodology.

This thesis does not adopt the general equilibrium approach because its information requirements are simply too high. To use it, one needs to estimate the technologies of all sectors of the economy as well as the preference structure of all consumer groups. In addition, since this chapter deals with the intertemporal loss of efficiency, a correct parametrization of consumers' preferences would normally require that the possibility of change in tastes be incorporated into the estimation. Finally, even if these information requirements could be met, the estimation would most likely proceed with simple functional forms to save degrees of freedom and for the sake of tractability.

Instead, a partial equilibrium approach is chosen in this thesis. More precisely, a producer prices approach in which only the revenues and costs of producers need to be estimated is taken. The essence of this approach is the following: given a vector of "optimal" or "reference" prices, maximize the productive sector's net value of output and compare this value to the distorted equilibrium net output vector, evaluating all inputs and ouputs at the "optimal" or reference prices.

This price-approach to the measurement of productive inefficiency can be found in Hicks (1941-42) and in a number of papers by Diewert (1981a, b, c, 1985b). It can be opposed to the quantity-approach underlying the Allais-Debreu methodology in which one good or basket of goods is used as a "reference good". But in both cases, price and quantity approaches, the same kind of question is being asked: "how much more output (evaluated at the reference prices in the price-approach, or of the reference good in the quantity-approach) can be obtained if the distortions characterizing the inefficient allocation are removed?". In principle, the removal of these distortions could affect very many prices and the welfare of many different consumers as the equilibrium conditions in one market after another are affected by the change. Thus a general equilibrium approach is required on theoretical grounds; as noted, however, the practical implementation of such a model is extremely difficult, so it is decided to focus exclusively on the productive side of the economy.

In Diewert (1981a) this (partial equilibrium) producer prices approach is put to work to obtain a quadratic approximation to the loss of output due to (imperfect) rate of return regulation in a static context. As was pointed out in the Introduction to this thesis, Diewert's is one of only a handful of papers that deal with the evaluation of monopoly regulation. The task of this chapter is to extend the analysis to the case of a dynamic economy in which the capital accumulation decisions of producers are fully endogenous. A one-sector measure is derived in the next section. The estimated model of producer behavior of Chapter 4 is then used to generate estimates of the loss of output due to the A.-J. effect. As it turns out, however, the existence of important non-convexities in Bell's technology renders the computation of the loss of output due to monopolistic pricing <u>and</u> inefficient capital accumulation impossible with the derived loss formula. A two-sector planning model of the economy is developed in the closing section of this chapter and used to arrive at a more general loss formula that should, in principle, allow one to overcome the problem associated with the presence of important non-convexities.

5.1 A ONE-SECTOR DYNAMIC DEADWEIGHT LOSS MEASURE

In this section, the loss of output resulting from the pricing and investment decisions of a rate-regulated utility is evaluated in a one-sector model using the producer price approach outlined in 5.0. Suppose the technology of one or more regulated producers can be defined and described as in Chapter 2 and that a social planner wishes to maximize the net present value of the regulated sector's production (the value of outputs minus that of inputs) using the reference (or "optimal", more will be said below about that) prices $\{\tilde{p}^t\}$, $\{\tilde{w}^t\}$, $\tilde{Q}$, and $\tilde{R}$ over the horizon $t = 1, \ldots, t'$. Formally, the planner's problem is to choose $\{y^t\}$ and $\{s^t\}$ in order to maximize the social objective function (5.1):

$$\max_{\substack{\{y^t\},\, \{s^t\} \\ y^t \geq 0_I \\ s^t \geq 0_N}} \quad \Sigma_{t=1}^{t'} \tilde{R}(0,t) \, [\tilde{p}^t \, y^t - C(y^t, \tilde{w}^t, s^{t-1}, s^t)] + \tilde{R}(0,t') \, \tilde{Q} \, s^{t'} \,. \qquad \ldots(5.1)$$

If a solution to (5.1) exists and if:

(A19) $C(y^t, \tilde{w}^t, s^{t-1}, s^t)$ is twice continuously differentiable in its arguments;

then, the following first-order conditions are necessary at the unconstrained maximum of (5.1).

Conditions W1

$$R(0,t)\ [\tilde{p}^t - \nabla_{y^t} C(\tilde{y}^t, \tilde{w}^t, \tilde{s}^{t-1}, \tilde{s}^t)] = 0_I,$$

$$t = 1, \ldots, t'; \qquad \ldots(5.2a)$$

$$-R(0,t)\ \nabla_{s^t} C(\tilde{y}^t, \tilde{w}^t, \tilde{s}^{t-1}, \tilde{s}^t) -$$

$$R(0,t+1)\ \nabla_{s^t} C(\tilde{y}^{t+1}, \tilde{w}^{t+1}, \tilde{s}^t, \tilde{s}^{t+1}) = 0_N,$$

$$t = 1, \ldots, t'-1; \qquad \ldots(5.2b)$$

$$R(0,t')\ [-\nabla_{s^t} C(\tilde{y}^{t'}, \tilde{w}^{t'}, \tilde{s}^{t-1}, \tilde{s}^{t'}) + \tilde{Q}\ ] = 0_N. \qquad \ldots(5.2c)$$

Notice the "~" over y^t and s^t, which indicates that (5.2a)-(5.2c) hold at a social optimum. Also assume that the (strong) second-order sufficient conditions for an unconstrained maximum are satisfied at $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$. This implies that:

(A20) the matrix of second-order derivatives of (5.1) with respect to the components of y^t and s^t

evaluated at $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$ is negative definite (call that matrix A).

The essence of the producer prices approach to evaluating the loss of output due to the existence of any distortion is to compare the value of net production at $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$ to that at the distorted equilibrium $\{\overset{*}{y}^t\}$, $\{\overset{*}{s}^t\}$. By the definition of $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$:

$$\Sigma_{t=1}^{t'} \tilde{R}(0,t) [\tilde{p}^t \tilde{y}^t - C(\tilde{y}^t, \tilde{w}^t, \tilde{s}^{t-1}, \tilde{s}^t)]$$

$$\geq \Sigma_{t=1}^{t'} \tilde{R}(0,t) [\tilde{p}^t y^t - C(y^t, \tilde{w}^t, s^{t-1}, s^t)], \quad ...(5.3)$$

and, in particular,

$$\Sigma_{t=1}^{t'} \tilde{R}(0,t) [\tilde{p}^t \tilde{y}^t - C(\tilde{y}^t, \tilde{w}^t, \tilde{s}^{t-1}, \tilde{s}^t)]$$

$$\geq \Sigma_{t=1}^{t'} \tilde{R}(0,t) [\tilde{p}^t \overset{*}{y}^t - C(\overset{*}{y}^t, \tilde{w}^t, \overset{*}{s}^{t-1}, \overset{*}{s}^t)], \quad ...(5.4)$$

where $\{\overset{*}{y}^t\}$, $\{\overset{*}{s}^t\}$ are the quantities which solve the regulated monopolist's problem in Chapter 2. The producer prices measure of loss of output is simply the difference between the two terms in (5.4).

Therefore, if a complete characterization of the technology of the producers in the regulated sector <u>and</u> $\{\tilde{p}^t\}$, $\{\tilde{w}^t\}$ were available to the welfare analyst, the computation of the producer prices loss of output would involve solving equations (5.2) for $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$, computing the net value of output at this social optimum and comparing that value to the value of the observed, distorted net production vector evaluated at $\{\tilde{p}^t\}$, $\{\tilde{w}^t\}$. It is because this information is not available in general that the need arises to use approximations to this loss of output.

That the $[\{\tilde{y}^t\}, \{\tilde{s}^t\}]$-solution will in general differ from the distorted equilibrium $[\{\overset{*}{y}{}^t\}, \{\overset{*}{s}{}^t\}]$ can be deduced from a comparison of the first-order conditions of the two problems. Recall Conditions R of Chapter 2:

<u>Conditions R:</u>

$$(1-\overset{*}{u})\, R(0,t)\, [p^t - m^t - \nabla_{y^t} C(\overset{*}{y}{}^t, w^t, \overset{*}{s}{}^{t-1}, \overset{*}{s}{}^t)] = 0_I,$$

$t = 1, \ldots, t'$; ...(5.5a)

$$[R(0,t)\,(-\nabla_{s^t} C(\overset{*}{y}{}^t, w^t, \overset{*}{s}{}^{t-1}, \overset{*}{s}{}^t)) +$$

$$R(0,t+1)\,(-\nabla_{s^t} C(y^{*t+1}, w^{t+1}, s^{*t}, s^{*t+1}))] + \mu^t = 0_N,$$

$t = 1, \ldots, t'$; ...(5.5b)

$$(1-\overset{*}{u})\ [R(0,t')\ (-\nabla_{s^t}\ C(\overset{*}{y}^{t'},\ w^t,\ \overset{*}{s}^{t'-1},\ \overset{*}{s}^{t'}) + Q)] = 0_N \qquad \text{...(5.5c)}$$

As before, let $m^t \equiv -\nabla_y \varphi^t(\overset{*}{y}^t)\overset{*}{y}^t$, $\mu^t \equiv \{R(0,t+1)e^{t+1} [\overset{*}{u}/(1-\overset{*}{u})]\}$, and define $d^t \equiv (\overset{*}{p}^t - \tilde{p}^t)$. Also let $R(0,t) = \tilde{R}(0,t)$, $w^t = \tilde{w}^t$, and $Q = \tilde{Q}$. Then, following Diewert (1981a, b,c, d; 1985b), the following z-equilibrium can be defined where $z \in [0,1]$ can be thought of as a scalar of distortion.

<u>Conditions D1</u>

$$R(0,t)\ [\tilde{p}^t + z\ (d^t - m^t) - \nabla_y\ C(y^t,\ \tilde{w}^t,\ s^{t-1},\ s^t)] = 0_I,$$

$$t = 1,\ \ldots,\ t'; \qquad \text{...(5.6a)}$$

$$-R(0,t)\ \nabla_{s^t} C(y^t,\ \tilde{w}^t,\ s^{t-1},\ s^t) -$$

$$R(0,t+1)\ \nabla_{s^t} C(y^{t+1},\ \tilde{w}^{t+1},\ s^t,\ s^{t+1}) + \mu^t z = 0,$$

$$t = 1,\ \ldots,\ t'-1; \qquad \text{...(5.6b)}$$

$$R(0,t')\ [\ -\nabla_{s^t} C(y^{t'},\ \tilde{w}^{t'},\ s^{t'-1},\ s^{t'}) + \tilde{Q}\ ] = 0_N. \qquad \text{...(5.6c)}$$

Consider the set of equations (5.6), when z = 0 Conditions D1 reduce to Conditions W1. When z = 1, the first-order Conditions R obtain. In general then, unless $(d^t - m^t) = 0_I$ and $\mu^t = 0_N$, Conditions W1 and Conditions M will differ. Regard equations (5.6) as a system of t' x (I + N) equations in $\{y^t\}$ and $\{s^t\}$ where $\tilde{p}^t$, $\tilde{w}^t$, $\tilde{Q}$, $(d^t - m^t)$ and μ^t are fixed: these are the exogenously determined "optimal" or reference prices and the vectors of distortions d, m and μ, assumed fixed for convenience . (A20) and the implicit function theorem guarantee that such functions exist.

