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AN INTER-TEMPORAL MODEL OF FIRM BEHAVIOR UNDER UNCERTAINTY AND REGULATION

-by-

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ABSTRACT

An Inter-temporal Model of Firm Behavior

Under Uncertainty and Regulation

By

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Under conditions of stochastic demand a single period and a multiperiod model of firm behavior have been developed. In each case three conditions of market structure (a monopoly, a regulated monopoly, and a perfectly competitive industry) are analyzed.

Instead of maximizing the expected utility, the firm objective is to make production and/or price decisions that maximize its net present value. The net present value of the firm excess cast returns is determined from the equilibrium risk-return relationship in the capital markets.

The effect of technological progress on the firm production and price decisions have been analyzed. By improving its technology, a monopoly can increase its net present value. Thus, a monopolist has motivation to introduce cost cutting techniques.

A firm can not be effectively regulated by providing it a fair rate of return constraint and allowing it to

determine the product prices. Imposition of price or quality controls only would not eliminate monopoly excess returns. To ensure the fair returns for the firm, both the price and quality controls are necessary.

Regulation has been described as game theoretic in nature. The firm equilibrium depends upon the behavior of the regulators. If the regulators know the current firm environment and utilize this information to determine the fair product prices, active regulation would result. Active regulation provides an ideal scheme for the regulation of the firm. An actively regulated firm would produce efficiently and the consumers would be ensured a product at reasonable prices. Since, active regulation always ensures a zero net present value for the firm, the firm has no incentive to improve the production technology. So that the firm may introduce the cost cutting techniques, the regulators must provide incentives for it.

If the regulators do not have complete knowledge about the firm environment, they would prefer to make the present decision based on previous period technology and demand conditions of the firm. The above implies passive regulation and the existence of the regulatory lag. Knowing the avove behavior of the regulators, the firm would like to increase its return by adopting cost saving techniques. Thus, Passive Regulation provides a distinct economic incentive to the firm to improve the production technology. The firm would determine the present investment level that maximizes its net present value. The net present value of the firm is the sum of the discounted certainty equivalent of excess return earned by the firm for all future periods. The existence of the regulatory lag also encourages the firm to produce inefficiently. Depending upon the rate of technological progress, demand and output elasticities, the firm may overcapitalize or undercapitalize.

The models of firm regulation are simulated by using the parameters for the Electric Power Industry. The demand and production parameters, and the rate of technological progress are varied and the effect on price and production efficiency is studied. For passive regulation, the effect of firm horizon on the firm equilibrium is determined.

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CHAPTER I

INTRODUCTION

This chapter provides an introduction to the models developed in this study and should also help in understanding better the review of the existing literature given in the next chapter. This chapter also explains the points of difference between this study and other works on the subject.

The last two decades have witnessed a high growth of the regulated sector. During this period, many authors[1] have expressed dissatisfaction with the performance of the regulated industries. Consequently, the debate on how the economic activity should be regulated has raged in the literature.

The purpose of this study is to analyze the effects of regulation on the firm behavior.

The Hope Decision[2] provides legal guide lines for the regulation of a firm. It states that the equity holders of the regulated firm must be provided with a fair rate of return. The fair rate of return must be commensurate with

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[1] See Averch-Johnson (2), Barron & Taggart (8) and, Elton and Gruber (25).

[2] FPC vs Hope Natural Gas Company, 320 U.S. 591 (1944).

the return on investments with corresponding risks.

The objective of the regulatory body is to ensure that the consumers are provided an acceptable product at reasonable price. In accordance with the Hope decision, the regulators must also ensure an uninterrupted functioning of the firm, by providing a fair rate of return to its investors. Therefore, the first step for the regulators is to determine a fair rate of return.

The Capital Asset Pricing Model provides the market equilibrium relationship between the expected return from an asset and its market systematic risk. This implies that the regulators must determine a fair rate of return for the firm after considering the relationship between the market risk and the expected return. To accomplish this, the regulators must have knowledge about the risk of the firm. The risk of the excess cash returns of the firm depends on the underlying uncertainty in the revenues and costs of the firm. Although, utilities may have a good estimate of the expected revenues and costs for the next period, the expost results might be different from the exante estimates.

The above provides one important area of the departure of this study from the previously developed models of firm regulation. The models of firm regulation, reviewed in the next chapter, such as Averch-Johnson (2), Shepherd (69), do not recognize the existence of uncertainty in the firm excess returns. In these models the regulators subjectively determine a fair rate of return that the firm must have, and no consideration is given to the uncertainty in the firm revenues and the firm costs.

The present study determines a fair rate of return in accordance with The Capital Asset Pricing Model. The study develops a normative theory of firm regulation. After a fair rate of return is determined, the next step in the regulatory process is to determine a price level; that for the demand and production conditions of the firm provide it a fair rate of return. Regulated utilities serve a wide variety of consumers that may be differentiated in terms of volume, type of service, or geographic location. The product prices may be different for each type of consumer. Thus, a fair rate of return can be provided to the firm by many different price structures, and the regulatory body has much flexibility in fixing a price structure. Different price structures have different allocative and distributional effects in the economy.

ONE PERIOD HORIZON WITH PRODUCT QUALITY

Chapter III develops a model of firm behavior when it has one period horizon. The firm expected demand is affected by the product price and quality.

Previous research, such as Levhari and Peles (42), Schmalensee (66) and Spence (75) has shown that the product quality levels are determined by the conditions of the market structure and the characteristics of consumers' quality-demand schedules. These models have been developed under certainty, and the firm is considered to maximize its profits. As opposed to this, the analysis in Chapter III considers uncertain demand function and the firm maximizes its net present value. The analysis compares the price, quality and expected demand for a monopoly, perfectly competitive industry and the actively regulated monopoly.

Under the above conditions it is shown that both the price and quality regulation are necessary to eliminate the firm excess returns.

Multiperiod Horizon

Chapter IV extends this analysis to a multiperiod horizon. To keep the algebraic simplicity, the multiperiod analysis considers the product quality to be fixed. The expected demand is a function of price only. The regulators provide a price level to the firm that the firm must charge from its customers. The regulatory price is determined by the regulators after considering the firm demand and production conditions. The above differs from the models developed by Averch and Johnson (2), Shepherd(9), Klevorick (36) and Bailey & Coleman (4). In these models the price is determined by the firm after considering a regulatory constraint. The regulatory constraint is given to the firm by the regulators and it means that the firm should not earn more than a fair rate of return. The regulatory conditions assumed in these models do not represent the existing regulatory practices. These models do not give the behavioral foundations as to why a regulated firm should determine a price for its own product and abide by the fair rate of return constraint. If the firm does not live up to the expectations of the regulators, then what regulatory powers would ensure a desired firm behavior? The traditional models[3] on firm regulation do not address to such questions.

The study in Chapter IV assumes that the firm has a multiperiod horizon and in each period it faces an uncertain demand. The distribution of demand depends upon, the price level. For each state of nature there exists a price demand schedule. In the beginning of every period the firm makes an exante investment decision. The firm cannot change the investment levels during the period. After the demand uncertainty is resolved and the exact quantity demanded is known, the firm has to supply all that is demanded. To meet the expost demand, the firm has to vary the noncapital input. Therefore, an uncertainty in the firm demand also creates an uncertainty in the amount

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3 See Averch-Johnson (2), Shepherd (69) and Bailey & Coleman (4).

of noncapital input required by the firm. As opposed to above, the traditional models of firm regulation assume that the firm knows its demand levels with certainty and, therefore, also knows with certainty the amount of non-capital input required by the firm.

It is generally believed that the regulatory environment affects the pace of technological change in the regulated sector. The following explains the direction of this effect:

1. Regulation provides a climate to the firm that is conducive to its quick adoption of a new technology. This may be achieved by allowing a developmental allowance in the form of higher prices.
2. Existence of the regulatory lag may provide an increased incentive to the firm for the adoption of a new technology. During the period of the regulatory lag, the regulatory prices remain constant but the firm is free to change its technology and inputs. By improving its technology the firm can reduce its costs, therefore, increase its returns.
3. By ensuring a fair rate of return to the firm, regulation reduces the risk of the operation. Restriction to entry by new firms

further reduces uncertainty and insulates the firm from pressures of competition. Under such an environment, the firm does not have to remain modern in its technology. And regulation may retard the technological progress of the regulated firm.

It is generally believed that over the last few decades, the rate of productivity increases in the regulated sector has been faster than the rest of the economy.

The existence of technological change affects every aspect of the regulated firm. It affects the regulatory prices and consequently the product expected demand. Higher demands necessitate larger investments.

The traditional models of firm regulation have ignored the impact of the technological progress.[4]

This study develops a dynamic model of a regulated firm under conditions of technological progress and regulatory lag. It analyzes the interaction of the regulatory lag with the technological progress and determines their effect on firm production decisions and regulatory prices.

The study assumes that the firm does not make investments in the research and development. Information about

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4 Although Averch-Johnson (2) have discussed that the A.T.T. had made more than fair returns in the years 1956-1960, mainly because it had introduced technological improvements during this interval. But the Averch-Johnson model does not consider the effect of technological progress on the regulatory price.

the new improvements is provided to the firm by the suppliers of capital equipment. The assumption of the exogenous source of technical innovations is satisfied differently in different industries. For example, the electric power industry and the air transportation industry do not conduct research or develop equipment on their own but depend upon their suppliers. On the other hand, the telephone companies are vertically integrated and develop their own equipment.

The study also assumes that the secondary real asset markets are perfect; and that the firm can buy or sell the assets freely. This means that the capital is malleable. By buying or selling the capital at the end of each period, the firm can keep the plant size at the optional levels for the coming period.

The assumption of exogenous source of technical innovations and malleability of capital made in this study is also called <u>Disembodied Technical Change</u>. The assumption of Disembodied Technical Change has been extensively applied in the development of macro-growth theory.

The model developed in this study assumes that the firm improves its technology in every period. The rates of technological progress may be different for each period. The technological progress is Hicks-neutral. This means that the productivity of labor and capital improve in the same proportion and the shape of production isoquants remains unchanged.

The model does not represent any particular regulated industry. It assumes a homogeneous production function which may have increasing, decreasing or constant returns to scale.

Like all other models on firm regulation discussed in the next chapter the model developed in Chapter IV is under a partial equilibrium. The effect of price and demand changes in other industries do not affect the demand conditions for the regulated industry.

Chapter IV analyzes the firm under three conditions of market structure. They are:

1. Unregulated monopoly
2. Actively regulated monopoly, and
3. Passively regulated monopoly.

The following now provides a brief introduction to the three conditions of market structure.

Unregulated Monopoly

An inter-temporal model of an unregulated monopoly is developed in Chapter IV. Under similar production and demand conditions, the monopoly price and factor input decisions are compared to the decisions of a regulated monopoly.

The firm is assumed to have a multiperiod horizon, and in each period it faces an uncertain demand. The firm improves its technology over time. Capital is assumed to be malleable. The firm buys or sells assets at the end of each period and plans an optimal plant size for each period. The monopolist makes exante price and capital decisions.

Under the above conditions, the value maximizing monopolist would maximize the CEQ(Excess Returns) for each period. Where, The Excess Returns are equal to the revenue minus the costs and CEQ stands for the certainty equivalent.

The study shows that the monopolist would reduce the product prices every period. The CEQ(Excess Returns) earned by the monopolist increases every period. This implies that a monopolist would gain by introducing a new technology and would share the gains of technological progress with its customers. It is also shown that the monopolist would increase the size of its plant every period. The increased plant size is made necessary by the increased expected demand at lower prices.

Regulation

Two models of firm regulation are developed in Chapter IV. The models differ in their assumptions about the behavior of the regulatory body and, therefore, the regulatory process.

In each model the regulators and the firm know the distribution of demand for each period. The demand is independently and identically distributed over time. The regulators provide a price that the firm must charge. These prices provide a fair return to the firm at the demand and technology conditions that the regulators consider applicable. The firm determines an exante investment level that maximizes its value. The regulators and the firm determine the price and capital levels before the demand uncertainty for the coming period is resolved. These decisions are made after considering the forthcoming uncertainty but they may turn out to be inefficient expost. The firm cannot change its investment level during the coming period.

Active Regulation

Regulation is considered to be active when the regulators determine the most current demand and production conditions of the firm and then enforce product prices that eliminate the firm excess returns. The regulators and the firm have the same information and both know it. Under such conditions, the regulators determine a price level for each period that provides a zero CEQ(Excess

Return) to the firm. Earning of a zero certainty equivalent of excess return implies that the firm would earn a fair rate of return.

The regulators would act as leaders in a duopolistic game between the firm and itself. Being the leaders, they would try to achieve their objective of providing a fair rate of return to the firm, while keeping in view the reaction function of the firm. The reaction function of the firm is to maximize its value at the prices given to it by the regulators. The regulators know that the firm is a follower in the game. While, the firm knows that it has no other alternative but to act as a follower. Whatever price level is imposed by the regulators, the firm accepts it and optimizes with respect to that. The firm determines an investment level that maximizes its value.

The above explains that active regulation is game theoretic in nature, and the regulators and the firm are the players in the game.

The model developed in Chapter IV shows that the active regulation would eliminate the excess returns of the firm. The firm would plan efficient factor input levels. It is also shown that active regulation reduces the product prices. The model shows that the prices of an actively regulated firm would be lower than those of the unregulated monopoly.

Under conditions of technological progress the active regulation would also eliminate the firm excess returns. The firm would have no incentive to introduce the improved techniques and the firm would be indifferent to the adoption of the improved techniques. For the firm to be interested in the adoption of an improved technology, it must benefit by earning higher returns. To reduce the product prices, the regulators must ensure a regulatory environment that encourages the firm to adopt the cost saving techniques.

Many authors[5] have doubts about the practicality of active regulation. The lack of current information to the regulators may hinder the active regulation of the utility.

Passive Regulation

Passive regulation can result if the regulators do not have the complete and current information about the firm and its markets. The firm, being nearer to its markets, and the suppliers of capital equipment, has complete information about its environment. While, the regulators do not have direct access to such information and usually prefer to base their decisions on the results of the last period. The firm results of the last period may be publicly available to the regulators or given to

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5 See pages 8 and 9 in Shepherd W., and Gies Thomas, Regulation In Further Perspective, Ballinger Publishing Co., 1974.

them by the firm. The regulators feel safer in assuming that the conditions of the previous period would continue into the future. The cost and the possibility of error in forecasting future demand and technology may be prohibitive to the regulators.

The firm may follow accounting practices that might present the firm information more favorably to the regulators. Although the regulators base their decisions on the last period's actual conditions, the firm would prefer to make the present decisions after considering the anticipated future changes. The firm may even like to withhold complete information about the cost saving production changes for the next period that it anticipates to implement. Such information may not be independently available to the regulators.

The above reasons point to the fact that the regulators lag in their information about technological and demand conditions of the firm. The regulators determine the price for the present period based on the previous period conditions of the firm. They assume that the previous period conditions would continue into the present and the firm would keep unchanged the investment levels of the previous period.

A regulatory price is determined for the present period that at the capital level, demand, and technology of the previous period provides a fair rate of return to the firm.

The firm is considered to earn a fair rate of return when the certainty equivalent of excess return is zero. The certainty equivalents of the firm excess returns are determined through the Capital Asset Pricing Model.

The firm knows that the regulators behave passively and that the present price levels are based on the previous period capital levels. The firm sets the present capital levels by keeping in view that it would affect the future prices and, therefore, the future excess returns. Under the lagged regulation, the firm sets the present investment levels that maximizes the net present value of the firm. The net present value of the firm is the sum of the discounted certainty equivalent of the excess returns for all future periods.