Further assume that:

(A21) the reference price vector is:

$$(\tilde{p}, \tilde{w}, \tilde{Q}, \tilde{R}) \equiv (\overset{*}{p}, w, Q, R).$$

This means that the loss of output due to regulation is to be evaluated using the observed, distorted prices that prevail in the regulated equilibrium. Hence, the question being asked is: "how much more output, evaluated at the actual (observed) prices, can society get if the distortions affecting the regulated sector's decisions are removed?". Assumption (A21) is somewhat arbitrary. In fact, there is some arbitrariness in choosing <u>any</u> reference price vector $(\tilde{p}, \tilde{w}, \tilde{Q}, \tilde{R})$. In addition, doing away with (A21) would require that the "exogenously" determined reference prices be computed, a task which would require that a general equilibrium model be estimated. This chapter therefore aims at answering the more limited question above, as is done in Diewert (1981a) in a static context. This procedure is actually very similar to that suggested by Harberger (1971).[1]

The strategy developed by Diewert to derive loss formulae that approximate the difference in value between the two programs $[\{\overset{*}{y}^t\}, \{\overset{*}{s}^t\}]$ and $[\{\tilde{y}^t\}, \{\tilde{s}^t\}]$ is to express welfare as a function of z, which is done in (5.6), and to use a Taylor series approximation to the second-order around $z = 0$ to evaluate the change in welfare. Using (5.1),

$$W(z) = \Sigma_{t=1}^{t'} R(0,t) [p^t y(z) - C(y(z), w, s^{t-1}(z), s^t(z)] +$$

$$R(0,t') Q s^{t'}(z). \qquad ...(5.7)$$

A second-order approximation of the change in welfare is:

$$W(1) - W(0) \cong W'(0) (1-0) + (1/2) W''(0) (1-0)^2. \qquad ...(5.8)$$

This requires that $W'(0) = [\partial W(z)/\partial z]_{z=0}$ and $W''(0) = [\partial^2 W(z)/\partial z^2]_{z=0}$ be evaluated.

$$W'(0) = \Sigma_{t=1}^{t'} R(0,t) [\nabla_z y^t(0) (p^t - \nabla_y C(t)] +$$

$$\Sigma_{t=1}^{t'-1} \nabla_z s^t(0)[-R(0,t) \nabla_{s^t} C(t) - R(0,t+1) \nabla_{s^t} C(t+1)] +$$

$$\nabla_z s^{t'}(0) [-R(0,t') \nabla_{s^{t'}} C(t') + R(0,t') Q], \quad \text{...(5.9)}$$

where $C(t) \equiv C(y^t(z), w^t , s^{t-1}(z), s^t(z))$.

Thus, using Conditions D1 and evaluating at $z = 0$:

$$W'(0) = z \{ [\Sigma_{t=1}^{t'} R(0,t) m^t \nabla_z y^t(0)] -$$

$$[\Sigma_{t=1}^{t'-1} \mu^t \nabla_z^T s^t(0)] \} + 0 = 0. \quad \text{...(5.10)}$$

Differentiating again with respect to z, and evaluating at $z = 0$ gives:

$$W''(0) = \Sigma_{t=1}^{t'} [R(0,t) m^t \nabla_z^T y^t (0)] -$$

$$\Sigma_{t=1}^{t'-1} \mu^t \nabla_z^T s^t(0). \quad \text{...(5.11)}$$

Therefore,

$$W''(0) = [\ \bar{m}^{\,T},\ -\mu^T\ ] \begin{pmatrix} \nabla_z\, y(0) \\ \nabla_z\, s(0) \end{pmatrix}, \qquad \ldots(5.12)$$

where $\bar{m}^{\,T} = [R(0,1)\, m^{tT},\ \ldots,\ R(0,t')\, m^{t'T}]$ and

$$\bar{\mu}^{\,T} = [\mu^{1T}\ ,\ \ldots,\ \mu^{t'-1}\ ,\ 0_N^T\ ].$$

Finally, using (A19) and (A20), the derivatives of y(z) and s(z) with respect to z around z = 0 can be computed as:

$$\begin{pmatrix} \nabla_z\, y(0) \\ \nabla_z\, s(0) \end{pmatrix} = A^{-1} \begin{pmatrix} \bar{m} \\ -\bar{\mu} \end{pmatrix}. \qquad \ldots(5.13)$$

Using (5.10), (5.12) and (5.13), (5.8) can be written as:

$$\begin{aligned} -L_1 &= W(1) - W(0) \\ &\cong (0.5)\ W''(0) \\ &= (0.5)\ [\ \bar{m}^{\,T}\ ,\ -\bar{\mu}^{\,T}\ ]\ A^{-1}\ [\bar{m}^{\,T}\ ,\ -\mu^T\ ]^T < 0. \end{aligned} \qquad \ldots(5.14)$$

The inequality in (5.14) follows from the negative definiteness of A at z = 0 while L_1 is the (positive) deadweight loss due to imperfect regulation. Notice that the information needed to compute L_1 is quite limited: knowledge of the distortion vectors $\bar{m}$ and $\bar{\mu}$ and local knowledge of the Hessian matrix of the regulated sector's cost function with respect to $\{y^t\}$ and $\{s^t\}$ evaluated at $z = 0$. There is however one drawback in the computation of L_1: the matrix A^{-1} is defined at the unobserved "optimal" allocation of resources. Two possible ways of dealing with this difficulty are: (i) the use of a quadratic approximation to the cost function in applied work, such as the normalized restricted quadratic cost function (see Lau, 1976; and Denny et al., 1981b), which has the nice property that the Hessian of C(t) is a matrix of constants; or (ii) approximate A^{-1} by A^{*-1}, where the latter is the Hessian of C(t) evaluated at the observed (distorted) equilibrium.

The loss formula (5.14) can also be specialized to handle a number of specific situations. For instance, if the regulated producers are price-takers and constrained to supply any feasible quantity at the regulated price, their revenue (and outputs) become exogenous. The regulated producers' objective is then to maximize, under the regulatory constraint, their expected profit by choosing $\{s^t\}$. In this case, the matrix A refers to the Hessian of C(t) with respect to $\{s^t\}$, and the loss of output becomes:

$$-L_2 = (1/2)\ [\ -\bar{\mu}^T]\ A^{-1}[\ -\mu^T\ ] < 0. \qquad \ldots(5.15)$$

Similarly, if the regulated producers are constrained to earn exactly the competitive rate of return, $\bar{\mu}^t = 0_N$ and L_1 is made to depend only on $\bar{m}^t$. Inspection of L_1 and L_2 immediately reveals that the deadweight loss is zero if and only if all distortions vanish; that is, if: $\bar{m} = 0_{(t'x\ I)}$ and $\bar{\mu} = 0_{(t'x\ N)}$. If $(\bar{m}^T, \bar{\mu}^T, 0^T_{(t'x\ N)}) > 0^T_{(t'x\ (I+2N))}$, where $a > 0$ implies $a_i \geq 0$ but $a_i \neq 0$ for all i, then the deadweight loss approximations are always stricly positive. One may conjecture that the loss formulae generally increase with the size of the distortions. It is possible to demonstrate that this is unambiguously the case if (i) only one distortion exists or, (ii) if all distortions are scaled up. Those two cases are examined and discussed further below.

Suppose there is a unique distortion, say $\bar{m}^t_i > 0$ whereas $\bar{m}^\Theta_j = 0$, for all other Θ and j, and $\bar{\mu} = 0^T_{(t'x\ N)}$. Then, L_1 reduces to:

$$L_1' = (-0.5)\ (0, \ldots, 0, \bar{m}^t_i, 0, \ldots, 0)$$

$$A^{-1}(0, \ldots, 0, \bar{m}^t_i, 0, \ldots, 0) > 0. \qquad \ldots(5.16)$$

Differentiating the quadratic function L_1' with respect to $\bar{m}^t_i$ gives:

$dL_1^1/d\bar{m}_1^t = -(0, \ldots, 0, 1, 0, \ldots, 0)$

$$A^{-1}\ (0, \ldots, 0, \bar{m}_1^t, 0, \ldots, 0) > 0. \qquad \ldots(5.17)$$

A analogous result naturally holds for $(dL_1^1/d\bar{\mu}_n^t)$, and similarly for L_2 with appropriate modifications. This shows that, in the extreme case of a unique distortion, welfare is inversely related to the magnitude of $\bar{m}_1^t$ or $\bar{\mu}_n^t$.

Consider now the change in welfare that would result from scaling up or down all distortions. Let k be a positive scalar, then it is easily shown that the deadweight loss approximations are multiplied by the square of this scalar. Formally, the loss formulae are homogeneous functions of degree two in the distortions.

This can easily be verified:

$$L\ (k\bar{m}^T, k(-\bar{\mu}^T), k(0^T_{(t'x\ N)}))$$

$$= (1/2)\ (k\bar{m}^T, -k\bar{\mu}^T, 0^T_{(t'x\ N)})$$

$$A^{-1}\ (k\bar{m}^T, -k\bar{\mu}^T, 0^T_{(t'x\ N)})^T$$

$$= (1/2)\ k^2\ (\bar{m}^T, -\bar{\mu}^T, 0^T_{(t' \times N)})\ A^{-1}\ (\bar{m}^T, -\bar{\mu}^T, 0^T_{(t' \times N)})$$

$$= k^2\ L_1\ (\bar{m}^T, -\bar{\mu}^T, 0^T_{(t' \times N)}). \qquad \ldots(5.18)$$

Those two last results are proved in Diewert (1981a) for the static measure of loss along with some other propositions. Since the structure of matrix A is similar to the corresponding matrix in Diewert (1981a), most of the propositions proved in the latter hold in this context as well.

Since it has long been known that "removing" only one distortion from a non-optimal state of the economy may not increase welfare (this is the typical second-best result), the previous properties of the loss formulae should not come as a surprise.

5.2 TENTATIVE RESULTS ABOUT THE DEADWEIGHT LOSS DUE TO INEFFICIENT REGULATION

The computation of the deadweight loss formulae L_1 and L_2 requires that the following quantities be estimated: (i) the vectors of deviations from optimal prices, and (ii) the inverse of matrix A, whose elements are the Hessian of the cost function evaluated at each period with respect to output and capital. This inverse should in principle be evaluated at the social welfare optimum but the strategy taken in this chapter consists in using the Hessian at the distorted equilibrium as an approximation to calculate the "true" A^{-1}.

This dissertation has produced information on the vectors of distortions and the Hessian matrix of Bell's cost function. However, there remains one major difficulty: the matrix A^{-1} must be negative definite. In the particular case of Bell Canada, the cost function is <u>not</u> convex in capital and output, whether the Hessian of the cost function is estimated using either the exogenous or the endogenous output model. Even if economies of scale are compatible with negative definiteness of the matrix A^{-1}, the very large scale economies estimated in 4.1 and 4.2 result in the marginal cost function for toll output declining almost everywhere;

this makes the cost function definitely non convex and A^{-1} resolutely non negative definite.

Maybe another approximation of A^{-1} could be used. Alternatively, an estimate of the welfare loss due to inefficient capital accumulation alone can be computed since the firm's objective function is concave in the capital stock. This approximation to the deadweight loss is but a fraction of the total loss of output since it does not capture the losses due to inefficient output production. But it can serve to assess the losses implied by overcapitalization.

This last alternative is selected and the deadweight loss due to inefficient capital accumulation is computed using equation (5.15). The matrix A is estimated using the results of the model with exogenous outputs. The present value of the stream of foregone output evaluated at the actual prices is computed and the (present value of the) average yearly loss is divided into the average value of (actualized) variable costs to convey a better idea of the magnitude of the losses. The results are reported in Table 5.1. Even though the regulatory parameter is not statistically significant when v_1 is used, the losses are computed for the two versions of the model. Moreover, since the variability in the excess return variables is quite high, the losses are computed for four different time periods: 1953-60, 1961-66, 1967-72 and 1973-79[2].

There are three salient features of the numbers in Table 5.1. First, the estimated losses are extremely sensitive to the choice of the user cost of capital variable. It is easy to see why: the parameter estimates of the capital-related coefficients and the excess return variables are very sensitive to the specification of the user cost variable as is evident from Tables 4.1 and 3.4. Second, the estimated losses are virtually nil when v_1 is used. Remember that the estimated Lagrange multiplier is not significant under this specification. The v_1-specification, although performing somewhat less well than the v_2-specification, does seem to indicate that rate of return regulation has very little impact on the investment decisions of the firm and that losses, if any, are negligible. This result may depend on the assumption that β is a constant. Third, the estimated losses under the v_2-specification are rather small but are not negligible. The losses represented nearly four percent of total cost in the early sixties. The losses practically vanish at the end of the period as the excess return on capital tends towards zero (see Table 3.4).

But the preceding table should he handled with care! The reasons are simply the sensitivity of the results to the

TABLE 5.1

ESTIMATES OF THE DEADWEIGHT LOSS DUE TO INEFFICIENT CAPITAL ACCUMULATION

Percentage of average yearly variable costs represented by the losses:

	v_1		
1953-60	1961-66	1967-72	1973-79
0.15	0.06	0.09	0.05

	v_2		
1953-60	1961-66	1967-72	1973-79
1.35	3.72	1.18	0.04

choice of a particular user cost variable, and the intrinsic limitations of the loss formula estimated: the figures in the last table take into account only the losses due to "overcapitalization". The loss in efficiency arising from the $\bar{m}$ - distortions are completely ignored.

5.3 A TWO-SECTOR DYNAMIC DEADWEIGHT LOSS MEASURE DUE TO REGULATION

Finally, for completeness another approach is developed here to deal with some of the conceptual problems involved in single-sector measures of deadweight loss. The very capital intensive nature of regulated monopolies suggest that if overcapitalization does in fact occur, it will entail a reduction in the stock of capital available for other uses. In a dynamic context, the endogeneity of the capital formation process is of crucial importance. But the impact of regulation on that process is not fully captured by the loss measure L_1. In this section, a "competitive sector" is brought into the analysis and linked to the regulated sector in the following way: each sector produces an intermediate input that the other sector uses. The planner's problem consists in maximizing the net present value of the economy's production. The derived measure of the loss of output approximates the difference, in value, between two plans for the (two-sector) economy: given a vector of reference producer prices, the net discounted value of outputs for the two sectors is maximized and compared to the net (discounted) value of outputs generated in the imperfectly regulated economy.

The model of capital accumulation that was used in Chapter 2 is again utilized to describe the technology and behavior of the competitive producers. The production possibilities open to these producers are described by one-period technology sets $\{S_t^c\}$. Each element of these sets is an (J + I + 2N) tuple $\{x, y, \hat{s}^0, \hat{s}^1\}$, where x_j (j = 1, ..., J) are inputs (if negative) or outputs (if positive) used or produced by the competitive producers, y is a vector of inputs produced by the regulated sector, and $\hat{s}^0$ and $\hat{s}^1$ are the beginning-and-end-period N-dimensional stock vectors. The prices corresponding to the x-vector are $w^t = (w_1^t, \ldots, w_J^t) \gg 0_J$ and assumed competitively determined and exogenous to the producers. Those x_i's are the same that are (possibly) used by the regulated sector's producers which are also assumed to be price-takers with respect to them.

Assume the planner allocates to the competitive producers a given set of quasi-fixed inputs $(y^t, \hat{s}^t)$ at the beginning of each period and that those producers aim (or are instructed) to maximize the current value of gross profits, w x , <u>given</u> the level of the quasi-fixed stocks. As a result, a one-period restricted profit function $\pi(w^t; y^t; \hat{s}^{t-1}, \hat{s}^t)$ can be defined, similar to that in Diewert and Lewis (1982). Now assume the competitive producers are the net suppliers of the capital goods to the rest of the economy, hence to the regulated sector. Let $\hat{s}^t \equiv (\bar{s}^t - s^t) \equiv$ (total stocks in the economy - stocks allocated to the regulated sector) $\equiv$ competitive sector's stocks. This means that the competitive sector produces all the investment goods in the economy and transfers some of them to the regulated sector.

The planner's problem consists in selecting $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$ and $\{\tilde{\bar{s}}^t\}$ (the time path of outputs produced and stocks used in the two sectors) in order to maximize the discounted net value of outputs using the reference prices $\{\tilde{p}^t = p^t\}$, $\{\tilde{w}^t = w^t\}$, $\{\tilde{R} = R\}$ and $\tilde{Q} = Q$.

Let $C(t) \equiv C(y^t, \tilde{w}^t, s^{t-1}, s^t)$ and $\pi(t) \equiv \pi(\tilde{w}^t; y^t, \hat{s}^{t-1}, \hat{s}^t) \equiv \pi(\tilde{w}^t; y^t, \bar{s}^{t-1} - s^{t-1}, \bar{s}^t - s^t)$.

The social valuation function to be maximized is:

$$\max_{\{y^t\}, \{s^t\}, \{\bar{s}^t\}} \quad \Sigma_{t=1}^{t'} R(0,t) [\pi(t) - C(t)] + R(0,t')\, \bar{s}^{t'} Q. \qquad ...(5.19)$$

$y^t \geq 0_I$

$s^t \geq 0_N$

$\bar{s}^t \geq 0_N$

Using the differentiability of C(t) and π(t), the necessary conditions (5.20) obtain:

Conditions W2

$$R(0,t)\ [\ \nabla_Y \pi(t) - \nabla_Y C(t)\ ] = 0_I, \quad t = 1, \ldots, t'; \qquad \ldots(5.20a)$$

$$R(0,t)\ [-\nabla_{s^t} C(t) - \nabla_{\bar{s}^t} \pi(t)\ ]$$

$$+ R(0,t+1)\ [-\nabla_{s^t} C(t+1) - \nabla_{\bar{s}^t} \pi(t+1)\ ] = 0_N\ ,$$

$$t = 1, \ldots, t'-1; \qquad \ldots(5.20b)$$

$$R(0,t')\ [-\nabla_{s^{t'}} C(t') - \nabla_{\bar{s}^{t'}} \pi(t')\ ] = 0_N\ ; \qquad \ldots(5.20c)$$

$$R(0,t)\ [\ \nabla_{\bar{s}^t} \pi(t)\ ] + R(0,t+1)\ [\ \nabla_{\bar{s}^t} \pi(t+1)\ ] = 0_N,$$

$$t = 1, \ldots, t'-1; \qquad \ldots(5.20d)$$

$$R(0,t')\ [\ \nabla_{\bar{s}^{t'}} \pi(t') + Q\ ] = 0_N. \qquad \ldots(5.20e)$$

These Conditions W2, which are $t' \times (I + 2N)$ in number in the $[t' \times (J + 1) + 3N]$ exogenous variables $\{\tilde{w}^t\}$, $\{R(0,t)\}$, s^0, $\bar{s}^0$ and Q, state that the value of the marginal product of each quasi-fixed factor of production must be the same in both sectors. Also assume that:

(A22) the (strong) second-order sufficient conditions for an unconstrained (interior) maximum of (5.16) hold at $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$. $\{\tilde{\bar{s}}^t\}$.

This implies, as in 5.1, that the matrix of derivatives of (5.20) with respect to the choice variables evaluated at the socially optimal allocation is negative definite. Let this matrix be M. It can be verified that M is a symmetric, $t' \times (I + 2N)$ by $t' \times (I + 2N)$ matrix which has the Hessian matrices of C(t) and $\pi(t)$ with respect to $\{\tilde{y}^t\}$, $\{\tilde{s}^t\}$, and $\{\tilde{\bar{s}}^t\}$ as elements.

In a context in which the competitive producers pay for the regulated outputs at prices $\overset{*}{p} > \tilde{p}$ and the regulated producers use the distorted-by-regulation user cost of capital, the implicit shadow prices of these inputs should diverge from their social cost by $m = \overset{*}{p} - \nabla_y\pi$ and μ. Hence the same strategy as that pursued in 5.1 can be utilized to generate a z-equilibrium and Conditions D2. Again, when z=0 a social optimum obtains in which the shadow prices of all intermediate inputs are equalized everywhere. On the other hand, when z=1, a distorted system obtains.