Through present investment decisions, the firm would like to increase the sum of the discounted future CEQ (excess returns). However, any increase in the sum of the discounted future CEQ(excess returns) must be more than any decrease in the CEQ(excess returns) for the current period.

It is shown in Chapter IV that according to the above criteria, the investment decision of the firm would be different than if there had been no regulatory lag. It is discussed that without the regulatory lag, the firm would maximize the certainty equivalent of excess return for that period only. In that case, the firm solves a series of single period problems.

It is proved in Chapter IV that passive regulation would lead to inefficient decisions by the firm. Under conditions of technological progress, firm conditions would exist when the firm would plan to invest less than the efficient levels. This would lead to earning of more than fair returns by the firm.

The above conclusion is at variance with the traditionally accepted conclusion by Averch-Johnson (2)--who contend that the regulated firms overcapitalize.

The analysis also shows that under passive regulation the regulatory prices would be higher, and consequently the expected demand would be lower than if the firm had been actively regulated.

Chapter IV, limits the analysis of the passively regulated firm to a three period example. The analysis considers perfectly competitive starting conditions for the firm. Because of the algebraic intractability, the analysis could not be extended to longer horizons or non-perfectly competitive starting conditions. However, the simulation results for these conditions are provided in Chapter V.

Chapter V presents the simulation results of a monopoly, actively regulated and passively regulated monopoly.

The firm parameters of the electric utility industry are used.

Over the firm horizon, the price and investment levels are compared for the above three conditions of market structure. The simulation results confirm the analytical results of Chapter IV. In addition, it is shown that the longer the firm horizon, the greater is the flexibility available to the firm to affect future returns. Increased firm horizon increases the inefficiency of the production decisions and raises the regulatory prices. The simulations also show that the firm quickly adjusts for the effect of any undesirable starting condition and plans for an optimal investment level.

The next chapter provides a critical review of the literature on the regulation of the firm.

CHAPTER II

CRITICAL REVIEW OF LITERATURE ON FIRM REGULATION

2.1 INTRODUCTION

This chapter gives a brief review of the literature on some of the models of the regulated firm. In regard to regulation, four fundamental issues have merited the attention of theorists.

They are:

1. Efficiency in Production
2. Regulatory Lag
3. Technological Change, and
4. Quality of the Product.

This chapter presents brief description of each of the above mentioned issues. First, the issue of efficiency in production is examined by reviewing the Averch-Johnson (A-J) model. It is argued by A-J(2) that the regulated firms use their resources inefficiently. The studies that support or contradict this model are summarized. Second, some important aspects of the effects of the regulatory lag are discussed. The proposition that the regulatory lag improves the firm efficiency is presented.

Third, the sources and importance of the technological change in the regulated sector are described. Finally, the literature on how regulation effects the quality of the product is summarized.

Each of the models discussed in this Chapter is subject to some limitations. These limitations are listed and some means to overcome them are given in this research.

2.2 EFFICIENCY IN PRODUCTION

The issue of "efficiency in production" is examined in this section by reviewing the Averch-Johnson (A-J) model of firm regulation. The Averch-Johnson model was developed 15 years ago. Since then, it has been the subject of great attention in the literature. The conclusion established by Averch-Johnson is that If an upper rate of return (on capital) constraint is provided to the regulated firm, the firm would use factors innefficiently. In this case the firm does not equate the marginal rate of factor substitution to the ratio of factor prices. The firm has an incentive to overcapitalize and use capital up to a point where the marginal productivity of capital is less than the market cost of capital.

Given below is a brief review of the Averch-Johnson model.

Let:

S = Fair rate of return

x = Quantity demanded

$p(x)$ = Firm inverse demand function

L = Labor input

K = Capital input

i = Cost of capital

W = Wage rate

π = Profits

The profit earned by the firm is the difference between the total revenue and the total costs. It is assumed that the firm maximizes its profits by deciding labor and capital inputs subject to the regulatory constraint that the firm would not earn more than the fair rate of return.

The problem of the firm is:

$$\underset{L,\,K}{\text{Maximize}}\ \pi = \underset{L,K}{\text{Max}}\ p(x)\ x(K, L) - iK - WL \qquad (2.1)$$

$$\text{Such that} \quad p(x)\ x(K, L) - SK - WL \leq 0 \qquad (2.2)$$

The Lagrangian expression can be defined as

$$\text{Max } L\ (K, L, \lambda) = p(x)x - iK - WL - \lambda\left[p(x)x - SK - WL\right] \qquad (2.3)$$

The Kuhn Tucker conditions are:

$$\left(p + \frac{\partial x}{\partial p}\right)\frac{\partial x}{\partial K} - i - \lambda\left\{\left(p + \frac{\partial x}{\partial p}\right)\frac{\partial x}{\partial K} + S\right\} = 0 \qquad (2.4)$$

$$\left(p + \frac{\partial x}{\partial p}\right)\frac{\partial x}{\partial L} - W - \lambda\left\{\left(p + \frac{\partial x}{\partial p}\right)\frac{\partial x}{\partial L} + W\right\} = 0 \qquad (2.5)$$

$$\lambda\left(px - SK - WL\right) = 0 \qquad (2.6)$$

$$\text{and } \lambda,\ L,\ K \geq 0 \qquad (2.7)$$

The model embodied in equations (2.4) to (2.7) has two important points of interest:

(a) When: $\lambda = 1$, Equation (2.4) would be satisfied for $i = S$. Or, the cost of capital and the fair rate of rate return are equal.

(b) The interesting case is when $s > i$ and $0 < \lambda < 1$ or when the fair rate of return is higher than the cost of capital.

From (2.4) and (2.5)

$$\frac{-dL}{dK} = \frac{i}{W} - \frac{\lambda}{1 - \lambda}\left(\frac{S - i}{W}\right)$$

$$\text{or } \frac{-dL}{dK} < \frac{i}{W} \qquad (2.8)$$

Equation (2.8) implies that the factor usage is to a point where the rate of technical substitution is less than the ratio of factor prices. At the optimal point, because of the regulatory constraint, the marginal productivity of capital is less than the market cost of capital. It is then concluded by A-J that the firm finds it advantageous to increase its capital base. The firm would substitute capital for labor and earn a fair rate of return that is higher than the cost of capital. A-J further contend that the firm's desire to overcapitalize is reflected in its adoption of technical innovations that are capital intensive. This would increase its capital base and therefore total profits.

The Averch-Johnson model is a simple model of regulation. In this model too much has been sacrificed for the sake of simplicity. The model contains too many unrealistic assumptions. Some of these assumptions are listed below:

(1) The regulators give a fair rate of return constraint to the firm, while the firm is free to choose the price level and factor input levels.

(2) Demand and cost conditions are certain.

(3) The firm maximizes its profits instead of value.

(4) The model does not recognize the existence of a regulatory lag.

The A-J model has been supported as well as criticized in the literature.

Shepherd (69) while discussing the capital intensity in the telephone industry has argued that the Bell System has always preferred capital intensity. In the early 1960's while choosing between two alternative satellite technologies, the Bell System advocated the Random Orbital System over the Snychronous Orbit System. Random Orbital System would have required a large capital investment in about fifty satellites and in complex and expansive tracking stations. Synchronous Orbit method was simple and less capital intensive. The Synchronous approach was developed and pushed through by Hughes Aircraft, a new competitor.

Shepherd (69) argues further that the lower depreciation rates by the Bell System keep high the volume of past investment that is eligible for inclusion in the rate base. He also claims that a utility tends to slow the adoption of a technology that decreases the existing base.

In another example, supporting the overcapitalization proposition, Shepherd cites that the carriers would prefer to own an equipment rather than lease it. He contends that leasing could be more efficient than owning in case of office space, vehicles and equipment.

Although Shepherd has supported A-J model, through the above examples, none of his arguments have the advantage of critical analysis of the technical and cost factors relevant to the case. Subjective opinions based on impressions and rhetoric are inconclusive.

Klevorick (36) while supporting A-J's analysis, argues that the fair rate of return should not be subjectively determined by the regulators. It must be endogeneously determined by the model. He advocates that the fair rate of return allowed to the firm must maximize a social welfare function. Social welfare is defined as the sum of the consumer surplus and the firm surplus. It is shown by him that the social welfare function is maximized when the fair rate of return is equal to the cost of capital. He further contends that if the regulators do intend to maximize the social welfare subject to fair rate of return and the firm's input efficiency constraint; there would be situations where the regulators would like to set a fair rate of return, higher than the cost of capital.

Spann (74) has tested the electric utility industry data by using the translog production function. The translog production function is a Taylor series expansion of an arbitrary production function. The Cobb-Douglas and the CES are the special cases of it. The data for the first year of the operation of the plants built between 1959 and 1963 was used for the analysis. Both the plant and the firm data confirm the A-J model.

Courville (16) tested the A-J model by using the Cobb-Douglas production function on the generation of electric power. Transmission and distribution aspects of the firm were excluded, because, he considered that they are probably characterized by fixed proportions. The rate of technical substitution was compared to the factor input price ratio. Separate tests were conducted for three vintage groups of the plants. It was concluded that the overcapitalization existed at the plant level.

Patterson (62) conducted another test of the A-J model on the electric utility industry by using a modified Cobb-Douglas and a general form of cost function. Plants that had a large increase of capacity before the sample period were considered for the analysis. The operation of the plants that had stringent regulation was compared to those that had no regulation. It was found that as regulation tightens, unit costs increase. Patterson concluded that in both instances the evidence supports the A-J model.

Baron and Taggart (8) have developed a model of firm regulation. In this model, regulation is conducted through price controls. Instead of a rate of return constraint the firm is given a price level that it must charge. Under a price control the firm maximizes its value by choosing optimal input levels. Baron and Taggart, in a single period framework, show that the firm may overcapitalize or under-capitalize. The degree of capitalization depends on whether the capital levels can increase or decrease the product prices, which in turn depends upon demand and output elasticities. They tested their hypothesis for the electric utility industry at the firm level. A firm rather than a plant was selected to be the subject of study because the regulatory constraint is applied to the firm--and not to the plant.

The electric utilities FPC data for the year 1970 was used in the empirical analysis. In this study Baron and Taggart conclude: That undercapitalization exists in the electric utility industry. These conclusions directly contradict the A-J model. This is the first study that has contradicted the A-J model analytically and empirically.

The Baron and Taggart model is more general and realistic than the A-J model. One important feature of this model is that it incorporates price regulation. The firm is provided a price level that it must charge. The model considers demand uncertainty and allows debt utilization and debt-tax advantage to the firm. However, the model lacks because of the following:

(1) They consider one period firm horizon.

(2) The regulatory lag is not considered.

Earlier we presented the main arguments of Klevorick's study conducted under conditions of certainty. In another study Klevorick (37) has considered regulation in a dynamic context. The timing of the rate reviews is random. The firm maximizes the expected present value of its cash flows. Technological progress takes place through internal R & D expenses of the firm. Klevorick confirms that the firm would produce inefficiently but would not necessarily overcapitalize. Klevorick's maximization of expected present value of the firm is not a valid objective function for the shareholders of the firm. Because of the general nature of the demand, production, research functions and regulatory constraints, the issue of overcapitalization could not be resolved. Except for the questionable objective function for the firm and ignoring the issue of fair rate of return, Klevorick's model has been conceived correctly. It is the first attempt that has highlighted and grappled with the real issues such as regulatory lag and research and development.

In view of the above discussion, we observe again that more and more authors are now at variance with the A-J model. Baron and Taggart (8), through price regulation, although in a one period context, have disputed the existence of overcapitalization.

Their empirical study finds the existence of undercapitalization in the electric utility industry. Klevorick (37), in a dynamic context, has shown that regulation does result in inefficient production but not necessarily through overcapitalization.

All the models mentioned above are either mis-specified or have not addressed to the main issues in regulation. The issues listed below need to be considered together, in the same model.

(1) Price regulation

(2) Regulatory lag

(3) Technological change.

The purpose of this research is to address to these issues simultaneously and to show that under these conditions the firm may undercapitalize or overcapitalize. This task is undertaken in Chapter II.

2.3 REGULATORY LAG

Regulatory lag refers to the fact that the regulatory reviews are made noncontinuously in time and therefore the regulators tend to ignore the impact of technological and demand changes that might take place during the elapsed time interval.

In the period between the regulatory reviews, the price level remains constant but the firm is free to change the factor inputs. At the time of the regulatory review, the regulators may have the same information regarding the technology and the demand conditions of the firm; or the regulators may be lagging in such information and may act on the basis of information that is not completely updated. During the period between the reviews, the firm can take advantage of any favorable changes in the demand and cost conditions, and thus earn excessive returns.

Bailey and Coleman (4) extend the Averch-Johnson model to include a regulatory lag. In their model the regulatory reviews are conducted between specified points in time and regulation is excercised by the imposition of rate of return constraint. Bailey and Coleman have shown that lags provide a distinct economic benefit by encouraging a more efficient production. The amount of overcapitalization reduces as the regulatory lag is increased. If the regulatory lag is infinite, the firm would produce efficiently and earn monopoly profits. This is because an infinite lag implies that no regulation would be conducted and hence the firm would make monopoly decisions. However, when the regulatory lag is zero the firm would overcapitalize (A-J model). For a regulatory lag greater than zero, but less than infinite, the efficiency of the firm would improve--and as mentioned above, maximum efficiency would be attained at infinite lag.

The basic structure of the Bailey and Coleman model and the A-J model is the same and they share two main deficiencies:

(1) A fair rate of return constraint is imposed by the regulators. The regulatory prices are determined by the firm, and

(2) The issue of how the fair rate of return is determined by the regulators, remain unaddressed in both the models.

Elton and Gruber (25) have formulated an intertemporal financial model of the firm. A regulatory lag in the firm rate reviews is considered. The model assumes a downward sloping investment schedule for the firm. This means that the higher the amount of investment, the lower the cutoff rate of return on the marginal investment. The model concludes that if the allowed rate of return is equal to the required rate of return to the equity holders, the cutoff rate for the regulated firm and the unregulated firm are identical. In this case the regulatory lag does not affect level of the new investment by the firm. However, it is shown that when the allowed rate of return is different from the required rate of return, the regulatory lag affects the investment policy and the value of the firm.

The model given in this paper will consider regulatory lag. The model assumes that the regulators do not have up to date information about the firm. It proves that the firm would use information lag to increase future prices and earn excessive returns.

2.4 TECHNOLOGICAL CHANGE

This section, first, provides a brief discussion of the reasons, why the issue of the technical change is important in regulation. This is followed by a summary of the results of the model by Westfield (69) which has considered technical progress in regulation. The issue of technical change is of special importance both to the regulators and to the firm. For the regulators, in terms of public policy, some important points are:

(1) How does regulation affect the technological change in the regulated sector?

(2) What measures can be taken by a regulatory body to encourage the introduction of new techniques and innovations by the firm?

(3) How should regulatory prices be determined so that firms may not earn more than fair returns, while it adopts new technology or improves upon

the existing technology?

For the firm, technological change is of special interest for these reasons.

(1) By improving its technology, the firm may be able to increase its rate of return.

(2) A sophisticated technology decreases pressures of competition for the firm by increasing barriers to entry.

There are three main reasons that account for increase of pace of technical change in the regulated sector. First, under conditions of regulatory lag the firm has the incentive to introduce the cost cutting techniques and earn excessive returns during the interval between the regulatory reviews. Second, the regulatory agency may underwrite the risk of the firm and therefore encourage the firm to test a new equipment which it otherwise may not be willing to consider. Third, the firm may like to increase the barriers to entry by adopting a sophisticated technology.[1]

There is one reason that explains the slowdown of technical change in the regulated sector. The regulated firm being a natural monopoly is insulated from the pressures

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1 See the discussion on technical change in the telephone industry by William G. Shepherd (69). William M. Carton, "Technological Change in the Regulated Industries," The Brookings Institution, Washington, D.C., 1971.

of competition--hence the entry of aggressive firms that have a new and better technology is discouraged by the regulatory environment.[2]

The four reasons listed above operate simultaneously and, depending upon their magnitude, the net effect may be to encourage or slow the pace of technical change in the regulated sector.

Given next is a brief summary of the model by Westfield (69) that has analyzed the issue of technical change in the regulated sector. Westfield has classified technical change into two types. (1) Changes that affect the demand and revenue of the firm (such changes result from the change in the nature of the product or its uses). (2) Changes that result from the shifts in the production function of the firm and affect its cost function.

In this analysis, Westfield (69) has considered changes of the second type only. The model has been developed under conditions of certainty. The firm maximizes profits instead of value. The fair rate of return is subjectively determined by the regulators. The model is single period in nature and the existence of regulatory lag is ignored.

The research given in Chapter IV of this paper under-

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[2] Same as footnote 1.

takes to overcome the above shortcomings of the Westfield paper.

Except for Baron and Taggart (7) none of the models discussed above analyze the question of the determination of fair rate of return. The fair rate of return is subjective-ly determined by the regulators. The exogenous treatment of the fair rate of return is erroneous. The following presents a brief summary of the models of regulation developed by Leland (39) and Myers (55). Both of these models determine a fair rate of return for the regulated firm by considering the equilibrium risk-return relationships in the capital markets. Leland (39) suggests that under conditions of uncertainty the regulatory agency should set a product price at which the stock market value of the firm is equal to the value of the assets of the firm. This would provide a fair rate of return to the firm, and all shareholders would be unanimous with respect to the production decisions of the firm. The resulting output would imply a simultaneous production and capital market equilibrium. The fair rate of return earned by the stockholders, would be commensurate with the risk of the firm.

Although it develops an objective criteria for the determination of the fair rate of return, the Leland model is difficult to implement. Since the assets of the firm are non-homogeneous and of different vintages, it is difficult to find their market value and thus construct the regulatory constraint.

Myers (55) has developed a simple one-period model of regulation under uncertainty. He has shown that a regulated monopoly would only make perfectly competitive investment if a rate of return equal to the highest achievable under perfectly competitive conditions is allowed--and no rationing is permitted to the firm. These results are due to uncertainty in the revenue and cost conditions and are unrelated to the A-J type phenomenon.

2.5 QUALITY OF THE PRODUCT

The regulatory objective is to make sure that the firm provides a "fair" quality product to the consumers at "fair" prices. In practice, the regulatory agencies enforce the product prices, they pay scant attention to the product quality. The firm is free to choose the quality levels it feels appropriate and may earn excessive return. The quality levels planned by the firm depend upon the regulatory prices and the demand and production conditions.

Levehari and Peles (42) have formulated a model of firm behavior with respect to quality under different conditions of market structure. This model is developed under certainty. The authors do not address to the question of what should be the criterion for regulation. In this model regulation is conducted by arbitrarily fixing the quantity and quality that the firm should produce.

Spence (75) has also analyzed the firm quality decision with or without regulation. Spence's analysis of the regulatory environment, which is game theoretic in nature, is pragmatic in approach. The analysis is conducted under complete certainty. The regulators seek to maximize the social surplus which is the sum of consumer surplus and firm surplus. Both, Levehari and Peles (42) and Spence (75) have limited the analysis to certain demand and production conditions for the firm. Neither addresses the question of how the fair rate of return for the firm should be determined.

This Chapter concludes the discussion on four fundamental issues of firm regulation (efficiency in production, regulatory lag, technological change and quality of the product). In the next Chapter, an intertemporal model of firm regulation is developed. The model considers the inter-action of the regulatory lag with the technological change when the regulators behave passively. Regulation is conducted through price controls rather than by giving a fair rate of return constraint to the firm. The next Chapter shows that the existence of regulatory lag would encourage the firm to produce inefficiently.

CHAPTER III

A SINGLE PERIOD MODEL OF FIRM BEHAVIOR WITH QUALITY ATTRIBUTES

3.1 INTRODUCTION

This chapter analyzes the firm's quality decisions under different conditions of market structure. Three conditions of market structure are compared. They are: a monopoly, a regulated monopoly and a perfectly competitive industry. The chapter starts with a description of the market and production conditions of the firm. Then, a description of the perfectly competitive market, where the product prices are determined through industry concensus, is given. The equilibrium price and product quality levels are determined. This is followed by the analysis of monopoly decisions. Finally, the equilibrium price and quality levels in a regulated industry are determined. It is shown that for the regulators to eliminate the monopoly's excess returns, both quality and price controls are necessary.

3.2 THE ENVIRONMENT

The analysis assumes the following market and production conditions.

Market Conditions

The firm faces an uncertain demand curve. The expected industry demand for the product is a function of the quality and the price. It is assumed that the quality of the product is a cardinal measure. All the consumers in the market give the same cardinal index to the same quality of the product. P, X and q are the price, expected market demand and quality of the product respectively. The monopolist faces a separable demand function of the following type:

$$\tilde{x} = \tilde{\theta} x(P,q)$$

$\tilde{\theta}$ is the multiplicative stochastic element. It may assume values between θ and α. Such that:

$$E(\tilde{\theta}) = 1 \qquad E(\tilde{x}) = E(\tilde{\theta})x = x \tag{3.1}$$

COV $(\tilde{\theta};\tilde{r}_m)$; is the covariance of $\tilde{\theta}$ with $\tilde{r}_m$. $\tilde{r}_m$ is the return on the market portfolio.

x(P,q) is the industry demand function under certainty. The demand at the same price and quality under certainty coincides with the expected demand under the uncertain conditions that are assumed here. The industry demand for any state of nature is equal to the value of the stochastic element for that state of nature times the demand under certainty.

The expected demand function has the following characteristics:

$$\frac{\partial x}{\partial p} < 0, \quad \frac{\partial x}{\partial q} > 0, \quad \frac{\partial p}{\partial q} > 0, \quad \frac{\partial^2 p}{\partial q^2} < 0 \text{ and } \frac{\partial^2 x}{\partial p^2} > 0. \qquad (3.2)$$

The expected demand for a given quality level is downward sloping and convex to the origin. Expected demand remaining constant, consumers will be willing to pay a higher price when the product quality is improved. For a given expected demand the P-q schedule is concave downward. The rate of increase in price decreases, as quality is improved. The market will reach near saturation at some levels of quality and would not be willing to pay more for additional improvements in quality. Valuation of marginal quality is positive but decreases with increases in quality. And if the price remains the same, any improvements in quality will induce consumers to buy additional quantities of the product. Therefore, price remaining constant, increases in quality will increase the market expected demand.

Before the uncertainty is resolved, the firm does not know how much will be demanded of it. Expost, it has to supply and hence produce the entire demand.

This chapter compares the monopoly decisions under the above conditions with those of the perfectly competitive industry. To be able to accomplish above, a perfectly competitive environment of the following nature is assumed.

Perfectly Competitive Industry

It is assumed that there are numerous buyers and sellers in the market. All have complete and costless access to all information. Through a futures contract, the numerous participants agree at a price for which they will buy or sell the product. The analysis assumes that all participants have homogenous expectations about the industry demand. The industry demand is stochastic and its characteristics are discussed in the previous section. Through homogenous expectations and industry concensus one price will exist for the same quality. The quantity that would be demanded at the concensus price is uncertain. It is assumed that each firm inherits a demand distribution similar to the industry. Industry demand is shared by the firms in accordance with a criteria already agreed upon. The firms may agree to divide the actual industry demand among themselves in proportion to their expected supply levels. Expost, all firms supply all that is demanded at the contracted price. Hence, for any firm in the perfectly competitive industry, the demand is uncertain. For a given product price and quality each firm knows its expected demand.

A perfectly competitive industry where the price of the product is determined through industry concensus, and the demand is stochastic, is also considered by Hymans (30) and Dreze and Grabszewicz (24). Their analysis determines the firm output levels that maximize the expected utility of the firm.

It is assumed that p_c, x_c and q_c are the price, expected quantity and the quality supplied by the perfectly competitive industry. X_f is the expected quantity supplied by the representative firm. Similar to the industry demand, the firm demand function is also of the separable type. The industry demand function is given by:

$$\tilde{x}_c = \theta \; x_c(p_c, q_c)$$

The demand function of any firm in the perfectly competitive industry is given by:

$$\tilde{x}_f = \tilde{\theta} \; x_f$$

The distribution of demand for the monopoly firm and any firm in the perfectly competitive industry is similar.

In addition to the industry demand conditions stated above, the following capital market environment is assumed to exist.

It is assumed that the necessary conditions exist for the Capital Asset Pricing Model equilibrium to hold. Investors have utility functions that are defined over the means and variance of the returns. There are no taxes.

In addition to the market conditions described above, the firm is assumed to have the following production conditions.

Production Conditions

The production (of the output) needs two factors--labor and capital. The factors are bought in perfect markets; and the cost of each factor is known, certain, and remains constant. For any given quality level, the firm has a constant return to scale production function which means that the quality remaining constant the total cost function is linear.

The above implies that the firm has a linear expansion path and with the quality remaining constant, the optimal factor input ratio remains constant at all levels of output. For a given quality level the marginal cost is constant and is equal to the average cost.

L(q) and K(q) are the labor and capital required per unit of output at the quality level of q. W is the wage per unit of labor. Then the cost of production per unit is given by:

$$MC(q) = WL(q) + K(q) \tag{3.3}$$

where MC(q) is the marginal cost per unit at the quality level of q.

It is assumed that the marginal cost increases with quality. So $\frac{\partial MC(q)}{\partial q} > o$ for all levels of output. It is further assumed that $\frac{\partial^2 MC(q)}{\partial q2} > 0$. This means, that the rate of increase of cost increases, as the product quality is improved. Output remaining constant, the total cost function is convex to the origin and is an increasing function of quality.

The above assumption of increasing marginal costs due to quality is believed to be reasonable and representative of many known production processes. This implies that the increases in quality would require additional inputs for capital and labor.

It was discussed earlier, that the firm determines a price that it plans to charge; and it would supply all that is demanded at that price. For a given price the demand is uncertain and has a known probability distribution. The quantity that the firm would need to supply is also uncertain and has the same distribution as the demand. The uncertainty in the supply levels makes the total cost of output uncertain, even though, marginal cost per unit is constant at all levels of output.

Assuming that C is the total cost of output and $\tilde{X}_f$ is the demand or supply for the firm. The total cost of output can be given by:

$$\tilde{C} = \left[WL(q) + K(q)\right] \tilde{X}_f \qquad (3.4)$$

The following additional notations are assumed:

$\tilde{Y}_f$ = The firm's excess return

Y_f = The firm's expected excess return

ϕ_f = The certainty equivalent of the firm's excess return

i = The riskless rate of return

$\tilde{r}_m$ = The return on the market portfolio. The market portfolio holds all the securities in the market in proportion to their market value.

σ_m^2 = The variance of market return

λ = The market price of risk

P = The exante price determined by the firm.

The revenue of the firm is given by: $P\tilde{X}_f$

The firm excess return can be determined after subtracting the total costs from the total revenue. Such that:

$$\tilde{y}_f = (P - MC)\ \tilde{X}_f$$

By the application of Capital Asset Pricing Model, the certainty Equivalent of total returns at the end of the period can be determined as follows:

$$CEQ(\tilde{y}_f) = E(\tilde{y}_f) - \lambda\ COV(\tilde{y}_f, \tilde{r}_m)$$

Substituting that: $\tilde{y}_f = (P\text{-}MC)\ \tilde{x}_f$

$$E(\tilde{y}_f) = y_f = (P\text{-}MC)\,x_f$$

and $COV(\tilde{y}_f, r_m) = y_f COV(\tilde{\theta}, \tilde{r}_m)$

$CEQ(y_f)$ can be written as follows:

$$\phi_f = (P\text{-}MC)\,x_f\left[1 - \lambda\ COV(\tilde{\theta}, \tilde{r}_m)\right] \qquad (3.5)$$

(3.5) implies that the certainty equivalent of excess return earned by the firm is directly proportional to the expected quantity that the firm plans to produce and supply. The above assumes that the product quality remains constant. $1 - \lambda COV(\tilde{\theta}\tilde{r}_m)$ is the certainty equivalent of a dollar of excess return. It depends upon the uncertainty of the industry demand and its relationship with the return on the market portfolio.

This chapter analyzes the firm behavior under three conditions of market structure. They are:

1. Perfect Competition
2. Monopoly, and
3. Regulated monopoly.

Under each of the above conditions, it is assumed that the firm returns follow the Principle of Increasing Uncertainty.

Principle of Increasing Uncertainty

Principle of Increasing Uncertainty means that, as the net expected revenue by the firm increases, its riskiness also increases.

Leland (40) considers that the Principle of Increasing Uncertainty has a strong intuitive appeal. He determines the decisions of a quantity or a price setting monopolist when the firm faces an Uncertain demand. The firm returns follow the Principle of Increasing Uncertainty.

The present study assumes that the total risk of the net cash returns increases with the increase in its expected value. It is assumed that both the systematic risk and unsystematic risk increase with the increase of expected net cash returns. This implies that the covariance of the net cash returns with the market returns, increases with the increase of expected net cash returns.

Such that: $$\frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial y_f} > 0 \qquad (3.6)$$

where y_f is the expected net cash returns.

In addition to the production conditions described above, it is assumed that the firm has a single period horizon. The firm makes exante decisions that maximize the end of period CEQ(excess return). This also implies the firm makes exante decisions that maximize its net present value.

The next section analyzes the firm behavior when it is working in a perfectly competitive environment.

Perfectly Competitive Industry

All firms in the perfectly competitive industry have homogeneous expectations about the industry demand. They form an industry consensus about the price at which each firm would sell the product. Based on the expected market demand, each firm plans its expected supply level. Each firm is small enough that, individually, it cannot affect the market demand conditions. Constant returns to scale production function is a result of constant factor productivity at all levels of output. After the industry demand is known, the quantity demanded from each firm is determined by the division of the industry demand by the number of firms in proportion to their expected supply levels.

Irrespective of the market structure, new firms would find it beneficial to enter; if they can earn normal or better than normal returns in the business. When the returns to scale are constant, and the market is perfectly competitive all firms would earn a zero CEQ(Excess Return)— irrespective of the size or age of the firm. The firms that are already in business would earn the same rate of return as those just entered. If due to industry expansion, the returns to existing firms are more than normal, new firms would enter and increase the expected supply. This would lower prices and CEQ(excess returns) for all firms. The existence of constant returns to scale would ensure a zero net present value for any firm in the industry.

When the technology is decreasing returns to scale, there exists an optimal firm size. If the industry is perfectly competitive, all firms would plan to operate at the optimal expected supply levels. At the optimal firm size, the firm would earn a positive CEQ(Excess Return). When the expected market demand is more than the expected supply by the existing firms, new firms would enter. The existing firms would keep on earning positive excess returns and the new firms may earn equal to or less than the existing firms.

The following analysis assumes that the firm quality decisions are made exante. The firm objective function is to maximize, ϕ_f, the CEQ(Excess Return).

The industry price P_c is unaffected by the firm decisions. For the constant returns to scale production function, the firm expected supply is arbitrarily determined by the firm. The subscript c and f denote the industry and firm respectively.