Conditions D2

$$R(0,t)\ [\ \nabla_Y \pi(t) - m^t z - \nabla_Y C(t)\ ] = 0_I\ ,$$

$t = 1, \ldots, t'$; ...(5.21a)

$$R(0,t)\ [-\nabla_{s^t} C(t) - \nabla_{\bar{s}^t} \pi(t)\ ]$$

$$+\ R(0,t+1)\ [-\nabla_{s^t} C(t+1) - \nabla_{\bar{s}^t} \pi(t+1)] + \mu^t z = 0_N\ ,$$

$t = 1, \ldots, t'-1$; ...(5.21b)

$R(0,t')\ [\ \nabla_{s^{t'}} C(t') + \nabla_{\bar{s}^{t'}} \pi(t')\ ] = 0_N$; ...(5.21c)

$$R(0,t)\ [\ \nabla_{\bar{s}^t} \pi(t)\ ] + R(0,t+1)\ [\ \nabla_{\bar{s}^t} \pi(t+1)\ ] = 0_N\ ;$$

$t = 1, \ldots, t'-1$; ...(5.21d)

$$R(0,t') \; [\; \nabla_{\bar{s}^{t'}} \pi(t') + \tilde{Q} \;] = 0_N \; . \qquad \ldots(5.21e)$$

As before, the negative definiteness of M (see (A22)) guarantees that the $[\{y^t\}, \{s^t\}, \{\bar{s}^t\}]$-solution to (5.21) can be expressed as functions of the exogenous variables $\{\tilde{w}^t\}$, $\{R(0,t)\}$, $\{m^t\}$, $\{\mu^t\}$, $\tilde{Q}$ and z around z = 0. Using the implicit function theorem, the gradient of $\{y^t(z)\}$, $\{s^t(z)\}$ and $\{\bar{s}^t(z)\}$ with respect to z at z = 0 can be computed as:

$$\begin{pmatrix} \nabla_z \; y(0) \\ \nabla_z \; s(0) \\ \nabla_z \; \bar{s}(0) \end{pmatrix} = (\bar{m}^{\,T}, -\mu^T \,, 0^T_{(t'xN)}) \; M^{-1} \qquad \ldots(5.22)$$

Defining welfare as a function of the scalar z and taking the first and second derivatives of W(z) with respect to z at z=0 gives:

$$W'(0) = z \; [\Sigma_{t=1}^{t'} \nabla_z^T \; y^t(0) \; \bar{m}^{\,t} + \Sigma_{t=1}^{t'} \nabla_z^T \; s^t(0) \; \bar{\mu}^{\,t}$$

$$+ \Sigma_{t=1}^{t'} \nabla_z^T \; \bar{s}^{\,t}(0_N) \;] = 0 \; , \qquad \ldots(5.23)$$

and

$$W''(0) = [\ \Sigma_{t=1}^{t'} \nabla_z^T y^t(0)\ \bar{m}^{\ t} - \Sigma_{t=1}^{t'} \nabla_z^T s^t(0)\ \bar{\mu}^{\ t}]$$

$$= [\nabla_z^T y(0),\ \nabla_z^T s(0),\ \nabla_z^T \bar{s}(0)]\ [\bar{m}^{\ T},\ -\bar{\mu}^{\ T},\ 0^T_{(t' x\ N)}]^T \qquad \ldots(5.24)$$

Using (5.22), the approximate change in welfare can be shown to be equal to:

$$W(1) - W(0) = W'(0) + 0.5\ W''(0)$$
$$= (0.5)\ [\bar{m}^T,\ \bar{\mu}^T,\ 0^T_{(t'xN)}]\ M^{-1}\ [\bar{m}^T,\ \bar{\mu}^T,\ 0^T_{(t'xN)}] \qquad \ldots(5.25)$$

The deadweight loss approximation (5.25) has two interesting features: (i) it takes into account the impact on the unregulated sector of the economy of the monopolistic character of the pricing decisions in the regulated sector as well as the effect of overcapitalization on other production; (ii) since each element of M is made up of elements of the Hessians of $\pi(t)$ and $C(t)$, even if $C(t)$ is not positive definite in y and s, M can still be negative definite. For instance, in the case of a single regulated output, it can easily be verified that the first element of M is equal to the sum of $[\ \partial^2\pi / \partial y^2\ ]$ and $[-\partial^2 C/\partial y^2]$. Thus even if the short-run marginal cost function of producing y is flat or slightly decreasing, which would make the matrix A entering L_1 non negative definite, the value of the marginal product of y in the competitive sector may decline fast enough so that matrix M will still be well behaved and assumption (A22) maintained. The range of technologies over which the loss formula (5.25) is well defined is thus larger than that for the measures of loss derived in 5.1.

NOTES TO CHAPTER 5

1. Notice that, were $\tilde{p}$ given, all the developments that follow would still be correct. All that would be required is setting $d^t \neq 0_I$.

2. The small negative values in the e_i series are set equal to zero in the computation of the losses.

CHAPTER 6

CONCLUSION

This thesis has introduced a number of dynamic elements into the theoretical and empirical analysis of the behavior of a monopolist facing rate of return regulation. Expectations, adjustments costs, an intertemporal regulatory constraint and lagged price adjustments have been the focus of the analysis. The accomplishments and limitations of the research can be most easily reviewed under two sets of observations: the first deals with the theoretical developments and the second deals with the empirical models and the results presented in Chapters 3 and 4.

6.1 The aim of the theoretical part of this thesis has been (i) the development of a dynamic model of a rate-regulated firm, and (ii) the derivation of loss formulae that allow the computation of the deadweight loss due to inefficient regulation.

Although one can find many models for a rate-regulated utility in the literature, very few are cast in a dynamic framework. The model presented in this thesis is a very general model of capital accumulation under an intertemporal profit constraint. This model is then used to generate propositions about the behavior of the utility. Some of these propositions can be found elsewhere in the literature but they are derived in contexts that differ on one or many points from that in this dissertation. Chapter 2 can in fact be regarded as the basis upon which the empirical analysis of Chapters 3 and 4 and the theoretical work of Chapter 5 are built.

The major accomplishments of this thesis on the theoretical front are (i) the derivation of an A.-J. effect in a very general intertemporal framework and, (ii) the results of the last chapter where approximations to a dynamic deadweight loss are worked out. Those extend the work of Diewert (1981a) into a dynamic environment.

However, the theoretical work in this thesis suffers many shortcomings. Among them are the partial equilibrium nature of the loss formulae, which ignore consumers' losses. The approximations of Chapter 5 could possibly be modified in future research by building up a consumer side. Equally important would be the development of formulae for the computation of deadweight loss in cases where the utility's technology exhibits serious non convexities (as is the case with Bell Canada). Another limitation of the analysis in

Chapter 5 is the reliance on exogenously determined reference prices. The producer side of the economy could also be developed to encompass all production units. This would require that clearing conditions in intermediate input markets be taken into consideration, and would give the analysis a more general-equilibrium flavour. In short, there is much work to be done in the literature on the measurement of waste in a regulated environment where output and input prices are distorted by market or regulatory failures.

6.2 Turning to the empirical work now, the most important accomplishment here is found in the specification of a model of producer behavior incorporating both the impact of regulation and dynamic elements such as adjustment costs, rational expectations and lags in the adjustment of the price level. When work on the empirical section of this thesis began, no papers existed that incorporated adjustment costs in the empirical analysis of a rate-regulated utility. Since then, the papers by Bernstein (1986, 1987) introduced them in the analysis of telecommunications in Canada. But the insertion of these costs in a model of a regulated utility is a novelty, as is the effort made to determine the sensitivity of the conclusions concerning overcapitalization to the choice of different user cost variables.

It is useful at this point to sum up the major conclusions of the estimation. In the first place, this dissertation makes it quite clear that dynamic elements play a crucial role in the capital accumulation decisions of Bell. In particular, remember that adjustment costs play a significant role in all estimated models, be it with exogenous or endogenous outputs and regardless of the user cost of capital specification. Consequently, previous models of Bell's behavior that postulate a long-run equilibrium may lead to erroneous conclusions, and particularly so when these concern the effect regulation has on the investment decisions of Bell.

In addition, the estimation results indicate that the Averch-Johnson hypothesis cannot be rejected in the case of Bell since at least in two out of four estimated models the regulatory parameter appears significant, has the proper sign and falls within the theoretical range defined in Chapter 2.

Moreover, the statistical results suggest that the user cost of capital specification has an impact on the conclusions reached about the A.-J. effect. Which specification, and conclusion, is the more appropriate is not definitely established. However, the estimated models under the v_2-specification seem in general to outperform the v_1-

specification: the DCF method may do a better job at tracking Bell's cost of capital than the CAPM model. In this case, the A.-J. effect would seem to be a supported hypothesis.

The results presented in Chapter 4 suggest that neglecting both adjustment costs (and expectations) and regulation leaves out two significant influences on the utility's investment decisions, but two influences that work in opposite directions. This latter follows because the presence of convex costs of adjustment slows down the rate at which a firm builds up its capital stock, whereas tying the firm's profitability to its capital stock induces it to "overcapitalize". It is therefore difficult to determine if previous studies biased the marginal cost of capital to the utility upwards or downwards, since most ignored both of these effects.

The lagged price responses introduced here are novel in the literature on econometric models of the regulated utility. The estimates from the endogenous output models, despite their theoretical shortcomings, do indicate that the hypothesis of instantaneous price adjustments must be rejected, and they stress the importance of dynamic regulatory features that have been left out of empirical analyses to date (although theoretical work on the subject can be found in Klevorick 1973, 1974; more on this point later).

Finally, the estimated models have allowed the computation of the welfare losses imputable to inefficient capital accumulation. Those losses are small but not negligible. It would be desirable to obtain the information about the competitive sector's technology that is necessary to implement the more general loss formulae of Chapter 5. But notwithstanding its obvious limitations, the effort undertaken in 5.2 is a novel attempt to use second-order approximations actually to estimate the deadweight loss due to rate of return regulation. Further attempts are critically needed if a practical appraisal of the magnitude of the costs of regulation is ever to be obtained. The tentative results of Chapter 5 offer not only indications as to the size of the losses involved but point out some computational problems that hinder their estimation.

There are a number of weaknesses where immediate improvements are possible. The modeling of technological change is one case in point. It is possible that the chosen specification for technological change is responsible for the (few) failures in the elasticity of costs with respect to local output. It would also be interesting to determine just how sensitive the estimation is to the specification of technological change and to the choice of a particular proxy.

Another possible extension that is suggested by the empirical results would be to endogenize the "stickiness" of prices by developing a choice model for a regulated monopolist with costs of adjustment defined over price changes. These costs are certainly not negligible in the case of a regulated enterprise, which needs to justify its "required price increases" at rate hearings. Or a model could be formulated in which prices could be adjusted only at specified intervals, or in which marginal costs are perceived only with a lag. At any rate, a sounder theoretical basis to the model of lagged price adjustments estimated in Chapter 4 is desirable. This is one direction future research could fruitfully look into. Finally, it should be noted that the conclusions concerning the importance of adjustment costs are arrived at under the maintained hypothesis of rational expectations on the part of the utility. Even though this seems a very reasonable hypothesis, any test concerning the adjustment cost parameter is in fact a test of the joint hypothesis of adjustment costs and rational expectations. Other expectations formation processes may therefore lead to different conclusions.