The problem of any firm in the perfectly competitive industry can be stated as:

$$\underset{(q_f)}{\text{MAX}} \quad \phi_f \ (P_c, \ X_f, \ q_f) = 0 \tag{3.7}$$

The necessary conditions for the above are:

$$\frac{\partial \phi_f}{\partial q_f} \ (P_c, \ X_f, \ q_f) = 0 \tag{3.8}$$

$$\phi_f \ (P_c, \ X_f, \ q_f) = 0 \tag{3.9}$$

(3.8) implies that the firm sets its quality level such that the marginal change in the CEQ(Excess Return) is equal to zero. (3.9) implies that the Optimal CEQ(Excess Return) earned by the firm is equal to zero.

Rewriting (3.9) after substituting the value of ϕ_f from (3.5)

$$\phi_f = x_f \left[P_c(q_c, X_c) - MC(q_c)\right]\left[1 - \lambda \ \text{COV}(\tilde{\theta}, \tilde{r}_m)\right] = 0$$

$(1 - \lambda \ \text{COV}(\tilde{\theta}, \tilde{r}_m))$ is the certainty equivalent of a dollar of expected net revenue and is positive. For (3.10) to hold the following should be true

$$P_c(q_c, X_c) - MC(q_c) = 0$$

or $$P_c(q_c - X_c) = MC(q_c) \quad (3.10)$$

Hence the equilibrium product price is equal to the marginal cost.

A slight increase in the planned total expected supply in the industry would reduce the concensus market price lower than the marginal cost. Considering the anticipated losses, some firms would like to restrict the expected output or some firms would leave the industry. This would increase the anticipated market price to the marginal cost and re-establish the market equilibrium.

The above shows that all firms in the perfectly competitive industry (with constant returns to scale technology) operate such that the price is equal to the marginal cost.

Rewriting (3.8):

$$\frac{\partial \phi f}{\partial q_f} = \frac{\partial}{\partial q_f} \left[P_c\ (q_c, X_c) - MC(q_c)\right] X_f \left[1 - \lambda\ \mathrm{COV}(\tilde{\theta} r_m)\right] = 0 \quad (3.11)$$

After simplification (3.11) can be written as follows:

$$X_f \left\{ \left[\left(\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \right) \left(1 - \lambda \mathrm{COV}\ (\tilde{\theta} r_m) \right] \right. \right.$$

$$\left. + \left[P_c\ (q_f, X_c) - MC(q_f)\right] - \lambda \frac{\partial \mathrm{COV}(\tilde{\theta} r_m)}{\partial y_f} \cdot \frac{\partial y_f}{\partial q_f} \right\} = 0 \quad (3.12)$$

Substituting $\frac{\partial y_f}{\partial q_f} = X_f \left[\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \right]$

Simplifying (3.12), and rewriting:

$$\left[\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f}\right]\left[(1 - \lambda COV(\tilde{\theta},\tilde{r}_m)) + (P_c - MC(q_f))(-\lambda \frac{\partial COV(\tilde{\theta},\tilde{r}_m)}{\partial y}\right] = 0 \qquad (3.13)$$

Because P = MC, therefore, the last term in (3.13) is zero. Rewriting (3.13):

$$\left(\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f}\right)\left(1 - \lambda COV(\tilde{\theta},\tilde{r}_m)\right) = 0 \qquad (3.14)$$

as $1 - \lambda COV(\tilde{\theta},\tilde{r}_m) > 0$

hence $\frac{\partial P_c}{\partial q_f} = \frac{\partial MC}{\partial q_f}$ (3.15)

(3.15) is independent of firm expected supply levels. This implies that any firm in the perfectly competitive industry would provide quality such that the marginal value of quality is equal to the mqrginal cost due to quality. This implies that if a price P_c exists in the perfectly competitive industry, then all firms would sell the same quality product.

A simultaneous solution of (3.8) and (3.9) will provide the equilibrium price and quality levels that would exist in the perfectly competitive industry. The second order conditions are shown to be satisfied in Appendix (3.1).

Fig. (3.1) represents the industry equilibrium. X_1, X_2 and X_c are the expected industry supply levels.

$$X_1 < X_2 < X_c$$

In this case the firm equilibrium is made possible by the assumptions of:

Increasing marginal cost due to quality and decreasing marginal valuation of quality by the consumers.

These assumptions are reasonable with regard to real world conditions.

X_c is the equilibrium expected industry demand. From (3.10) and (3.15), the industry equilibrium will exist at that output quality where price is equal to the firm marginal cost. The change in firm price due to quality is equal to the change in firm marginal cost due to quality.

The above proves that when all firms face the same price and cost function; then, they produce products of the same quality. Hence, only a unique quality level would be produced by the perfectly competitive industry.

The next section presents the discussion of the monopoly decision.

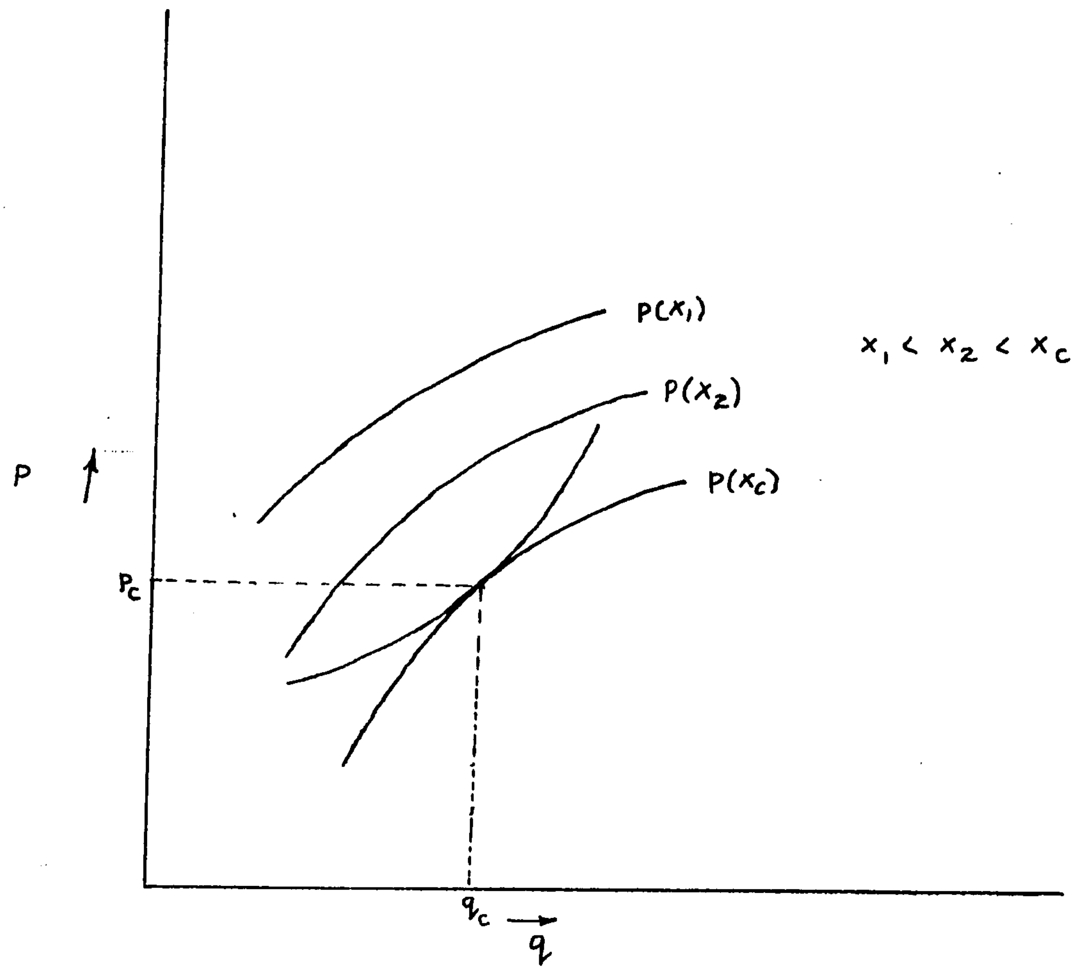

FIGURE 3.1

Monopoly

This section analyzes the market price, quality and expected demand levels when the industry has only one supplier.

It is generally believed that the industry production process affects and is affected by the industry market structure. However, for purposes of this analysis, it is assumed that the production process of this monopoly is the same as that considered, previously, for the firms in the perfectly competitive industry.

The cost function has constant returns to scale but is increasing with respect to quality. The subscript m denotes a monopoly. Let $D(P_m, q_m)$ be the industry expected demand at price P_m and quality q_m. Let X_m be the expected supply level by the firm.

The monopolist would determine the price P_m, and quality q_m, that maximizes the CEQ(Excess Return) for the firm (end of period) CEQ(Excess Return) is denoted by ϕ_m. Price and quality decisions are made ex-ante. However, after the demand uncertainty is resolved and the exact quantity demanded is known, the firm would produce and supply the entire demand.

The problem of the monopolist can be stated as:

$$\underset{(P_m, q_m)}{\text{Max.}} \left[\phi_m \right] \tag{3.16}$$

$$\text{S/T} \quad X_m = D\ (P_m, q_m);\ X_m,\ P_m \text{ and } q_m \geq 0$$

$$\text{Where} \quad \phi_m = \left[P_m - MC(q_m) \right] X_m \left[1 - \lambda\ COV(\tilde{\theta}, \tilde{r}_m) \right]$$

$$Y_m = \left[P_m - MC(q_m) \right] X_m$$

The First Order Conditions for the constrainted optimization given in (3.16) are:

$$\frac{\partial \phi_m}{\partial X_m} = \frac{\partial \phi_m / \partial P_m}{-\partial D / \partial P_m} = \frac{\partial \phi_m / \partial q_m}{-\partial D / \partial q_m} \tag{3.17}$$

Where

$$\frac{\partial \phi_m}{\partial X_m} = \left[P_m - MC(q_m) \right] \left[1 - COV(\tilde{\theta}, \tilde{r}_m) - \lambda \frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial Y_m} X_m \frac{\partial Y_m}{\partial X_m} \right] \tag{3.18}$$

$$\frac{\partial \phi_m / \partial P_m}{-\partial D / \partial P_m} = \frac{X_m \left[1 - \lambda\ COV(\tilde{\theta}, \tilde{r}_m) - (P_m - MC(q_m)\ \lambda \frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial Y_m} \cdot \frac{\partial Y_m}{\partial P_m} \right]}{-\frac{\partial D}{\partial P_m}} \tag{3.19}$$

And,

$$\frac{\partial \phi_m / \partial q_m}{-\partial D / \partial q_m} = \frac{-X_m (1 - \lambda COV(\tilde{\theta}, \tilde{r}_m)) \frac{\partial MC}{\partial q_m} + (P_m - MC) X_m - \lambda \frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial Y_m} \cdot \frac{\partial Y_m}{\partial q_m}}{-\partial D / \partial q_m} \tag{3.20}$$

The following analysis shows that the monopoly price is higher than the marginal cost of the product.

Simplifying (3.18) and (3.19)-by substituting

$$\frac{\partial Y_m}{\partial X_m} = P_m - MC(q_m)$$

$$\text{and} \quad \frac{\partial Y_m}{\partial P_m} = X_m$$

From (3.18) and (3.19) it can be shown that:

$$- \left[P_m - MC(q_m) \right] \left[1 - \lambda\ COV(\tilde{\theta}, \tilde{r}_m) - \lambda \cdot \frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial Y_m} . X_m . (P_m - MC(q_m)) \right]$$

$$= X_m \cdot \frac{\partial P_m}{\partial X_m} \left[1 - \lambda\ COV(\tilde{\theta}, \tilde{r}_m) - (P_m - MC(q_m))\ \lambda \frac{\partial COV(\tilde{\theta}, \tilde{r}_m)}{\partial Y_m} X_m \right]$$

This can be further simplified as:

$$\left[P_m - MC(q_m) + X_m \frac{\partial Pm}{\partial X_m}\right]\left[1 - \lambda \ COV\ (\tilde{\theta},\tilde{r}_m) + (P_m - MC)\ \frac{\partial COV\ (\tilde{\theta},\tilde{r}_m)}{\partial Y_m}\right] = 0 \qquad (3.21)$$

The second term (3.21) is positive for the following reasons:

a. $1 - \lambda\ COV(\tilde{\theta},\tilde{r}_m) > 0$

(it is the certainty equivalent of a dollar of net expected cash return)

b. $\frac{\partial COV\ (\tilde{\theta},\tilde{r}_m)}{\partial Y} > 0$

(the Principle of Increasing Uncertainty)

c. $(P_m - MC) \nless 0$

(a firm would not like to continue, if it knows that the expected net revenues are negative).

For the above reasons the first term of (3.21) is equal to zero.

$$P_m - MC(q_m) + X_m \frac{\partial P_m}{\partial X_m} = 0 \qquad (3.22)$$

Substituting $\frac{\partial P_m}{\partial X_m} < 0$, (3.22) implies that

$$P_m - MC(q_m) > 0 \qquad (3.23)$$

Hence, the monopoly price is higher than the marginal cost or in this case, the average unit cost of the product.

The following shows that the certainty equivalent of a dollar of expected excess return earned by the monopolist is lower than that earned by any firm in the perfectly competitive industry.

From (3.10) and (3.23), the following is true

$$\left[P_m - MC(q_m)\right] X_m > \left[P_c - MC(q_c)\right] X_f \qquad (3.24)$$

$$\text{or} \qquad Y_m > Y_f$$

(3.24) means that the expected net cash return of the monopolist is higher than all firms in the perfectly competitive industry. (The expected net cash return in the perfectly competitive industry is zero.)

From the Principle of Increasing Uncertainty and (3.24) it can be stated that:

$$\underset{\text{(monopoly)}}{COV(\tilde{\theta}, \tilde{r}_m)} > \underset{\text{(perfectly competitive)}}{COV(\tilde{\theta}, \tilde{r}_m)}$$

$$\text{and} \quad \underset{\text{(Monopoly)}}{1 - \lambda COV(\tilde{\theta}, \tilde{r}_m)} < \underset{\text{(perfectly competitive.)}}{1 - \lambda COV(\tilde{\theta}, \tilde{r}_m)} \qquad (3.25)$$

The term in (3.25) is the certainty equivalent of a dollar of net expected cash returns. Hence the certainty equivalent of a dollar of net expected cash return for a monopoly is lower than the certainty equivalent of a dollar of the net expected cash return for a firm in the perfectly competitive industry.

The following analysis shows that a monopolist would set the price and quality such that the market valuation of the marginal quality is equal to the costs due to marginal quality.

Equations (3.19) and (3.20) can be written as:

$$X_m \frac{\partial D}{\partial q_m}\left[1-\lambda\, COV(\tilde{\theta},\tilde{r}_m) - (P_m - MC(q_m))\,\lambda \cdot \frac{\partial COV(\tilde{\theta}\tilde{r}_m)}{\partial Y_m} \cdot \frac{\partial Y}{\partial P_m}\right]$$

$$= \frac{\partial D}{\partial P_m}\left[- X_m\,(1-\lambda\, COV(\tilde{\theta},\tilde{r}_m))\,\frac{\partial MC}{\partial q_m} - (P_m - MC)\cdot X_m\,\frac{\partial COV(\tilde{\theta}\tilde{r}_m)}{\partial Y_m} \cdot \frac{\partial Y_m}{\partial q_m}\right] \quad (3.26)$$

making the following substitutions

$$\frac{\partial Y_m}{\partial P_m} = X_m \text{ and } \frac{\partial Y_m}{\partial q_m} = \frac{-\partial MC}{\partial q_m} X_m\,,\ \frac{\partial P_m}{\partial q_m} = -\frac{\partial D}{\partial q_m}\Big/\frac{\partial D}{\partial P_m}$$

(3.26) can be written as:

$$\frac{\partial P_m}{\partial q_m} = \frac{\partial MC}{\partial q_m}\cdot\frac{X_m}{X_m}\;\frac{\left[1-\lambda\, COV(\tilde{\theta}\tilde{r}_m) - \lambda\,(P_m - MC)\cdot X_m\cdot \frac{\partial COV(\tilde{\theta}\tilde{r}_m)}{\partial Y_m}\right]}{\left[1-\lambda\, COV(\tilde{\theta}\tilde{r}_m) - \lambda\,(P_m - MC)\cdot X_m\cdot \frac{\partial COV(\tilde{\theta}\tilde{r}_m)}{\partial Y_m}\right]} \quad (3.27)$$

or $$\frac{\partial P_m}{\partial q_m} = \frac{\partial MC}{\partial q_m}$$

The left hand side of (3.27) shows the change in price for any small change in the product quality. In other words it is the marginal valuation of quality by the consumers. While the right hand side represents the change in the marginal or average cost due to change in quality.

Hence at the optimal quality level the marginal valuation of quality by the consumers is equal to the marginal costs due to quality. It was shown earlier that this condition also holds for any firm in the perfectly competitive industry.

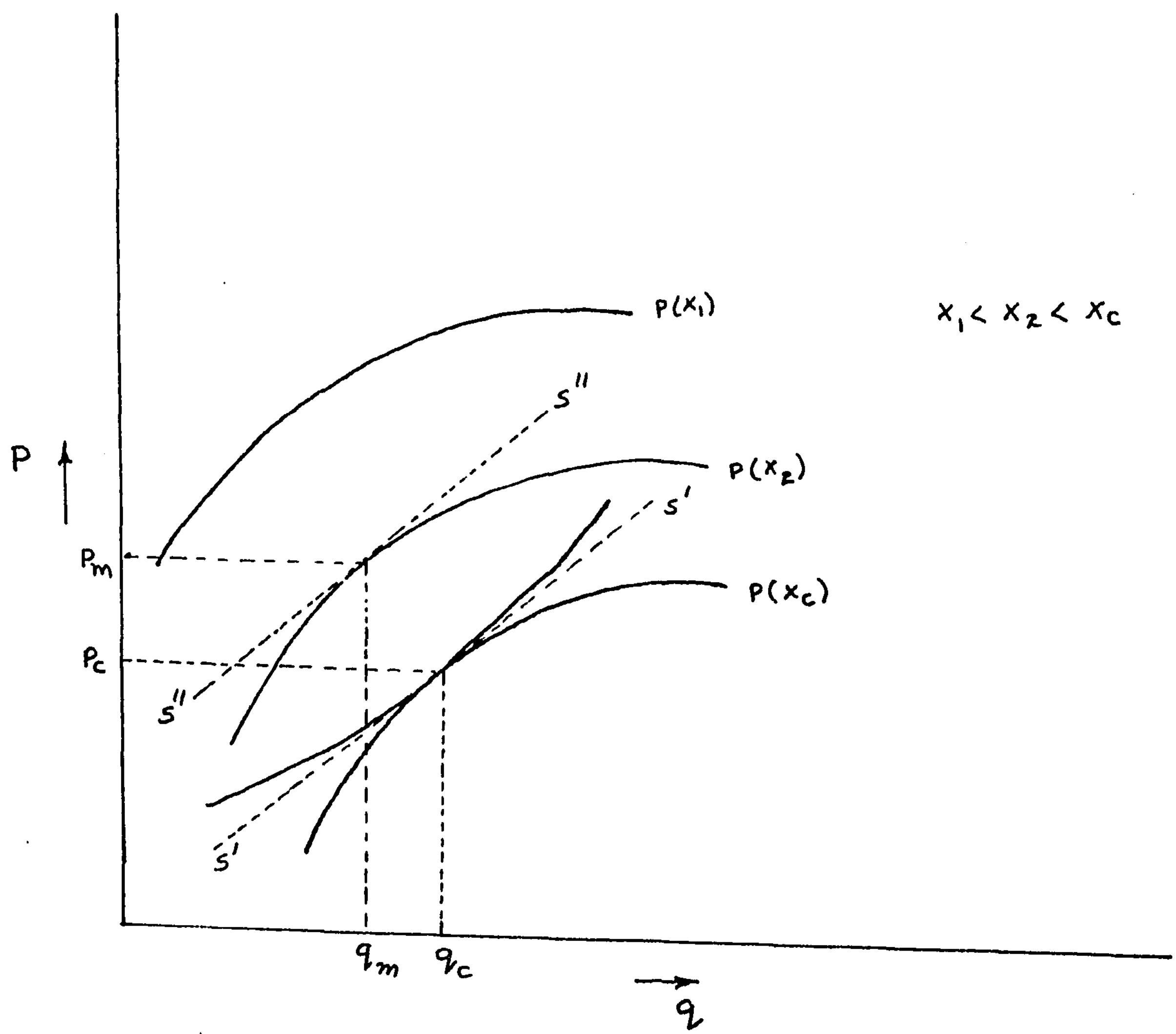

FIGURE 3.2

Comparison of Monopoly Decisions with the Perfectly Competitive Industry

The following presents that the expected supply levels for a monopolist is lower than the expected supply anticipated for the perfectly competitive industry.

The necessary First Order Conditions for the firm equilibrium in the perfectly competitive industry are given in (3.10) and (3.15)

$$P_c(q_c, X_c) = MC(q_c) \tag{3.10}$$

$$\frac{\partial P_c(q_c, X_c)}{\partial q_c} = \frac{\partial MC(q_c)}{\partial q_c} \tag{3.15}$$

The corresponding necessary First Order Conditions for a monopolist are given in (3.22) and (3.27)

$$P_m - MC(q_m) + X_m \frac{\partial P_m}{\partial q_m} = 0 \tag{3.22}$$

$$\frac{\partial P_m}{\partial q_m}(q_m, X_m) = \frac{\partial MC(q_m)}{\partial q_m} \tag{3.27}$$

Also we know from the demand and production conditions, that the cost function is convex downward in quality while the price function is concave downward in quality. Such that:

$$\frac{\partial^2 MC}{\partial q^2} > 0 \quad \text{and} \quad \frac{\partial^2 P}{\partial q^2} < 0.$$

Fig. (3.2) represents the industry equilibrium for the perfectly competitive industry and the monopoly firm.

If we start at the equilibrium of the perfectly competitive industry and reduce the quantity supplied from X_c to X^1.

Because $\partial P/\partial X < 0$

Therefore, there exists a $X^1 < X_c$ which makes $P(q_c, X^1) > P(q_c, X_c)$

By changing X sufficiently, for a known q_c and X^1 can be found that satisfies (3.22). Now, since $\partial P/\partial q > 0$; $\partial^2 P/\partial q^2 < 0$; $\partial MC/\partial q > 0$ and $\partial^2 MC/\partial q^2 > 0$. An X^1 and q^1 exist.

Such that: $$\frac{\partial P}{\partial q}(X^1, q^1) = \frac{\partial MC(q^1)}{\partial q^1}$$

which is also the first order condition for a monopolist.

Hence by changing X and q, there exists a $X_m < X_c$ and $q_m > q_c$ that satisfies the necessary first order conditions for a monopolist.

Hence the monopoly would plan to supply a lower expected quantity ($X_m < X_c$) than the perfectly competitive industry.

The following analysis shows that a monopolist would supply (a) a higher quality product if $\partial^2 P/\partial q \partial X < 0$; and (b) a lower quality product if $\partial^2 P/\partial q \partial X > 0$ than the perfectly competitive industry. $\frac{\partial^2 P}{\partial q \partial x} < 0$ implies that the marginal revenue product of quality decreases as the supply levels increase. The opposite is true for $\partial^2 P/\partial q \partial X > 0$.

(a) When $\frac{\partial^2 P(X,q)}{\partial q \partial X} < 0$.

Rewriting (3.15), the necessary condition for the perfectly competitive industry.

$$\frac{\partial P(q_c, X_c)}{\partial q} = \frac{\partial MC(q_c)}{\partial q}$$

Because $\partial^2 P/\partial q\partial X < 0$; therefore for an $X < X_c$, the following holds:

$$\frac{\partial P(X, q_c)}{\partial q} > \frac{\partial MC(q_c)}{\partial q} \tag{3.30}$$

Now, because $\frac{\partial^2 P}{\partial q^2} < 0$ and $\frac{\partial^2 C}{\partial q^2} > 0$

therefore, an increase in q from q_c would decrease $\frac{\partial P(q_c, X)}{\partial q}$ and increase $\frac{\partial MC}{\partial q_c}$. Hence, there exists a $q > q_c$ and $X < X_c$ for which (3.30) would turn into an equality. Or this would satisfy the First Order Conditions for a monopolist.

Hence for $\frac{\partial^2 P}{\partial q\partial X} < 0$ the monopolist would supply a higher quality than the perfectly competitive levels.

An intuitive explanation of the above would be the following: By restricting output supply, the monopolist raises the marginal valuation of quality. And it is then advantageous to produce higher quality.

(b) when $\frac{\partial^2 P(X,q)}{\partial q\partial X} > 0$.

for an $X < X_c$, (3.15) the necessary condition for a firm in the perfectly competitive industry would change to the following inequality.

$$\frac{\partial P(X,q_c)}{\partial q} < \frac{\partial MC(q_c)}{\partial q} \tag{3.31}$$

Since $\frac{\partial^2 P}{\partial q^2} < 0$ and $\frac{\partial^2 MC}{\partial q^2} > 0$, a decrease of q from q_c would give a q for which $\frac{\partial P(X,q)}{\partial q} = \frac{\partial MC(q)}{\partial q}$

Hence, there exists a $q < q_c$ and a $X < X_c$ for which the necessary First Order Condition for a monopolist are satisfied.

For $\frac{\partial^2 P}{\partial q \partial X} > 0$, the monopolist would supply less quality than the perfectly competitive levels.

An intuitive explanation of above would be the following: By restricting output supply, the monopolist reduces the marginal valuation of quality and hence finds advantageous to lower the quality. The next section analyzes the decisions of the regulated monopoly.

3.6 REGULATED MONOPOLY

The following analyzes, the price, the expected supply, and the quality provided by a regulated firm.

The objective of the regulators is to provide price control, or quality control or both so as to eliminate excess returns to the firm. On the other hand, the objective of the firm is to maximize its net present value by choosing the firm price and quality.

If the regulators provide only price controls, then the firm would be free to choose the quality level. The expected supply would be determined by the expected demand. However, if the regulators are only concerned about the product quality and apply quality controls to the firm, then the firm would be free to choose the price.

The following considers three types of firm regulatory practices. They are:

1. Price controls only
2. Quality controls only, and
3. Both price and quality controls.

Let P_r, q_r, and X_r be the price, quality and expected supply from the regulated firm.

PRICE CONTROLS ONLY

In this case, the regulators fix a price level at which the product must be sold. The firm fixes the quality and expected quantity is determined through the expected demand function. The following analysis shows that only price controls by the regulators would not eliminate the monopoly excess returns. The regulated firm would set a quality level that would be lower than the one supplied by the perfectly competitive industry. The price given by the regulators would be higher than the marginal cost of the product.

The regulators make an assumption about the quality of the product that they expect the firm would supply.

Considering q to be the quality, the regulators' objective is to fix the product price P_r. The reaction of the regulators is to set a price that provides a fair rate of return to the firm.

The reaction function of the regulators is:

CEQ(excess return) = 0

or

$$X_r(P_r,q)\ (P_r-MC)\ (1-\lambda\ COV(\tilde{\theta},\ \tilde{r}_m)) = 0 \qquad (3.32)$$

On the other hand, the reaction of the firm is to set q_r, that, for a given price level maximizes the value of the firm.

The problem of the firm is:

$$\underset{(q_r)}{\text{Maximize}}\ \text{CEQ(excess return)} \qquad (3.33)$$

$$\text{S/T} \qquad X_r - D(P_r,q_r) = 0$$

The necessary condition for the problem given in (3.33) is:

$$\left[P_r-MC(q_r)\right]\left[1-\lambda Cov(\tilde{\theta},\tilde{r}_m)\right]\frac{\partial D}{\partial q} - D\left[1-\lambda\ COV(\tilde{\theta},\tilde{r}_m)\right]\frac{\partial MC}{\partial q}$$

$$+ D\left[P_r-MC(q_r)\right]\left[-\lambda\ \frac{\partial Cov(\tilde{\theta},\tilde{r}_m)}{\partial Y}\cdot\frac{\partial Y}{\partial q}\right] = 0 \qquad (3.34)$$

$$\text{where } Y = \left[P_r-MC(q_r)\right]D \qquad (3.35)$$

$$\text{and } \frac{\partial Y}{\partial q} = \left[P_r-MC(q_r)\right]\frac{\partial D}{\partial q} - D\frac{\partial MC}{\partial q} \qquad (3.36)$$

After substituting (3.36), (3.34) can be written as:

$$\left\{\frac{\partial D}{\partial q}\left[P_r-MC(q_r)\right] - D\frac{\partial MC}{\partial q}\right\}\left\{1-\lambda\ Cov(\tilde{\theta},\tilde{r}_m) - \lambda\ D\frac{\partial Cov}{\partial Y}(P-MC)\right\} = 0 \qquad (3.37)$$

The First Order Condition is satisfied,

When in (3.37), first and/or second term is equal to zero. The first term represents the change in expected net revenue for the changes in quality. While the second term represents the adjusted certainty equivalent of a dollar of net expected revenue. The certainty equivalent of a dollar of net expected revenue must always be positive. Hence for (3.37) to hold the following must be true.

$$\frac{\partial D}{\partial q} \quad (Pr - MC(q_r)) - D \frac{\partial MC}{\partial q_r} = 0 \qquad (3.38)$$

Since $\frac{\partial D}{\partial q} > 0$, and $\frac{\partial MC}{\partial q_r} > 0$.

Hence (3.38) would hold only if

$P_r - MC(q_r) > 0$

and $P_r > MC(q_r)$ (3.39)

The above has shown that when the firm is given a price level that it must charge; it would reduce the product quality such that the cost/unit of the product is lower than its price. The certainty equivalent of the total excess return earned by the firm is positive.

Appendix (3.2) shows that at the optimal quality level the second order conditions would be satisfied. and an optimal quality would exist.

If the price set by the regulators is the same as would hold in the perfectly competitive industry.

In that case $P_r = P_c(x_c, q_c) = MC(q_c)$.

The above discussion concludes that $P_r > MC(q_r)$

or

$P_c(x_c, q_c) > MC(q_r)$

Hence: $q_r < q_c$ (3.40)

(3.40) shows that if the regulatory price is equal to the price in the perfectly competitive industry the firm would provide lower quality than the perfectly competitive industry.

Since $\frac{\partial D}{\partial q} > 0$

(the price remaining constant, the demand increases with a higher quality).

For $q_r > q_c$

$D(P_c, q_r) < D(P_c, q_c)$ (3.41)

(3.41) implies that the monopolist would have to supply a lower expected quantity than the perfectly competitive industry.

Appendix (3.5) shows that $\frac{dq_r}{dP_r} \gtrless 0$ (3.42)

The sign of (3.42) depends upon the cost function and the demand function. Therefore, increasing the price of the product by the regulators would not always imply that the firm would increase the quality of the product.

The next section analyzes the imposition of only the quality controls.

QUALITY CONTROL ONLY

In this case, the regulators fix a quality level that the firm must produce. The firm determines the price level at which it would sell the product. The following analysis shows that the quality controls only would not eliminate the monopoly excess returns. The regulated firm would set a price level that is higher than the marginal cost of the product. If the quality level required by the regulators is equal to the quality supplied by the perfectly competitive industry, the firm would set a price higher than that which would exist in the perfectly competitive industry.

Assuming that q_r is the regulated quality level, and P_r is the firm price level where x_r is the expected supply.