6.3 A better understanding of the behavior of regulated monopolists, of the impact of rate-regulation on utilities' decision-making processes, and of the importance of the costs imposed on society by regulatory institutions, is the ultimate objective of this thesis. The progress made on each of these issues here has just been reviewed. If there is no doubt that totally satisfying answers to these questions are still missing, it is hoped that the findings of this thesis have helped to pave the way towards the desired end.

BIBLIOGRAPHY

Allais, M. (1973). "La Théorie Générale des Surplus et l'Apport Fondamental de Vilfredo Pareto." Revue d'Economie Politique, 83:1044-1097.

Auerbach, A.J. (1982). "The theory of Excess Burden and Optimal Taxation." in: Hanbook of Public Economics

Averch, H., and L.L. Johnson (1962). "Behavior of the Firm under Regulatory Constraint." Americain Economic Review, 52(december):1052-1069.

Bailey, E.E. (1973). Economic Theory of Regulatory Constraint, Mass.:D.C.Heath.

Baumol, W.J. (1977). "On the Proper Cost Tests for Natural Monopoly in a Multiproduct Industry." American Economic Review, 67(december):809-822.

Baumol, W.J. and A.K. Klevorick (1970). "Input Choices and Rate-of-Return Regulation: an Overview of the Discussion." Bell Journal of Economics and Management Science, 1(2):162-190 (autumn).

Bawa, V.S. and D.S. Sibley (1980). "Dynamic Behavior of a Firm Subject to Regulatory Review." International Economic Review, 21(3):627-642.

Berndt, E. and B.C. Field (eds.)(1981). Modeling and Measuring Natural Resource Substitution, The MIT Press.

Berndt, E., C.J. Morrison and G.C. Watkins (1981). "Dynamic Models of Energy Demand: an Assessment and Comparison." in: Berndt, E. and B.C. Field (eds)(1981), op. cit..

Bernstein, J.I. (1980). "A Corporate Econometric Model of the British Columbia Telephone Company." in: Anderson, O. (ed.)(1980). Public Utilities, North-Holland.

Bernstein, J.L. (1986). "Dynamic Factor Demands and Adjustment Costs: An Analysis of Bell Canada's Technology." Department of Economics, Carleton University.

Bernstein, J.I. (1987). "An Examination of the Equilibrium Specification and Structure of Production for Canadian Telecommunications." Departement of Economics, Carleton University and The National Bureau of Economic Research.

Blackorby, C., D. Primont, and R.Russell (1978). Duality, Separability, and Funcional Structure: Theory and Economic Applications, North-Holland.

Boadway, R.W. and N. Bruce (1979). "Depreciation and Interest Deductions and the Effect of the Corporate Income Tax on Investment." Journal of Public Economics, 11:93-105.

Boiteux, M. (1951). "Le Revenu Distribuable et les Pertes économiques." Econometrica, 19:112-133.

Boyes, W.J. (1976). "An Empirical Examination of the Averch-Johnson Effect." Economic Inquiry, 14 (march)

Braeutigam, R.R. and J.P. Quirk (1984). "Demand Uncertainty and the Regulated Firm." International Economic Review, 25(1):45-60.

Brechling, F. (1975). Investment and Employment Decisions, Manchester, England.

Brennan, M.J. and W.B. Schwartz (1982). "Consistent Regulatory Policy under Uncertainty." Bell Journal of Economics, 13:506-24.

Breslaw, J. and J.B. Smith (1983). "Des observations empiriques encourageantes pour la théorie dualiste." L'Actualite Economique, 59(2):230-239.

Breslaw, J. and J.B. Smith (1982). "The Restrictiveness of Flexible Functional Forms and the Measurement of Regulatory Constraint". Land Economics, 26(1):73-76.

Breslaw, J. and J.B. Smith (1982b). " Efficiency, Equity and Regulation: an Optimal Pricing Model of Bell Canada." Canadian Journal of Economics, 15(4):634-648 (november).

Burness, H.S., W.D. Montgomery and J.P. Quirk (1980)."Capital Contracting and the Regulated Firm." American Economic Review, 70(3):342-354.

Callen, J., G.F. Mathewson, and H. Mohring (1976). "The Benefits and Costs of Rate of Return Regulation." American Economic Review, 66(3):290-297 (june).

Caves, D.W., L.R. Christensen and J.A. Swanson (1981). "Productivity Growth, Scale Economies and Capacity Utilization in U.S. Railroads, 1955-74." American Economic Review: 993-1002.

Courville, L. (1974). "Regulation and Efficiency in the Electric Utility Industry." Bell Journal, 5(spring):53-74.

Courville, L. and M.G. Dagenais (1977). "On New Approaches to the Regulation of Bell Canada." Canadian Public Policy, 3(1):76-89.

Courville, L., A. de Fontenay and R. Dobell (1983). Economic Analysis of Telecommunications, Theory and Applications, North-Holland.

Cowing, T.G. (1978). "The Effectiveness of Rate of Return Regulation:An Empirical Test Using Profit Functions." in: M.A. Fuss and D.L.McFadden, eds., Production Economics:A Dual Approach to Theory and Applications, Amsterdam, North-Holland.

Christensen, L.R. and D.W. Jorgenson (1969). "The Measurement of U.S. Real Capital Input, 1929-1967." Review of Income and Wealth, (Dec.):293-320.

Das, S.P. (1980). "On the Effect of Rate-of-Return Regulation under Uncertainty." American Economic Review, 70(june):456-460.

Debreu, G. (1951). "The Coefficient of Resource utilization." Econometrica, 19:273-292.

Dechert, W.D. (1984). "Has the Averch-Johnson Effect Been Theoretically Justified?" Journal of Economic Dynamics and Control, 8:1-17.

Denny, M. M. Fuss, and C. Everson, L. Waverman (1981a)."Estimating the Effects of Technological Innovations in Telecommunications: The Production Structure of Bell Canada." Canadian Journal of Economics, 15(1).

Denny, M., M. Fuss and L. Waverman (1981b). "Substitution Possibilities for Energy: Evidence from the U.S. and Canadian Manufacturing Industries." in: E.R. Berndt and B.C. Field (eds.) Modeling and Measuring Natural Resource Substitution.

Demsetz, H. (1969). "Information and Efficiency: Another ViewPoint." Journal of Law and Economics, 12.

Diewert, W.E. (1977). "Walras' Theory of Capital Formation and the Existence of a Temporary Equilibrium." in: E. Schwodiauer, ed., Equilibrium and Disequilibrium in Economic Theory, Dordrecht, Holland.

Diewert, W.E. (1981a). The Welfare Effects of a Regulatory Constraint: A Production Efficiency Approach. Discussion Paper no.81-17(january), Department of Economics, University of British Columbia.

Diewert, W.E. (1981b). "On Measuring the Loss of Output Due to Nonneutral Business Taxation." in: Depreciation, Inflation and the Taxation of Income from Capital, C.R. Hulten (ed.), Washington, D.C.: The Urban Institute Press.

Diewert, W.E. (1981c). A Dynamic Approach to Measuring the Loss of Output Induced by Trade Restrictions. Discussion Paper no.81-39 (march), Department of Economics, University of British Columbia.

Diewert, W.E. (1981d). The Measurement of Deadweight Loss in an Open Economy. Discussion Paper no.81-40 (december), Department of Economics, University of British Columbia.

Diewert, W.E.(1981e). "The Measurement of Deadweight Loss Revisited." Econometrica, 49(5) (september):1225-1244.

Diewert, W.E.(1982). "Duality Approaches to Microeconomic Theory." in: K.J. Arrow and M.D. Intriligator (eds.) (1982), Handbook of Mathematical Economics, vol.II, North Holland .

Diewert, W.E.(1983). "The Measurement of Waste Within the Production Sector of an Open Economy." Scandinavian Journal of Economics 85: 159-79.

Diewert, W.E. (1985a). Efficiency Improving Incentive Schemes for Regulated Industries, Discussion Paper no.85-34 (november), Department of Economics, University of British Columbia.

Diewert, W.E. (1985b). "A Dynamic Approach to the Measurement of Waste in an Open Economy." Journal of International Economics, 19: 213-40.

Diewert, W.E. and T.R. Lewis (1982). "The Comparative Dynamics of Efficient Programs of Capital Accumulation and Resource Depletion." in: Economic Theory of Natural Resources, W. Eichhorn, R. Henn, K. Neumann and R.W. Shephard, (eds.), Vienna: Physica-Verlag.

Dorfman, R., P.A. Samuelson and R.M. Solow (1958). Linear Programming and Economic Analysis, McGraw-Hill, New York.

El-Hodiri, M. and A. Takayama (1981). "Dynamic Behavior of the Firm with Adjustment Costs under Regulatory Constraint." Journal of Economic Dynamics and Control, 3(1):29-41.

Färe, R. and J.Logan (1983). "The Rate-of-Return Regulated Firm: Cost and Production Duality." Bell Journal of Economics, 14(2):405-410 (autumn).

Fromm, G. (ed.)(1977). Studies in Public Regulation, Cambridge: The MIT Press.

Fuss, M.A. and L. Waverman (1977a). Multi-Product, Multi-Input Cost Functions for a Regulated Utility: The case of Telecommunication in Canada. Technical Working Paper no.7810, Institute for Policy Analysis.

Fuss, M.A. and L. Waverman (1977b). "Regulation and the Multiproduct Firm: the case of Telecommunications in Canada." in: Fromm, G. (ed), Studies in Public Regulation, The MIT Press.

Fuss, M.A. and L. Waverman (1981). The Regulation of Telecommunication in Canada. Technical Report no.7, Economic Council of Canada.

Gollop, F.M. and Karlson, S.H. (1980). "The Electric Power Industry: an Econometric Model of Intertemporal Behavior." Land Economics, 56(3):299-314.

Gould, J.P. (1968). "Adjustment Costs in the Theory of Investment of the Firm." Review of Economic Studies, (january):44-55.

Green, C. (1980). Canadian Industrial Organization and Policy, McGraw-Hill Ryerson.

Gordon, M.J. (1977). "Comparison of Historical Cost and General Price Level Adjusted Cost Rate Base Regulation." Journal of Finance, (december) 32(5), pp.1501-12.