The reaction of the firm is to set P_r such that for a given quality level maximizes the CEQ(excess return) for the firm.

The problem of the firm is:

Maximize CEQ(excess return)
(P_r)

$$\text{S/T} \qquad X_r - D(P_r, q_r) = 0 \tag{3.43}$$

The problem given above can be rewritten as:

$$\underset{(P_r)}{\text{Maximize}} \quad \left[P_r - MC(q_r)\right] X_r \left[1 - \lambda \; COV(\tilde{\theta}, \tilde{r})\right] \tag{3.44}$$

$$\text{S/T} \qquad X_r - D(P_r, q_r) = 0$$

The necessary condition for the optimization given in (3.44) is:

$$\left[P_r - MC(q_r)\right]\left[1-\lambda COV(\tilde{\theta},\hat{\tilde{r}}_m)\right]\frac{\partial D}{\partial P} + D\left[1-\lambda COV(\tilde{\theta},\hat{\tilde{r}}_m)\right]$$
$$+D\left[(P_r - MC(q_r))\left(-\frac{\partial COV}{\partial Y}(\tilde{\theta},\hat{\tilde{r}}_m)\cdot\frac{\partial Y}{\partial P}\right)\right] = 0 \quad (3.45)$$

Where $Y = \left[P_r - MC(q_r)\right] D$ (3.46)

and $\frac{\partial Y}{\partial P} = \left[P_r - MC(q_r)\right]\frac{\partial D}{\partial P} + D$ (3.47)

After substituting (3.47), (3.45) can be written as:

$$\left[(P_r - MC(q_r))\frac{\partial D}{\partial P} + D\right]\left[1-\lambda\, COV(\tilde{\theta},\hat{\tilde{r}}_m) - D\lambda\frac{\partial COV(\tilde{\theta}\hat{\tilde{r}}_m)}{\partial Y}(P_r - MC)\right] \quad (3.48)$$
$$= 0$$

The first term of (3.48) represents the change in expected net revenue while the second term represents the certainty equivalent of a dollar of net expected revenue. The second term is positive and for (3.48) to hold the first term must be equal to zero.

$$P_r - MC(q_r)\frac{\partial D}{\partial P} + D = 0 \quad (3.49)$$

Since $\frac{\partial D}{\partial P} < 0$, for (3.49) to hold $P_r - MC(q_r) > 0$.

The above has shown that when the firm is given a quality level that it must produce, it would increase the product price more than the cost per unit of the product. Under these circumstances the certainty equivalent of total excess return earned by the firm would be positive.

Appendix (3.3) shows that at the optimal price level, the second order conditions would be satisfied, and an optimal quality would exist that the firm would produce.

The following considers a case where the quality set by the regulators is the same as would hold in the perfectly competitive industry. In that case

$P(q_c,X_c) = MC(q_c) = MC(q_r)$

But $P_r(q_r,X_r) > MC(q_c)$

or $\quad P_r > P_c$

The price set by the firm is higher than the price that would exist in the perfectly competitive industry.

We know that $\frac{\partial D}{\partial P} < 0$ -(quality remaining constant the demand decreases with the increase in the price).

Or $D(P_r,q_c) < D(P_c,q_c)$ (3.50)

(3.50) implies that the monopolist would plan to sell a lower expected quantity than the perfectly competitive industry.

Appendix (3.4) shows that $\frac{dp_r}{dq_r} \gtrless 0$ (3.51)

The sign of (3.51) depends upon the cost function and the demand function. Therefore increasing the quality of the product would not always imply that the firm would increase the price of the product.

It was shown that the regulated firm would always set a price higher than the marginal cost of the product. Only quality controls would not be sufficient to eliminate the excess returns of the firm. The firm would earn positive CEQ(excess returns).

The next section shows that price and quality controls are both necessary to eliminate the excessive returns earned by the regulated monopoly.

PRICE AND QUALITY CONTROLS

The following shows that the price and quality controls together would reduce the monopoly's excess returns to zero. Any deviation of price and quality from perfectly competitive levels would reduce the expected supply level of the firm.

Let P_r, q_r, and X_r be the price, quality and expected supply of the regulated firm. While P_c, q_c and X_c are the corresponding quantities for the perfectly competitive industry.

The reaction function of the regulators is to set a price and quality such that the firm CEQ(excess return) is eliminated. The reaction function of the regulators is:

$$X_r(P_r,q_r)(P_r-MC(q_r)(1-\lambda\ COV(\tilde{\theta},\tilde{r}_m)) = 0 \qquad (3.52)$$

Where $1 - COV(\tilde{\theta},\tilde{r}_m) > o$; and

$$X_r(P_r,q_r) > 0$$

Therefore for (3.52) to hold, the necessary condition is:

$$P_r-MC(q_r) = 0 \qquad (3.53)$$

(3.53) means that the regulated price should be equal to the marginal cost of the product at the regulated quality.

Now, if only price or only quality controls are imposed by the regulators, the firm would set the quality or price that would not satisfy (3.53). It is shown in previous sections that only price or only quality controls result in excessive returns to the firm.

(3.52) is only satisfied when for a higher quality a higher price is provided.

Referring to Figure (3.2).

<u>For $q_r > q_c$</u> $\quad MC(q_r) > MC(q_c)$ (3.54)

Because $\frac{\partial P}{\partial q} > 0$, $\frac{\partial^2 P}{\partial q^2} < 0$ and $\frac{\partial^2 MC}{\partial q^2} > 0$ (3.55)

From (3.52) $P_r = MC(q_r)$

Therefore $P(X_c,\ q_r) < MC(q_r)$ (3.56)

$P(X_c, q_r) < P(q_r, X_r)$ (3.57)

Since $\frac{\partial X}{\partial P} < 0$ (3.58)

Therefore, $X_r < X_c$ (3.59)

Hence, when the regulated price and quality are higher than the price and quality of the perfectly competitive industry, the expected supply from the regulated firm would be lower than expected supply of the perfectly competitive industry.

<u>For $q_r < q_c$</u>

$MC(q_r) < MC(q_c)$

Because $\frac{\partial P}{\partial q} < 0$, $\frac{\partial^2 P}{\partial q^2} < 0$, $\frac{\partial MC}{\partial q} > 0$ and $\frac{\partial^2 MC}{\partial q^2} > 0$

From (3.52) $P_r = MC(q_r)$

Therefore $P(X_c, q_r) < MC(q_r)$

or $P(X_c, q_r) < P(X_r, q_r)$

Since $\frac{\partial X}{\partial P} < 0$

Therefore $X_r < X_c$

CONCLUSION

Under conditions of demand and uncertainty (when expected demand is affected by product price and quality, returns to scale are constant) it was shown that a monopolist would restrict expected output. If the valuation of marginal quality increases with quality, the monopolist would supply higher quality levels than if the industry had been perfectly competitive. The opposite would be true if the marginal valuation of quality decreases with quality.

If the principle of increasing uncertainty is true, the certainty equivalent of a dollar of expected net revenue earned by the monopolist is lower than that earned by any firm in the perfectly competitive industry.

The regulatory agency would be unsuccessful in eliminating the excess returns of the regulated monopoly, if only the price controls are imposed. By reducing the product quality, the firm would reduce the output costs and therefore earn more than fiar returns.

Similarly, only quality controls would be insufficient to eliminate the firm CEQ(excess returns) and the firm would raise the product price.

It was shown that a model of firm regulation based on price and quality controls is more realistic. The traditional fallacy that the fair rate of return for the regulated firm should be higher than the cost of capital was discarded. The Capital Asset Pricing Model is used to determine a fair rate of return for the regulated firm.

APPENDIX 3.1

The following discusses the second order conditions for the optimal quality, q_f for the firm in the perfectly competitive industry.

Rewriting (3.12), with the following notations.

$$P_c = P_c(q_f, X_c)$$

$$MC = MC(q_f)$$

$$COV = COV(r_m)$$

$$\frac{\partial \phi_f}{\partial q_f} = x_f \Big\{ \Big(\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \Big)\big(1 - \lambda \, cov(\tilde{e}, \tilde{r}_m)\big) + (P_c - MC)\Big(-\lambda \frac{\partial cov}{\partial y_f} \cdot \frac{\partial y_f}{\partial q_f}\Big) \Big\} \qquad (3.12)$$

Substituting that $\frac{\partial y_f}{\partial q_f} = x_f \Big[\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \Big]$

$$\frac{\partial \phi_f}{\partial q_f} = x_f \Big\{ \Big(\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \Big) \Big[(1 - \lambda \, cov) + (P_c - MC) x_f \Big(-\lambda \frac{\partial cov}{\partial y}\Big) \Big] \Big\}$$

The second derivative is

$$\frac{\partial^2 \phi}{\partial q_f^2} = x_f \Big\{ \Big(\frac{\partial^2 P_c}{\partial q_f^2} - \frac{\partial^2 MC}{\partial q_f^2} \Big) S + \Big(\frac{\partial P_c}{\partial q_f} - \frac{\partial MC}{\partial q_f} \Big) \frac{\partial S}{\partial q_f} x_f \Big\}$$

Where $= 1 - COV + (P_c - MC)\, X_f - \lambda \frac{\partial cov}{\partial y}$

and from the first order condition given in (3.12)

$$\frac{\partial P_c}{\partial q_f} = \frac{\partial MC}{\partial q_f}$$

Therefore

$$\frac{\partial^2 \phi_f}{\partial q_f^2} = x_f \Big[\frac{\partial^2 P_c}{\partial q_f^2} - \frac{\partial^2 MC}{\partial q_f^2} \Big] D$$

Since P_c = MC and (1- COV) > 0, this implies that $S > 0$.

As $\frac{\partial^2 P_c}{q_f^2} < 0$ and $\frac{^2 MC}{q_f^2} > 0$,

hence $\frac{\partial^2 \phi_f}{q_f^2} < 0$, and the second order conditions are satisfied.

APPENDIX 3.2

The following discusses the sufficient conditions for a regulated firm equilibrium when only price controls are given to the firm.

(3.34) gives the first order conditions.

Rewriting (3.34)

$$\frac{\partial \phi}{\partial q_r} = \left[P_r - MC\right]\left[\frac{\partial D}{\partial q}(1- \quad COV) - \lambda D \frac{\partial COV}{\partial Y} \cdot \frac{\partial Y}{\partial q}\right] - \qquad (1)$$

$$- D(1- COV) \frac{\partial MC}{\partial q} = 0$$

$$\text{where } \frac{\partial Y}{\partial q} = (P-MC) \frac{\partial D}{\partial q} - \frac{D \partial MC}{\partial q} \qquad (II)$$

Substituting (II) in (I)

$$\frac{\partial \phi}{\partial q_r} = \left[\frac{\partial D}{\partial q} (P_r - MC) - D \frac{\partial MC}{\partial q}\right]\left[1- \quad COV - \lambda D \frac{\partial COV}{\partial Y} (P-MC)\right] \qquad (III)$$

The first order condition is satisfied when in first and/or second term is equal to zero. The first term represents the change in expected revenue minus the change in expected cost while the second term represents the adjusted certainty equivalent of a dollar of expected net revenue.

The certainty equivalent of a dollar of net expected revenue must always be positive.

Hence for (III) to hold the following must be true.

$$\frac{\partial D}{\partial q} (Pr-MC) - D \frac{\partial MC}{\partial q} = 0$$

Let us now get the second derivative.

$$\frac{\partial^2 \phi}{q_r^2} = \left[\frac{\partial^2 D}{\partial q^2} \quad (P_r - MC) \; - \; \frac{\partial MC}{\partial q_r} \; \frac{\partial D}{\partial q} - D \; \frac{\partial^2 MC}{\partial q^2} \right]$$

$$\left[1 - \quad COV \; - \lambda \, D \quad \frac{\partial COV}{\partial Y} - \; (P - MC) \right]$$

Since the second term is positive, the second order conditions for an optimum would be satisfied when the first term is negative.

The first term represents the change in expected marginal revenue minus the change in expected marginal cost. For a stable firm equilibrium this must be negative.

Hence the second order conditions are satisfied when

$$\frac{\partial^2 D}{\partial q^2} \quad (P_r - MC) \; - \; \frac{\partial MC}{\partial q_r} \; \frac{\partial D}{\partial q} < \frac{D \, \partial^2 MC}{\partial q_r} \; + \; \frac{\partial MC}{\partial q_r} \; \frac{\partial D}{\partial q_r}$$

The left hand side represents the change in expected marginal revenue, while the right hand side represents a change in expected marginal cost.

APPENDIX 3.3

The following discusses the sufficient conditions for a firm equilibrium when only quality controls are given to the firm.

(3.50) gives the first order conditions for a monopolist.

$$\frac{\partial \phi_r}{\partial P_r} = \left[P_r - MC\right]\left[(1- \quad COV) \frac{\partial D}{\partial P} - D\lambda \frac{\partial COV+}{\partial Y} \cdot \frac{\partial Y}{\partial P} \right] \qquad (I)$$

$$+ D(1- \lambda COV(\tilde{\theta}, \tilde{r}_m))$$

where $\frac{Y}{P} = \left[P_r - MC\right] \frac{\partial D}{\partial P} + D.$ (II)

Substituting (II) in (I)

$$\frac{\partial \phi_r}{\partial Pr} = \left[P_r - MC\right]\left[(1- \quad COV) \frac{D}{P} - D \quad \frac{\partial COV}{\partial Y}\left\{(P_r - MC) \frac{D}{P} + D\right\}\right]$$

$$+ D(1- \quad COV)$$

$$\frac{\partial \phi_r}{\partial P_r} = \left[(P_r - MC) \quad \frac{D}{P} + D\right]\left[1 - \quad COV - D \quad \frac{COV}{Y} (P_r - MC)\right] = 0 \qquad (III)$$

The first term represents the change in expected net revenue while the second term represents the certainty equivalent of a dollar of net expected revenue.

The second term must be positive. Hence, for (III) to hold the first term must be equal to zero.

$$(P_r - MC) \frac{\partial D}{\partial P} + D = 0$$

Since $\frac{\partial D}{\partial P} < 0$, $P_r - MC > 0$

and $P_r > MC$

Let us now discuss the second order conditions

$$\frac{\partial^2 \phi r}{\partial P_r^2} = \left\{(P_r - MC)\frac{\partial^2 D}{\partial P^2} + \frac{\partial D}{\partial P} + 1\right\}\left\{1- \quad COV\ D \lambda \frac{\partial COV}{\partial Y}(P_r - MC)\right\} \quad (IV)$$

The second term is positive, (discussed before):

Hence for the second order conditions to be satisfied

$$(P_r - MC)\ \frac{\partial^2 D}{\partial P^2} + \frac{\partial D}{\partial P} + 1 < 0 \qquad (V)$$

(V) provides the sufficient conditions for an optimal price. This implies that a change in expected net revenue due to price, must be negative.

APPENDIX 3.4

If the regulators provide the quality controls and the firm sets the price, the following discusses the change in firm price when quality controls are changed.

The first order condition given in appendix (3.3) provides that

$$\frac{\partial \phi}{\partial P_r} = \left[(P-MC)\ \frac{\partial D}{\partial P} + D\right]\left[1- \lambda COV - \frac{D\ \lambda\ \partial COV}{\partial Y}\ (P-MC)\right] = 0 \qquad \text{(I)}$$

and $(P-MC)\ \frac{\partial D}{\partial P} + D = 0$

Taking a total derivative of the first order condition with respect to q_r.

$$\left[\frac{dP_r}{dq} - \frac{dMC}{dq}\right]\frac{\partial D}{\partial P} + \left[P_r - MC\right]\left[\frac{\partial^2 D}{\partial P \partial q} + \frac{\partial^2 D}{\partial P^2}\ \frac{dP}{dq}\right]$$

$$+ \frac{\partial D}{\partial q}\ \frac{\partial D}{\partial P}\ \frac{dP}{dq} = 0$$

or $$\frac{dP}{dq}\left[\frac{2\partial D}{\partial P} + (P_r - MC)\ \frac{\partial^2 D}{\partial P^2}\right] = \frac{dMC}{dq}\ \frac{\partial D}{\partial P} - (P_r - MC)\ \frac{\partial^2 D}{\partial P \partial q} + \frac{\partial D}{\partial q}$$

or

$$\frac{dP}{dq} = \frac{\frac{dMC}{dq}\ \frac{\partial D}{\partial P} - (P_r - MC)\ \frac{\partial^2 D}{\partial P \partial q} + \frac{\partial D}{\partial q}}{2\ \frac{\partial D}{\partial P} + (P_r - MC)\ \frac{\partial^2 D}{\partial P^2}} \qquad \text{(II)}$$

The denominator of (II) represents $\frac{2}{P^2}$ quality remains constaint and price affects expected demand. For firm equilibrium, $\frac{\partial^2 \phi}{\partial P^2}$ must be negative.

The numerator represents the $\frac{\partial^2 \phi}{\partial P \partial q}$, which is the change in expected marginal net valuation of quality as price is improved.

When $\frac{\partial^2 \phi}{\partial P \partial q} < 0 \quad \frac{dP}{dq} > 0$

When $\frac{\partial^2 \phi}{\partial P \partial q} > 0 \quad \frac{dP}{dq} < 0$

Hence the sign of $\frac{dP}{dq}$ depends upon the effect of quality improvements upon the expected net revenue function.

APPENDIX 3.5

The following discusses the effect of change in the regulated price on the product quality. Product quality is determined by the firm.writing the first order condition by the firm.

$$\frac{\partial \phi}{\partial q_r} = \left[\frac{\partial D}{\partial q}(P_r - MC) - D\frac{\partial MC}{\partial q} \right]\left[1 - \lambda COV - \lambda D \frac{\partial COV}{\partial Y}(P - MC) \right] = 0$$

$$\left[\frac{\partial D}{\partial q}(P_r - MC) - D\frac{\partial MC}{\partial q} \right] = 0 \qquad (I)$$

Taking the total derivative with respect to P

$$\frac{\partial D}{\partial q}\left[1 - \frac{dMC}{dq}\frac{dq}{dP} \right](P_r - MC)\left(\frac{\partial^2 D}{\partial q}\frac{dq}{dP} + \frac{\partial^2 D}{\partial q \partial P} \right)$$

$$- D\frac{\partial^2 MC}{\partial q^2}\frac{dq}{dP} - \frac{\partial MC}{\partial q}\left[\frac{\partial D}{\partial q}\frac{dq}{dP} + \frac{\partial D}{\partial P} \right] = 0$$

After simplification

$$\frac{dq}{dP}\left[-\frac{\partial D}{\partial q}\frac{dMC}{dq} + (P_r - MC)\frac{\partial^2 P}{\partial q^2} - D\frac{\partial^2 MC}{\partial q^2} - \frac{\partial MC}{\partial q}\frac{\partial D}{\partial q} \right]$$

$$= -\left[\frac{\partial D}{\partial q} + (P_r - MC)\frac{\partial^2 D}{\partial q \partial P} + \frac{\partial MC}{\partial q}\frac{\partial D}{\partial P} \right]$$

$$\frac{dq}{dP} \quad \frac{-\left[\frac{\partial D}{\partial q} + (P_r - MC)\frac{\partial^2 D}{\partial q \partial P} + \frac{\partial MC}{\partial q}\frac{\partial D}{\partial P} \right]}{-\frac{\partial D}{\partial q}\frac{dMC}{dq} + (P_r - MC)\frac{\partial^2 D}{\partial q^2} - D\frac{\partial^2 MC}{\partial q^2} - \frac{\partial MC}{\partial q}\frac{\partial D}{\partial q}}$$

The denominator of (III) represents ; which is the change in expected marginal net revenue due to quality for change in quality. At the firm equilibrium

$$\frac{\partial^2 \phi}{\partial q^2} < 0$$

The numerator (III) represents $\frac{\partial^2 \phi}{\partial P \partial q}$, which is the change in the expected marginal net revenue of quality as price is increased.

When $\frac{\partial^2 \phi}{\partial p \partial q} > 0$ $\frac{dq}{dp} < 0$

and $\frac{\partial^2 \phi}{\partial p \partial q} < 0$ $\frac{dq}{dp} > 0$

Hence the sign of $\frac{dq}{dp}$ depends upon the expected net revenue function.

CHAPTER IV

AN INTER-TEMPORAL MODEL OF FIRM REGULATION UNDER TECHNOLOGICAL PROGRESS

The Environment

The following provides the environment in which the inter-temporal models of firm behavior have been developed. First, the demand conditions of the firm are described. Second, the firm production function and cost conditions are presented. Finally, the firm revenue and cost functions are developed and their behavior analyzed.

Market Conditions

1. The Capital markets and the investor behavior conditions necessary for the Capital Asset Pricing Model (CAPM) to hold exist during each period. The market risk-return relationship is provided by the CAPM, and it is used to evaluate the uncertain cash returns of the firm.

2. The riskless rate of return, the market price of risk, and the distribution of market return remains

constant over time.

3. The prices of capital good and labor are constant over time.

4. The secondary markets for assets are perfect. If in any period the plant capacity is different from the optimal levels, the firm would buy or sell capacity and keep the plant size optimal for that period. This assumes that the capital is malleable.

5. The model considers all equity financing.

6. $\tilde{X}_t$ and P_t are the demand and the price for period t. The firm faces a stochastic demand function of the following form:

$$\tilde{X}_t = D(P_t, \tilde{\theta}) = \tilde{\theta} P_t^{-n}$$

where $\tilde{\theta}_t \; \varepsilon(0, \infty)$, $E(\tilde{\theta}_r) = 1$ and $-n$ is the demand elasticity. $\tilde{\theta}_t$ is a random variable that has independent and identical distribution for each period. $Cov(\tilde{\theta}_t, \tilde{r}_m)$ is constant for each period. $\tilde{r}_m$ is the return on the market portfolio and is also independently and identically distributed over time. The expected demand is $x_t = P_t^{-n}$.

For a positive marginal revenue, $n > 1$. The regulators make exante price decisions. Before the actual demand is known to the firm, the regulators have to provide a price level that the firm must charge. For each price level there exists a distribution of demand level. There would be one price-quantity schedule for each state of nature. In accordance with the expected demand function, change in price would produce change in expected demand. The amount demanded and the price would always be positive. The demand would have a lower bound of zero and an upper bound of infinity. The regulated monopoly is required to supply all demand, expost.

The uncertainty for the demand and the revenue of this firm is expected to be resolved at the end of the period t.

$$\text{Revenue} = \tilde{R}_t = (\tilde{\theta}_t P_t^{-n}) = \tilde{\theta}_t P_t^{1-n}$$

$$E(\text{Revenue}) = R_t = P_t^{1-n}$$

The CEQ(Revenue) is determined through the Capital Asset Pricing Model.

If $\lambda = \frac{rm-i}{m2}$, is the market equilibrium price of risk.

$$\text{CEQ(Revenue)} = R - \lambda \ \text{COV}(\tilde{R}, \tilde{r}_m)$$

$$= P_t^{1-n}\left[1 - \lambda \ \text{COV}(\tilde{\theta} r_m)\right]$$

Assuming that $L_1 = 1 - \lambda \ \text{COV}(\tilde{\theta}\tilde{r}_m)$

L_1 is the certainty equivalent of a dollar of expected revenue. Then, $\text{CEQ}(R_t) = P_t^{1-n} L_1$.

Production Conditions

7. The production process of the firm is certain but the firm is obligated to satisfy the expost demand. The firm output is equal to the expost demand. Exante, the

quantity to be produced by the firm is uncertain, and has the same distribution as the demand. The firm uses two factors of production. They are labor and capital. Labor represents the non-capital base input by the firm.

8. The firm makes the capital decisions exante. Capital cannot be changed during the period and in the short run the capital levels are fixed. Therefore, to meet the expost demand the firm must vary the non-capital base input. (To meet the excessive power demands the electric power companies vary the fuel input while the telephone company would vary its labor input.) Capital being fixed in the short run, the labor input is stochastic and its uncertainty depends upon the uncertainty in the demand.

The analysis presented below assumes that the firm has a homogenous production function of the form:

$$\text{Output} = X_t = B_t L^{\alpha} K^{\beta}$$

where $\alpha + \beta = c$. And for $C \gtrless 1$, there exist increasing, constant and decreasing returns to scale, respectively.

9. B_t is the technological coefficient. It is assumed that B_t is affected through technological change. For technological progress $B_{t+1} > B_t$ and opposite would be true for technological regression. The technological change considered above is Hicks-Neutral. Under Hicks-Neutral technical progress the production function

shifts upward. The capital-labor ratio, the ratio of marginal product of capital and the marginal product of labor remains constant. The productivity of capital and labor improve in the same ratio.

10. It is assumed that the firm does not incur expenses for the technological progress. The progress results from the experience and the techniques provided to the firm by the equipment manufacturers.

The following analyzes the costs and revenue of the firm at different levels of price and capital.

The firm expected output X_t is given by the production function as below:

$$\tilde{\theta} X_t = B_t \tilde{L}_t^{\alpha} \; K_t^{\beta}$$

From the above relationship, the labor requirement (L_t) is given by: $\tilde{L}_t = B_t^{-1/\alpha} K_t^{-\beta/\alpha} \; (X_t)^{1/\alpha} \; (\tilde{\theta}_t)^{1/\alpha}$

if W is the wage rate, then the total cost of labor $= WL = WB_t^{-1/\alpha} K_t^{-\beta/\alpha} \; (X_t)^{1/\alpha} \; (\theta)^{1/\alpha}$. This means that the total cost of labor is also stochastic. Using the following simplifying notations:

$$A_t = B_t^{-1/\alpha}$$

$$g = E(\tilde{\theta}^{1/\alpha})$$

L_2 = certainty equivalent of a dollar of expected labor cost. The CEQ(Total labor cost) is given by:

$$CEQ(\text{Total labor cost}) = WA_t \; g \; L_2 K_t^{-\beta/\alpha} \;\; P_t^{-n/\alpha}$$

It is assumed that the interest rate (i) remains constant over time. When K_t is the firm investment, the total CEQ(cost of financing) = iK_t.

$$CEQ(\text{Total Cost}) = CEQ(\text{Labor Cost} + CEQ(\text{Cost of financing})$$

$$= WA_t g L_2 K_t^{-\beta/\alpha} P_t^{-n/\alpha} + iK_t \qquad (4.1)$$

ϕ_{t+1} is the CEQ(Excess Return) that are realized at the end of period t. It is the difference of CEQ(Revenue) and CEQ(Total Cost)

$$\text{or} \quad \phi_{t+1} = P_t^{1-n} L_1 - WA_t g L_2 \; K_t^{-\beta/\alpha} \; P_t^{-n/\alpha} - iK_t \qquad (4.2)$$

For a given price level, the capital K_t that maximizes ϕ_t can be derived from the first order condition:

$$\frac{\partial \phi_{t+1}}{\partial k_t} = 0$$

A solution to the first order condition provides the optimal K_t^{**}. Optimal K_t^* is given in (4.3) and a corresponding CEQ(Excess Return) is given in (4.4).

$$K_t^* = \left[G^{-\alpha} \;\; A_t^{\alpha} \; P_t^{-n}\right]^{1/c} \qquad (4.3)$$

$$\phi_{t+1}^* = P_t^{-n/c} \left[P_t^{1-n+n/c} \; L_1 - SA_t^{\alpha/c}\right] \qquad (4.4)$$

where

$$G = \frac{i\alpha}{WgL_2}$$

$$S = \frac{G^{-\alpha/c} i \; c}{\beta}$$

The equations (4.3) and (4.4) have been derived, when the firm is given a price level by the regulators and it is free to choose the level of investment. (4.3) gives the optimal level of investment as a function of the price level. It shows that the optimal investment level is a decreasing function of price. Higher prices would generate lower investment levels. The reason being, higher prices would reduce expected demand and, therefore, requires lower investment levels. For the optimal level of investment, the firm CEQ(Excess Return) is represented by (4.4). A graphical representation of ϕ_{t+1} as a function of price is given in figure (4.1). For $P_t < P^C$, ϕ_{t+1} is a concave function of P_t. For $P_t > P^C$, ϕ_{t+1} is a convex function. For details see Appendix (4.1). There exists a price level P_t^B where the firm would earn the highest CEQ(Excess Return). And a price P_t^A for which the CES(Excess return) would be zero.

The rest of this chapter develops models of firm behavior, under the above demand and production conditions. Three conditions of market structure are analyzed.

They are:

1. Monopoly
2. Actively Regulated Monopoly, and
3. Passively Regulated Monopoly.

4.4 An Inter-Temporal Model of a Monopoly

Under the demand and production conditions given in the previous section, the following analyzes the behavior of the monopolist. It is assumed that the monopolist has a T-Period horizon. The monopolist faces an uncertain demand in each period. The demand is independently and identically distributed over time. In each period the monopolist makes an exante price and investment decision. The price decision determines the distribution of demand, while the investment decision determines the distribution of non-capital base input. Capital input levels remain unchanged during the interval. While the quantity demanded and the amount of non-capital base factor needed, is known after the uncertainty is resolved.

The firm determines the exante, price and investment levels, that maximize the net present value of the firm. The net present value of the firm is the sum of discounted CEQ(Excess Returns) earned by the firm in the present and all the future periods.

In each period the firm makes an optimal decision by considering that whatever is the present decision or the outcome, optimal decisions would be made in all the future periods.

Therefore, to solve the present problem, the firm must determine the optimal decision rules for all the future periods. To do so, the firm must first determine an optimal decision rule for the last period. Then, an optimal decision rule for the last but one period must be determined. The last but one period decision rule is determined after considering that an optimal decision will be made for the last period.

In this way, moving backward one period at a time and recursively solving each period problem; finally, the present period problem is solved.

The following, now presents the dynamics of the firm decision making.

The firm would first determine an optimal decision rule for the last period. The firm would determine optimal price and capital levels that would maximize the CEQ (Excess Return).