Hansen, L.P. and K. Singleton (1982). "Generalized Instrumental Variables Estimation of Nonlinear Rational Expectations Models." Econometrica, 50(Sept.): 1269-86.

Harberger, A. (1964). "The Measurement of Waste." American Economic Review, 54(May):58-76.

Harberger, A. (1971). "Three Basic Postulates for Applied Welfare Economics." Journal of Economic Literature 9(september):785-97.

Harris, R.G. and D.Cox (1983). Trade, Industrial Policy, and Canadian Manufacturing, Ontario Economic Council Research Study, Toronto.

Harvey, A.C. (1981a). The Econometric Analysis of Time Series, Philip Allan Pub.

Harvey, A.C. (1981b). Time Series Models, John Wiley and Sons.

Hayashi, P.M. and J.M. Trapani (1976). "Rate of Return Regulation and the Regulated Firm's Choice of Capital-Labor Ratio: Further Empirical Evidence on the Averch-Johnson Model." Southern Economic Journal, 42(3):384-98.

Hicks, J.R. (1941-42). "Consumers' Surplus and Index Numbers." Review of Economic Studies 9:126-137.

Hicks, J.R. (1939). Value and Capital, Oxford: Clarendon Press.

Hotelling, H. (1938). "The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates." Econometrica, 6:242-269.

Joskow, P.L. (1972). "The Determination of the Allowed Rate of Return in a Formal Regulatory Proceeding." Bell Journal of Economics and Management Science, 3(spring):632-644.

Joskow, P.L. (1973). "Pricing Decisions of Regulated Firms: A Behavioral Approach." Bell Journal of Economics and Management Science, 4(spring):118-140.

Joskow, P.L. (1974). "Inflation and Environmental Concern:Structural Change in the Process of Public Utility Price Regulation." Journal of Law and Economics, 17(october):291-328.

Joskow, P.L. and R.G. Noll (1981). "Regulation in Theory and Practice." in: G.Fromm,ed., Studies in Public Regulation, Cambridge, Mass.:M.I.T. Press.

Kahn, A.E. (1970). The Economics of Regulation, Vol.1:Principles, N.Y.: John Wiley.

Kahn, A.E. (1971). The Economics of Regulation, Vol.2:Institutional Issues, N.Y.:John Wiley.

Kiss, F., S. Karabadjian, and B. Lefebvre (1981). "Economies of Scale and Scope in Bell Canada: Some Econometric Evidence." in: Courville, L., A. de Fontenay, and R. Dobell (1983): Economic Analysis of Telecommunications, Theory and applications, North-Holland.

Klevorick, A.K. (1971). "The Optimal Fair Rate of Return." Bell Journal of Economics and Management Science, 2:122-153.

Klevorick, A.K. (1973). "The Behavior of Firm Subject to Stochastic Regulatory Review." Bell Journal, 4(spring):57-88.

Klevorick, A.K. (1974). "The behavior of a Firm Subject to Stochastic Regulatory Review: Correction." Bell Journal of Economics and Management Science, 5(autunm):713-714.

Kolbe, A.L. and J.A. Read Jr., with G.R.Hall (1984). The Cost of Capital: Estimating the Rate of Return for Public Utilities, MIT Press.

Lau, L.J. and P.A. Yotopoulos (1972). "Profit, Supply, and Factor Demand Fonctions." American Journal of Agricultural Economics.

Lau, L.J. (1976). "A Characterization of the Normalized Restricted Profit Function." Journal of Economic Theory, (february):131-163.

Leland, H.E. (1972). "Theory of the Firm Facing Uncertain Demand." American Economic Review, 62(june):278-291.

Lucas, R.E., Jr. (1967). "Optimal Investment Policy and the Flexible Accelerator." International Economic Review 81: 78-85.

Mckay, D. (1976). Has the A.-J. Effect Been Empirically Verified?.- Social Science Working Paper no.132, California Institute of Technology.

Maddala, G.S. (1977). Econometrics, McGraw-Hill.

Malinvaud, E. (1953). "Capital Accumulation and the Efficient Allocation of Resources." Econometrica, 21:233-268.

Mangasarian, O.L. (1969). Nonlinear Programming, New-York, MvGraw-Hill.

Marino, A.M. (1978). "Peak Load Pricimg in a Neoclassical Model with Bounds on Variable Input Utilization." Bell Journal of Economics, 9(spring):249-259.

Marino, A.M. (1978). "Peak Load Pricing Under Regulatory Constraint: Two Remarks.." Southern Economic Journal 44(january):606-615.

Marino, A.M. (1979). "Capacity Choice under Regulation in a Variable Load Pricing Model with Diverse Technology." Southern Economic Journal 45: 858-866 (january)

Marino, A.M. (1981). "Optimal Departures from Marginal Cost Pricing: the Case of Rate of Return Constraint." Southern Economic Journal 48(1):37-49 (july).

McNicol. D. (1973). "The Comparative Statics Properties of the Theory of the Regulated Firm." Bell Journal of Economics and Management Science (autumn).

Meyer, R.A. (1975). "Publicly Owned versus Privately Owned Utilities: A Policy Choice." Review of Economics and Statistics (4).

Mortensen, D. (1973). "Generalized Costs of Adjustment and Dynamic Factors Demand Theory." Econometrica 41: 657-665.

Nakao, T. (1981). " The Effects of Demonopolization on the Aggregate Stock of Capital and the Welfare of a Society." Southern Economic Journal 48(2): 358-364.

Needy, C.W. (1976). "Social Cost of the A-J-W Output Distortion." Southern Economic Journal 42(3):486-489.

Nelson, R.A. (1982). "An Empirical Test of the Ramsey Theory and Stigler-Peltzman Theory of Public Utility Pricing." Economic Inquiry 20(2)(april).

Nelson, R.A. and M.E. Wohar (1983). "Regulation, Scale Economies,and Productivity in Steam-Electric Generation." International Economic Review 24(february):57-79.

Nelson, R.A. (1984). "Regulation, Capital Vintage, and Technical Change in the Electric Utility Industry." Review of Economics and Statistics 66(1):59-69.

Neuberg, L. (1977). "Two Issues in the Municipal Ownership of Electric Power Distribution System." Bell Journal of Economics 8.

Nickell, S. (1978). The Investment Decisions of Firms, Cambridge, England.

Niho, Y. and Musacchio, R.A. (1983). "Effects of Regulation and Capital Market Imperfections on the Dynamic Behavior of a Firm". Southern Economic Journal 49(3):625-36.

Peles, Y. and Stein, J.L. (1976). "The Effect of Rate of Return Regulation is Highly Sensitive to the Nature of the Uncertainty." American Economic Review 66(3):278-89 (june).

Perrakis, S. (1976). "On the Regulated Price-Setting Monopoly with a Random demand Curve." American Economic Review 66 (june):410-416.

Perrakis, S. (1976). "Rate of Return Regulation of a Monopoly Firm with Random Demand." International Economic Review 17(february):149-162.

Pescatrice, D.R. and J.M. Trapani III (1980). "The Performance and Objective of Public and Private Utilities Operating in the United States." Journal of Public Economics 13:259-276.

Petersen, H.C. (1975). "An Empirical Test of Regulatory Effects." Bell Journal of Economics 6(spring):111-126.

Petersen, H.C. (1976). "The Effect of `Fair Value' Rate Base Valuation in Electric Utility Regulation." Journal of Finance 31(5):1487-90.

Petersen, H.C. (1976). "The Effect of `Fair Value' Rate Base Valuation in Telephone Regulation." Engineering Economics 22(1):27-31.

Pindyck, R.S. and J.J. Rotemberg (1983a). "Dynamic Factor Demands and the Effects of the Energy Price Shocks." American Economic Review 73(5):1066-79.

Pindyck, R.S. and J.J. Rotemberg (1983b). "Dynamic Factor Demands under Rational Expectations." Scandinavian Journal of Economics 85(2):223-38.

Pratt, M.D. (1981). "Firm Behavior Under Regulatory Constraint:an Immanent Criticism [depreciation,tax policy and firm behavior under regulatory constraint]." Southern Economic Journal 48(1):235-38.

Rao, P. and Z. Griliches (1969). "Some Small Sample Properties of Several Two-Stage Regression Methods in the Context of Autocorrelated Errors." Journal of american Statistical Association, March.

Sandmo, A. (1971). "On the Theory of the Competitive Firm under Price Uncertainty." American Economic Review 61(March):65-73.

Schmalensee, R. (1974). "Estimating the Costs and Benefits of Utility Regulation." Quarterly Review of Economics and Business 14(2):51-64.

Schmidt, P. and C.A. Knox Lovell (1979). "Estimating Technical and Allocative Inefficiency Relative to Stochastic Production Function and Cost Frontiers." Journal of Econometrics 9:343-366.

Sheshinski, E. (1971). "Welfare Aspects of a Regulatory Constraint:Note." Americain Economic Review 61:175-178.

Shoven, J.B. and J. Whalley (1984). "Applied General-Equilibrium Models of Taxation and International Trade." Journal of Economic Literature 22(3):1007-1051.

Smithson, C.W (1978). "The Degree of Regulation and the Monopoly Firm:Further Empirical Evidence." Southhern Economic Journal 44(january):568-580.

Spann, R.M (1974). "Rate of Return Regulation and Efficiency in Production: An Empirical Test of the Averch-Jonhson Thesis." Bell Journal of Economics and Management Science 7(autumn):497-520.

Takayama, A. (1969). "Behavior of the Firm under Regulatory Constraint." Americain Economic Review 59(june):255-260.

Treadway, A. (1971). "The Rational Multivariate Flexible Accelerator." Econometrica 39: 845-855.

Waverman. L. (1982). The Process of Telecommunication Regulation in Canada. Working Paper no.28, Economic Council of Canada.

Wein, H.W. (1968). "Fair Rate of return and Incentives - Some General Considerations." in: H.M. Trebing, ed. Performance under Regulation, East Lansing, Michigan State University.

Wilcox, Clair (1968). Public Policies Toward Business, Homewood, Ill.:Irwin, 3rd. edition.

Woodland, A.D. (1975). "Substitution of Structures, Equipment and Labor in Canada Production." International Economic Review 16(february):171-187.

Zajac, E.E. (1970). "A Geometric Treatment of Averch-Jonhson's Behavior of the Firm Model." Americain Economic Review 60(march):117-125.

Zajac, E.E. (1972). "Lagrange Multiplier Values at Constrained Optima." Journal of Economic Theory 4:125-131.

APPENDIX A

The data base used in this thesis was assembled from a variety of sources. The bulk of the data was taken from recent submissions to the Canadian Radio-Television and Telecommunications Commission (CRTC) by Bell Canada. The following original sources were tapped:

(1) Bell Canada, Information Requested by National Anti-Poverty Organization (NAPO), 30 March 81-612 CRTC.

(2) Financial Statistics on Canadian Telecommunication Common Carriers, Department of Communications.

(3) The Financial Post Corporation Service, Maclean Hunter Ltd., various years and companies.

(4) Gestion Financière, Lustzig, Schwab and Charest, 1983.

(5) The Regulation of Telecommunications in Canada, M. Fuss and L. Waverman, Economic Council of Canada, 1981.

(6) Statistics Canada.

A.1 Output and variable input series for Bell (1952-1980)

Outputs

- Two output price variables were constructed for Bell corresponding to two output quantity variables: local and toll outputs. The price variables are Divisia price indexes normalized to 1.0 in 1976 and the output quantity variables are constant 1976$ of revenues in millions of $.

- (1) breaks down Bell's revenues into 10 categories of output: local service revenues, message toll service revenues (Intra-Bell; Trans-Canada and Adjacent Members; US and Overseas), other toll service revenues (WATS; TWX; private lines; miscellaneous other toll), directory advertising revenues and miscellaneous revenues. For each category of output both current $ figures and constant 1967$ figures are available. The local output price index is a Divisia price index using the constant 1967$ figures of local service revenues, directory advertising and miscellaneous revenues as output figures and the implicit prices derived by dividing the constant $ figures into the current $ figures. This index is then normalized to 1.0 in 1976 and divided into the sum total of those three sources of current revenues to give a local output quantity variable in millions of constant 1976$.

A similar procedure is employed to obtain the price and quantity of toll output. The toll output price index is a normalized Divisia price index of the seven remaining categories of revenues for Bell: intra-Bell, Trans-Canada, US and overseas, WATS, TWX,PL, miscellaneous other toll. The toll output quantity index is obtained by dividing this price index into the corresponding total current $ revenues series.

Labor

- The quantity of labor is millions of manhours unadjusted for quality change.

- The price of labor is the average hourly wage rate which is equal to total labor compensation in millions of current $ divided by the quantity of labor.

Materials

- The cost of materials, services, rents and supplies in current $ is divided by the corresponding figure in constant 1967$ to get a price index of materials. This price index is then renormalized to 1.0 in 1976 and divided into the current $ cost figures to obtain a constant 1976$ quantity index of materials in millions of $.

A.2 Capital input prices and quantities series

A.2.1 Capital stock series

- The quantity of capital is the constant 1976$ total average gross or net stock of capital (at reproduction cost). First, an asset price index of capital is obtained by dividing the current $ values of the stock of capital by the constant $ values and by renormalizing this series to 1.0 in 1976. Then this series is divided into the current \$ value of the average gross stock of physical capital to obtain a gross quantity of capital in millions of constant 1976\$.

- The quantity of net capital is KN = KG (1-δ) where KG is the quantity of gross capital and δ the (economic) depreciation rate. δ is estimated by taking the ratio of the value of depreciation expenses in constant 1976\$ over the value of the gross stock of physical capital in constant 1976\$.

A.2.2 Definition of the user cost of capital services and the allowed gross return on capital services.

Remember that Fuss and Waverman's user cost of capital services is given by:

$$v = q\left(\Theta c_B + c_E^i \frac{(1-\Theta)}{(1-t)} + \delta \right) - (\alpha-\delta) \frac{g\ t\ q}{(1-t)(\alpha+g)}, \quad i=1,2 \qquad \ldots(A1)$$

where q is the asset price of capital, Θ the fraction of the firm's capital financed by debt, δ is the economic depreciation rate ("EDEP" in Appendix B), α the accelerated depreciation rate ("ADEP" in Appendix B), t the tax rate on corporate income, g the treasury bond rate which is used as a proxy for the personal borrwing rate, c_B is the cost of debt,

c_E^1 is the cost of equity capital using the CAPM method and c_E^2 is the cost of equity capital using the DCF method.

The DCF method is probably the most widely used to compute c_E. It relies on the equivalence of the market price of a stock (MV) and the present value of the cash flows investors expect from the stock. By making the assumptions (i) that the discount rate will remain constant; (ii) that all relevant cash flows are dividends; and (iii) that the dividends are expected to grow at a constant rate x, the market value of a stock can be written as a perpetuity:

$$MV = D/(r+x) \ , \qquad \ldots(A2)$$

where D stands for the dividend. Solving for r, the discount rate required by the investors, gives:

$$c_E^2 \equiv r = (D / MV) + x \ . \qquad \ldots(A3)$$

Using (A3) to forecast backwards what the cost of equity capital was for Bell Canada, the actual values of D and MV can be used on the assumption that investors expected the dividends that were actually paid. The definition of x, however, is more problematic. The "sustainable" growth rate method is retained in this thesis. It consists in using that rate x which could be sustained by the growth in the firm's earnings. The expected growth rate of the dividends is then measured as the rate of return on book equity times the proportion of earnings that are not distributed to the shareholders. This gives the following formula for x:

$$x = (EPS/BV) \left[(EPS - D) / EPS \right], \qquad \ldots(A4)$$

where EPS is earnings per share and BV is the book value of equity. (A3) and (A4) complete the DCF model to compute c_E^2 for Bell.

The CAPM is based on a theory of capital market equilibrium which predicts that investors will hold only efficient portfolios: that is, portfolios with the highest return for a given risk level. To induce an investor to hold an investment which is more (less) risky than a portfolio containing all the stocks in the market ("the market portfolio"), one should give her a higher (lower) return than the return on all stocks. The competitive nature of the capital market leads to a "risk-return line" that gives the required rate of return by investors for any level of risk. The CAPM also holds that all the information about a firm's riskiness can be compounded into a single coefficient, called the beta coefficient. A firm's beta measures the volatility of its returns and the correlation of those returns with other assets. Let r_m be the rate of return of the market portfolio and r_j be the rate of return on asset j or firm j. Then, the beta of firm j is defined as:

$$b_j \equiv \sigma_{jm}/\sigma_m^2 \,, \qquad \text{...(A5)}$$

where σ_{jm} is the covariance between r_j and r_m and σ_m^2 is the variance of r_m. A beta value of one means that the return on asset j, on average, moves up or down by the same amount as the market return: both are equally risky. More precisely, it can be shown that:

$$b_j = p_{jm}\ (\sigma_j/\sigma_m), \qquad \text{...(A6)}$$

where p_{jm} is the correlation between r_j and r_m .

(A6) gives a means to determine just "how risky" a firm is. The CAPM solves the problem of how to compensate investors for risky projects by posing that the risk-return line is (Kolbe et al., 1984; p. 70):

$$E(r_j) = r_f + \{b_j\ (E(r_m) - r_f)\} \,, \qquad \text{...(A7)}$$

where $E(r_j)$ is the expected required return on asset j, r_f is a risk-free rate of return and $E(r_m)$ is the expected rate of return on the market. By assuming that r_f can be approximated by the return on short term Canadian treasury bills and that $[E(r_m) - r_f]$, the risk premium, is stable and can be estimated, and by estimating b_i by an ordinary least-squares regression of $(r_j - r_f)$ on $(r_m - r_f)$, (A7) can be used to generate the expected required rate of return on any firm's equity. This is done in Lustzig et al. (1983) for Bell: the estimated b-value is 0.2483 while the risk premium for the Canadian stock market (based on the performance of stocks at the TSE) is found to be 0.045.

The last quantity which needs to be defined is the allowed (gross) return on capital. The formula given in Fuss and Waverman is:

$$s = q\ (\theta\ c_B\ +\ s_E\ \frac{(1-\theta)}{(1-t)} + \delta\ ), \qquad \text{...(A8)}$$

where s_E is the allowed (gross) rate of return on equity. s_E is assumed to be equal to the actual rate of return on equity ("ROR" in Appendix B) as defined in Fuss and Waverman (1981). Finally, the allowed (gross) excess return on capital services can be obtained from (A1) and (A8):

$$e^i = (s - v^i) = q\ [\ (s\ -\ c^i)\ (1-\theta)\ /\ (1-t)\ ]\ +$$

$$(\alpha\ -\ \delta)\ [\ (\ q\ t\ g\ )\ /\ (1\ -\ t)\ (\alpha\ +\ g)]\ . \qquad \text{...(A9)}$$

The sources of the variables entering the user cost of capital computations appear in Table A.1. The values of

TABLE A.1

DATA SOURCES FOR THE GROSS SERVICE PRICE OF CAPITAL

Series Name	Source
q (asset price)	(1) ; see above
DEBT	(3)
EQUITY	(3)
$(\alpha-\delta)$*	(5)
t	(3)
g	(6)
DIV	(3)
MVS	(3)
BVS	(3)
EPS	(3)
δ	(1) ; see above
b	(4)
RP	(4)

* The values for α for 1979, 1980 are not included in (5), the value 0.156124 was used for 1978 through 1980.

v^1, v^2, s and e^i can be found in Tables 3.3 and 3.4.

A.3 Other variables sources.

A number of other, non-company related, variables were used in the empirical section of this research. Whenever necessary the series were converted into millions of constant 1976$ or renormalized to 1976 = 1.0. Table A.2 indicates the source of each variable.

TABLE A.2

DATA SOURCES, VARIOUS SERIES

Canadian GNP (millions of current $)	Stat. Can. 13-213/531
GNP of Quebec and Ontario (millions of current $)	Stat. Can. 13-213/531
Consumer Price Index	Stat. Can. 13-004
Population-Canada	Stat. Can. 91-201
Population Quebec	Stat. Can. 91-201
Number of phones in service	Stat. Can. 56-002
Number of households in Quebec and Ontario	Stat. Can. 93-801

APPENDIX B

YEAR	y_L	p_L	y_T	p_T
1952	178.5779	0.7122940	69.95073	0.8234367
1953	194.2879	0.7185213	75.96753	0.8266689
1954	211.1320	0.7180341	82.48059	0.8268611
1955	230.2288	0.7218907	95.71648	0.8274437
1956	254.6142	0.7226621	109.5865	0.8267443
1957	282.1068	0.7249027	120.7473	0.8232069
1958	306.0608	0.7312272	127.7318	0.8306466
1959	329.7831	0.7793001	140.1886	0.8624096
1960	353.7957	0.7815246	148.9939	0.8718478
1961	379.6783	0.7819778	159.9414	0.8646920
1962	407.6671	0.7827466	187.3890	0.8207524
1963	431.3107	0.7880629	200.1987	0.8256795
1964	452.4994	0.7880673	228.3193	0.8251603
1965	486.7681	0.7880549	257.5972	0.8233784
1966	526.6242	0.7878483	290.0707	0.8042866
1967	566.8604	0.7878483	324.9560	0.7970310
1968	605.0646	0.7885108	359.9938	0.7911246
1969	652.0020	0.7929423	413.4762	0.7961764
1970	698.3586	0.8028826	450.3413	0.8486897
1971	740.9561	0.8323030	470.6530	0.8643311
1972	776.4966	0.8557668	531.6042	0.8745227
1973	827.7736	0.8791051	617.5275	0.8940492
1974	900.6324	0.8979246	701.8339	0.9084769
1975	978.2822	0.9417528	799.1926	0.9429517
1976	1045.100	1.000000	867.7000	1.000000
1977	1104.039	1.062010	940.2824	1.032031
1978	1169.326	1.160155	1048.921	1.098843
1979	1213.960	1.238262	1136.082	1.170514
1980	1283.651	1.320530	1255.959	1.193590

APPENDIX B

YEAR	L	w_1	M	w_2
1952	48.40000	1.570682	64.20717	0.4469906
1953	49.00000	1.708735	69.01855	0.4462568
1954	51.80000	1.763900	77.14815	0.4557275
1955	56.10000	1.828414	88.43002	0.4557275
1956	60.20000	1.871146	103.5278	0.4733026
1957	62.60000	1.949904	104.3574	0.4829557
1958	61.30000	2.091582	114.8097	0.4903766
1959	57.60000	2.290729	120.7825	0.5000725
1960	55.10000	2.464083	126.2575	0.5061085
1961	51.80000	2.662471	131.7325	0.5078472
1962	51.60000	2.781085	141.1894	0.5149111
1963	53.20000	2.850667	148.6554	0.5247036
1964	54.10000	2.922810	148.9872	0.5376301
1965	55.50000	3.011189	162.5918	0.5547635
1966	58.30000	3.166364	169.0623	0.5796680
1967	56.60000	3.460724	165.2464	0.6027364
1968	54.60000	3.817894	172.8782	0.6229819
1969	55.50000	4.151423	206.0602	0.6493248
1970	56.10000	4.636506	205.8943	0.6741323
1971	55.20000	5.003822	244.5513	0.6996486
1972	55.10000	5.640980	250.3582	0.7229642
1973	57.80000	6.079481	265.1242	0.7573810
1974	61.60000	6.792906	280.2220	0.8336248
1975	61.30000	8.171729	277.5674	0.9190559
1976	64.30000	9.208647	299.3016	0.9999945
1977	66.60000	10.23515	335.3041	1.084091
1978	71.20000	10.83087	367.8225	1.163061
1979	73.10000	12.48873	370.3111	1.261642
1980	76.20000	14.14047	399.3454	1.401043

APPENDIX B

YEAR	K_N	K_G	q_N	q_G
1952	1170.983	1704.822	0.4886494	0.4914883
1953	1290.225	1865.836	0.4885213	0.4813392
1954	1409.998	2028.989	0.4765253	0.4785141
1955	1577.965	2243.140	0.4778940	0.4792835
1956	1765.067	2474.408	0.4885933	0.4896929
1957	1975.380	2731.531	0.4972208	0.4974134
1958	2204.473	3017.540	0.5039298	0.5031581
1959	2432.858	3305.867	0.5067290	0.5055859
1960	2669.571	3600.435	0.5071976	0.5056055
1961	2890.692	3885.731	0.5062802	0.5043581
1962	3106.851	4200.270	0.5065901	0.5001583
1963	3340.729	4465.952	0.5113854	0.5087829
1964	3567.874	4777.816	0.5131628	0.5103168
1965	3791.829	5096.278	0.5164262	0.5134924
1966	4038.109	5460.565	0.5327246	0.5294506
1967	4292.717	5865.151	0.5643978	0.5608211
1968	4539.174	6279.543	0.5960996	0.5920017
1969	4804.944	6719.255	0.6220259	0.6175833
1970	5061.501	7149.339	0.6582830	0.6529974
1971	5338.079	7617.403	0.6962617	0.6901302
1972	5635.387	8117.028	0.7295151	0.7230725
1973	5898.145	8581.882	0.7726328	0.7641913
1974	6200.414	9103.617	0.8444920	0.8330206
1975	6568.948	9754.627	0.9282764	0.9219727
1976	6928.801	10443.44	0.9999998	1.000006
1977	7278.731	11064.85	1.062589	1.066856
1978	7511.191	11554.13	1.145863	1.148611
1979	7699.002	12050.55	1.262488	1.259901
1980	8005.524	12674.45	1.391439	1.391129

APPENDIX B

YEAR	DEP	ADEP	v_1	v_2
1952	0.5870000E-01	0.5882400E-01	0.4802051E-01	0.7540052E-01
1953	0.5860000E-01	0.5874500E-01	0.5001744E-01	0.7248212E-01
1954	0.5810000E-01	0.9353900E-01	0.5580000E-01	0.9744100E-01
1955	0.5580000E-01	0.9744100E-01	0.4526142E-01	0.5884605E-01
1956	0.5550000E-01	0.9653900E-01	0.5329865E-01	0.5991736E-01
1957	0.5850000E-01	0.9835900E-01	0.5926170E-01	0.6145431E-01
1958	0.5840000E-01	0.6556100E-01	0.5411610E-01	0.6403612E-01
1959	0.6020000E-01	0.6680800E-01	0.7111114E-01	0.7195336E-01
1960	0.5980000E-01	0.6578800E-01	0.6213568E-01	0.6983341E-01
1961	0.5980000E-01	0.6520700E-01	0.6146279E-01	0.6725296E-01
1962	0.6030000E-01	0.6531200E-01	0.6919845E-01	0.7029698E-01
1963	0.6190000E-01	0.6753800E-01	0.6711682E-01	0.6925920E-01
1964	0.6260000E-01	0.6795900E-01	0.6926456E-01	0.7137297E-01
1965	0.6390000E-01	0.6896800E-01	0.7139041E-01	0.7404131E-01
1966	0.6510000E-01	0.7003400E-01	0.8065371E-01	0.7920803E-01
1967	0.6560000E-01	0.9951600E-01	0.7815917E-01	0.8493052E-01
1968	0.6680000E-01	0.9980800E-01	0.9221525E-01	0.9215649E-01
1969	0.6900000E-01	0.1001910	0.1052161	0.9763033E-01
1970	0.6920000E-01	0.1083220	0.1033216	0.1106156
1971	0.6970000E-01	0.1326050	0.9116820E-01	0.1146339
1972	0.7390000E-01	0.1385210	0.9923898E-01	0.1297081
1973	0.7720000E-01	0.1466110	0.1145049	0.1425785
1974	0.7950000E-01	0.1452860	0.1404638	0.1566471
1975	0.8400000E-01	0.1632080	0.1534073	0.1865399
1976	0.8670000E-01	0.1593450	0.1914557	0.2061271
1977	0.8690000E-01	0.1702510	0.1911813	0.2107956
1978	0.8860000E-01	0.1561240	0.2149607	0.2296701
1979	0.9080000E-01	0.1561240	0.2651202	0.2674904
1980	0.9160000E-01	0.1561240	0.3031141	0.2741821

APPENDIX B

YEAR	ROR	C_E^1	C_E^2	T_2
1952	0.7365500E-01	0.2184000E-01	0.6834100E-01	48.39000
1953	0.7119700E-01	0.2826600E-01	0.7070500E-01	49.30000
1954	0.7365300E-01	0.2543200E-01	0.5958900E-01	50.28000
1955	0.6923100E-01	0.2733100E-01	0.5332700E-01	50.19000
1956	0.6520300E-01	0.4042400E-01	0.5275200E-01	52.39000
1957	0.5790800E-01	0.4877400E-01	0.5274300E-01	55.47000
1958	0.6161100E-01	0.3371600E-01	0.5278300E-01	61.46000
1959	0.6846900E-01	0.5927300E-01	0.6075100E-01	65.41000
1960	0.7123100E-01	0.4319100E-01	0.5759400E-01	71.85000
1961	0.6801900E-01	0.3929100E-01	0.4942600E-01	75.91000
1962	0.6823000E-01	0.5169800E-01	0.5360400E-01	79.14000
1963	0.6960200E-01	0.4679100E-01	0.5061800E-01	86.92000
1964	0.7078500E-01	0.4866600E-01	0.5230100E-01	94.70000
1965	0.7873200E-01	0.5101500E-01	0.5570200E-01	96.84000
1966	0.6941400E-01	0.6112400E-01	0.5866000E-01	99.02000
1967	0.7922600E-01	0.5758200E-01	0.6896900E-01	100.0000
1968	0.8084400E-01	0.7384900E-01	0.7375300E-01	104.1200
1969	0.7755300E-01	0.8309900E-01	0.7123600E-01	106.7600
1970	0.8075400E-01	0.7108100E-01	0.8154000E-01	108.9500
1971	0.8183200E-01	0.4679900E-01	0.8100400E-01	110.3400
1972	0.8820800E-01	0.4678200E-01	0.9125900E-01	111.7600
1973	0.8967900E-01	0.6587300E-01	0.1069200	112.8400
1974	0.8412900E-01	0.8941600E-01	0.1110400	114.7400
1975	0.1229500	0.8512400E-01	0.1320300	116.4900
1976	0.8920400E-01	0.9984900E-01	0.1158500	117.5500
1977	0.8099500E-01	0.8449100E-01	0.1049600	118.3800
1978	0.9396900E-01	0.9793200E-01	0.1129400	121.5700
1979	0.1050500	0.1280500	0.1303500	122.5300
1980	0.9341600E-01	0.1391000	0.1137800	124.4000

APPENDIX B

YEAR	FNEW	A
1952	76.18000	0.00000
1953	77.32000	0.00000
1954	78.53000	0.00000
1955	79.46000	0.00000
1956	81.12000	0.03900
1957	83.03000	0.06900
1958	84.04000	0.23500
1959	85.37000	0.33700
1960	87.17000	0.49900
1961	88.02000	0.60200
1962	89.79000	0.57800
1963	91.75000	0.61900
1964	94.00000	0.71200
1965	95.87000	0.72900
1966	97.97000	0.73600
1967	100.0000	0.72100
1968	102.4100	0.78500
1969	104.2700	0.82300
1970	106.4300	0.82100
1971	108.0800	0.82200
1972	110.2700	0.84000
1973	112.4300	0.84200
1974	115.5800	0.84100
1975	117.7600	0.84900
1976	120.3100	0.84700
1977	122.3600	0.84600
1978	123.9900	0.84600
1979	126.4700	0.84600
1980	128.7000	0.84600