The subscript m, t denotes a monopoly variable for the period t. The firm problem for the last period is:

$$\underset{(P_{m,t};K_{m,t})}{\text{Maximize}} \left[\phi_{m,T+1} \right] \tag{4.5}$$

Assuming that $\phi^*_{m,T+1}$ is the optimal value. Now the firm would move one period backward and based on the information available at the end of period T-2, a decision rule for the period T-1 would be determined. The firm would determine $P_{m,T-1}$ and $K_{m,T-1}$, that would maximize its net present value. The problem for the last but one period is:

$$\underset{(P_{m,T-1};K_{m,R-1})}{\text{Maximize}} \left[\phi_{m,T} + \phi^{*}_{m,T+1} \Big/ (1+i) \right]$$

or

$$\underset{(P_{m,T-1};K_{m,T-1})}{\text{Maximize}} \left[\phi_{m,T} + V_{m,T} \right] \tag{4.6}$$

where $V_{mt} = \phi^{*}_{m,t+1} \quad (1+i)$

$V_{m,T}$ is the optimal value of the firm in the beginning of period T, and represents the discounted value of optimal CEQ(Excess Returns) for period T. The price and capital levels for period T-1 do not affect the cash flows for the future periods. $V_{m,T}$ is independent of $K_{m,t-1}$ and $P_{m,T-1}$. The independence of future cash returns to the present capital and price decisions of the firm is a result of the perfect secondary asset markets, and

$$\frac{\partial V_{m,T}}{\partial K_{T-1}} = \frac{\partial V_{m,T}}{\partial P_{T-L}}$$

Therefore, instead of (4.6) the problem of the firm in period T-1 is represented by:

$$\underset{(P_{m,T-1};\ K_{m,T-1})}{\text{Maximize}} \left[\phi_{m,T} \right]$$

Through induction, the monopolist's decision problem for any period t can now be generalized as:

$$\underset{(P_{mt},K_{mt})}{\text{Maximize}} \left[\phi_{m,t+1}\right] \tag{4.7}$$

Hence the monopolist would solve a series of single period problems. This simplification is a result of the assumed perfection secondary markets and malleability of capital. Under these conditions the monopolist would behave myopically, unconcerned about the future. Substituting for $\phi_{m,t+1}$ from (4.2), (4.7) can be written as:

$$\underset{(P_{mt},K_{mt})}{\text{MAX.}}\ \phi_{m,t+1} = \underset{P_{mt},K_{mt}}{\text{MAX}} \left[P_{mt}^{1-n}L_1 - WL_2gA_tK_{mt}^{-\beta/\alpha}P_{mt}^{-n/\alpha} - iK_{mt}\right] \tag{4.8}$$

The necessary conditions for the optimization in (4.8) are:

$$\frac{\partial\phi_{m,t+1}}{\partial P_{mt}} = (1-n)\ P_{mt}^{-n}\ L_1 - \ \frac{n}{\alpha}\ WgL_2A_tK_{mt}^{-\frac{\beta}{\alpha}}\ P_{mt}^{\frac{-n-\alpha}{\alpha}} \ = 0 \tag{4.9}$$

$$\frac{\partial\phi_{m,t+1}}{\partial K_{mt}} = WL_2gA_t\ \frac{\beta}{\alpha}\ \ K_{mt}^{-c/\alpha}P_{mt}^{-n/\alpha} \ - \ i \ = 0 \tag{4.10}$$

The first part of (4.9) represents the marginal decrease in CEQ(Revenue) for increased price while the second part represents the decrease in CEQ(Cost of Wages). The decreases in expected wages results from lower expected demand at higher prices. At the optimal price level, for a small increase in the price, the decrease of CEQ(revenue) would be equal to the decrease of the CEQ (Cost).

The first part of (4.10) represents the decrease in

CEQ(Wages) for increases in capital, while the second part represents the increase in the cost of financing. At the optimal level of capital, any small variation in capital should decrease the CEQ(cost of wages) equal to the increase in the cost of financing.

A simultaneous solution of the two necessary conditions in (4.9) and (4.10) provides the optimal levels of price and capital.

The following represents the optimal solution:

$$P^*_{mt} = \left[\frac{sn}{(n-1)L_1C}\right]^{\frac{c}{c-nc+n}} \cdot A_t^{K/_{c-nc+n}} \tag{4.11}$$

$$K^*_{mt} = G^{-\alpha/c}\left[\frac{sn}{(n-1)L_1C}\right]^{\frac{-n}{s-nc+n}} \cdot A_t^{\frac{\alpha}{c}\left[1-\frac{n}{c-nc+n}\right]} \tag{4.12}$$

where $G = \frac{i\alpha}{WGL_2\ \beta}$ and $S = \frac{G^{-\alpha/c}\ ic}{\beta}$

G and S are constants that depend upon the demand and production conditions.

After substitution of the optimal value of K_{mt} in (4.8), the CEQ(Excess Return) can be written as a function of price as below

$$\phi^*_{mt} = P_{mt}^{-n/c} \quad A_t^{\alpha/c}\left[\frac{n}{(n-1)_c} - 1\right] \tag{4.13}$$

The optimal CEQ(Excess Return) that a monopolist can earn would be nonnegative only if the term in the brackets is nonnegative.

$$\text{or} \quad \frac{n}{(n-1)\,c} - 1 > 0 \qquad (4.14)$$

$$\text{or} \quad c < \frac{n}{n-1}$$

No monopolist would continue business for long if he is sure that he can never earn a nonnegative CEQ(Excess Return). Therefore, to ensure a nonnegative optimal excess return it is assumed that $c < \frac{n}{n-1}$. This condition relates the demand and output elasticities to provide a region that would permit a monopolist to stay in business. To satisfy this condition an increase in the demand elasticity decreases the maximum allowable degree of returns to scale. This condition also rules out the possibility of expected total cost curve crossing the expected revenue curve from above, and in this way create firm disequilibrium.

The following discusses the change in optimal decisions of the firm, when its technology changes. Hicks Neutral Technical Change, implies a change in technological coefficient. For technological progress $B_t > B_{t+1}$ or $A_t < A_{t+1}$. The ratio of two adjacent optimal prices can be determined from the equation (4.11).

$$\frac{P_{m,t}}{P_{m,t-1}} = \left[\frac{A_t}{A_{t-1}} \right]^{\frac{\alpha}{c-nc+n}} \qquad (4.15)$$

(4.15) states that, under conditions of technological progress the product prices would reduce every period. Reduced costs would equate the firm CEQ(Marginal cost) to the CEQ(marginal revenue) at an increased level of expected output. This necessitates an increased expected supply. Therefore, the firm would prefer to reduce the prices. The monopolist finds it advantageous to pass on a portion of the benefits of improvements in technology to the customer.

If due to change in demand or output elasticities, $\alpha/c-nc+n$ increases, it would reduce the prices at a faster rate.

For technological regression $A_t > A_{t-1}$ the monopolist would increase the price of the product. Technological regression increases the expected marginal cost of the product. The firm equilibrium would result at a lower level of expected output. Hence the firm would prefer to increase the prices. After substituting the optimal value of price in (4.13) the monopolist's CEQ(Excess Return) for period t can be written as:

$$\phi^*_{m,t} = \left[\frac{sn}{(n-1)L_1C}\right]^{\frac{-n}{c-nc+n}} \cdot A_t^{\alpha c(1-n)} \cdot \left[\frac{n}{(n-1)c} - 1\right]$$

The above shows that the CEQ(Excess Return) earned by the firm would only be non-negative if:

$$\frac{n}{(n-1)c} > 1$$

The ratio of CEQ(Excess Return) earned by the firm is given below:

$$\frac{\phi_{m,t+1}}{\phi_{m,t}} = \left[\frac{A_t}{A_{t+1}}\right]^{\alpha c(n-1)} \qquad (4.16)$$

(4.16) means that for technological progress, the CEQ (Excess Return) earned by the firm would increase.

Hence technological progress leads to not only reduction in prices for the consumer but also increased excess returns for the monopolist. The opposite would be true for the technological regression.

The above proves that the monopolist would increase its CEQ(Excess Return) by improving the technology of the firm. This also shows that a monopolist would encourage the adoption of newer and better manufacturing techniques by the firm. It is also clear from (4.16), that if the returns to scale are increased, the improvement in the technology would increase the rate of growth of CEQ(Excess Return) of the firm. Increase in the output elasticity of labor would also increase the rate of growth of the CEQ(Excess Return of the firm).

(4.17) is derived from (4.12)

$$\frac{K_{m,t+1}}{K_{m,t}} = \left[\frac{A_{t+1}}{A_t}\right]^{\frac{\alpha(1-n)}{c-nc+n}} \qquad (4.17)$$

(4.17) implies that with the improvement of the technology, the capital investment by the monopolist would increase. The decreasing price increases the expected demand and the expected output. The increased expected output requires increased exante capital levels. A regression in the technology of the firm would require a decreasing investment level by the firm.

If L is the certainty equivalent of total labor used by the firm, then (4.10) can be written as:

$$- W \frac{\partial L}{\partial K_{mt}} - i = 0$$

or

$$- \frac{\partial L}{\partial K_{mt}} = \frac{i}{W}$$

This implies that the rate of technical substitution for the certainty equivalent of factor inputs is equal to the factor input price ratio. The monopolist makes efficient factor input decisions.

This completes the discussion of the monopoly behavior. It was shown that a monopolist would want to improve the technology of the firm. This would increase the CEQ

Return) for the firm. The monopolist would like to share the benefits of improved technology with its consumers, and would reduce the product prices.

4.4 Active Regulation

Active regulation means that the regulators have the same information as the firm, and therefore set prices that eliminate the firm CEQ(Excess Returns). Active Regulation also implies that there is no regulatory lag.

It is assumed that the firm and the regulators have similar expectations for the demand distribution and the technological change. The regulation is conducted through the imposition of price controls. The firm is constrained to charge only the regulated price to its customers. The objective of the regulators is to provide a fair rate of return to the owners of the firm. The regulators would determine a price level which (under the expected demand and technological conditions) would provide a fair rate of return on the firm investment. The objective of the firm is to maximize its net present value, while facing the regulatory constraint.

Under conditions of passive regulation, it has been argued by Averch-Johnson (2), that if the fair rate of return is equal to the cost of capital, the capital decisions by the firm are indeterminate. The regulators would provide a fair rate of return for any capital level chosen by the firm. Under these conditions the firm has no motivation to be efficient in its production process. The firm is indifferent to the level of capitalization.

The above description of the regulatory process by

Averch-Johnson assumes a completely passive behavior on the part of the regulators. However, when the regulators have the same information as the firm, there is no reason why the regulators should be passive and provide a fair rate of return on any level of capital invested by the firm. In fact, through price regulation the regulators can constrain the firm to produce efficiently or else leave the business. It is shown below that through active regulation the regulators can constrain the firm to behave as if it had been operating in a perfectly competitive environment. Any deviation from the efficient capital levels would mean negative CEQ(Excess Return) for the firm.

Under A-J's passive regulation, when the firm is given a rate of return constraint equal to the cost of capital, it is true that the firm's investment level is indeterminate. But in practice, the regulation is not conducted by providing a rate of return constraint to the firm. Firms are regulated by providing a price at which the firm can sell its product. The A-J model has been conceived in isolation of the regulatory practices.

Under active regulation, the regulators act as the leaders in the duopolistic game between the firm and the regulators. The leader knowing that it is the leader who optimizes his own objective, while considering the reaction function of the follower. Therefore, the regulators determine a price level that provides a fair rate of return to the firm at the efficient capital levels.

On the other hand, the firm knows that it is the follower and cannot affect the decisions of the regulators through its own actions. The firm has no alternative but to follow its own reaction function at the prices provided to it by the regulators. Therefore, the problem of the firm is to maximize its net present value while considering the regulatory constraint. The net present value is the sum of the discounted CEQ(Excess Return) for all the future periods. The firm has a T period horizon. To solve the problem for the present period, the firm has to know the optimal decision rule for all the future periods. Hence it is appropriate that the firm determine a decision rule for the last period and then work backward to the present period.

The firm's problem in the last period is to maximize the CEQ(Excess Return). The regulators would determine a price level that provides a fair return to the firm at the efficient capitalization.

Therefore, at the price level given by the regulators, the firm chooses optimal level of factor inputs. Subscript o,t denotes time period t under active regulation (zero regulatory lag). The following represents the necessary conditions for the last period:

$$\frac{\partial}{\partial K_{OT}} \phi_{0,T+1}(P_{OT}, K_{OT}) = 0 \qquad (4.18)$$

$$\text{and } \phi_{0,T+1}(P_{OT}, K_{OT}) \doteq 0 \qquad (4.19)$$

The regulators and the firm both know the reaction functions of each other. Both solve the problem represented in (4.18) and (4.19), and know the price and capital decision rules for the last period. Once the regulators have solved the problem (after considering the reaction function of the firm), the firm has no alternative but to choose an efficient level of capital for itself. (4.19) is the regulatory constraint. The regulators determine a price level that reduces the CEQ(Excess Return) to zero. (4.18) represents the reaction function of the firm. For a given price level of P_{OT}, the firm tries to maximize its CEQ(Excess Return) by setting an optimal K_{OT}.

A simultaneous solution of (4.18) and (4.19) would provide the optimal price (P_{OT}) and capital (K_{OT}).

Having determined an optimal decision rule for the last period, the firm would determine a decision rule for the last but one period. Based on the information set available at the beginning of the last but one period, the firm would plan to maximize its net present value at the end of the period. This is equal to the CEQ(Excess Return) for the last but one period plus discounted CEQ (Excess Return) for the last period.

Hence the last but one period problem is:

$$\underset{K_{o,T-1}}{\text{Maximize}} \left[\phi_{0,T}\,(P_{o,T-1},\, K_{0,T-1}) + \phi_{0,T+1}/(1+i) \right] \quad (4.20)$$

$$\text{S/T} \qquad \phi_{0,T}\,(P_{o,T-1},\, K_{0,T-1}) = 0$$

Perfection in secondary markets ensures that

$$\frac{\partial \phi_{0,T+1}}{\partial K_{0,T-1}} = 0 \quad (4.21)$$

From (4.18), (4.19) and (4.20), through induction, the firm and regulators problem for any period t can be generalized as below:

$$\underset{(K_{o,t})}{\text{Max}} \qquad \phi_{o,t+1}(P_{ot},K_{ot}) \quad (4.22)$$

$$\text{S/T} \qquad \phi_{o,t+1}(P_{ot},K_{ot}) = 0$$

Contingent upon a given value of P_{ot}, there is a unique function $\phi_{o,t+1}$. Its value depends upon $K_{o,t}$. (4.10) and (4.22) show that in this maximization problem, a function $\phi_{o,t+1}$ is being selected and then an optimum point on that function is being determined.

This implies that under active regulation, the multiperiod problem of the firm is reduced to single period problem. Hence, the firm has to make an investment decision that maximizes the CEQ(Excess Return) for that period only. After substituting the value of ϕ_{t+1}, the problem given in (4.22) can be rewritten as below:

$$\text{Maximize}\quad K_{ot} \left[P_{ot}^{1-n} L_1 - WL_2 g A_t K_{ot}^{-\beta/\alpha} P_{ot}^{-\frac{n}{\alpha}} - i K_{ot} \right] \qquad (4.23)$$

$$\text{S/T}\quad P_{ot}^{1-n} L_1 - WL_2 g A_t K_{ot}^{-\beta/\alpha} P_{ot}^{-\frac{n}{\alpha}} - i K_{ot} = 0$$

The necessary conditions are:

$$P_{ot}^{1-n} L_1 - WL_2 g A_t K_{ot}^{-\beta/\alpha} P_{ot}^{-n/\alpha} - i K_{ot} = 0 \qquad (4.24)$$

$$\beta/\alpha\ WL_2 g A_t K_{ot}^{-c/\alpha} P_{ot}^{-n/\alpha} - i = 0 \qquad (4.25)$$

The simultaneous solution of the necessary conditions provides the following optimal values for price and capital.

$$P^*_{ot} = \left[\frac{SA_t}{L_1}^{\alpha/c} \right]^{\frac{c}{c-nc+n}} \qquad (4.26)$$

$$K^*_{ot} = G^{-\alpha/c} \left[\frac{SA_t}{L_1}^{-\frac{\alpha(1-n)}{n}} \right]^{\frac{-n}{c-nc+n}} \qquad (4.27)$$

From the optimal values given above, the following relationship can be derived:

$$\frac{P^*_{o,t+1}}{P^*_{o,t}} = \left[\frac{A_{t+1}}{A_t} \right]^{\frac{\alpha}{c-nc+n}} \qquad (4.28)$$

and

$$\frac{K^*_{o,t+1}}{K^*_{o,t}} = \left[\frac{A_t}{A_{t+1}} \right]^{\frac{\alpha(n-1)}{c-nc+n}} \qquad (4.29)$$

Under conditions of technological change, these results are discussed below.

Technological progress implies that $A_{t+1} < A_t$. Substituting this in (4.28) means that the regulatory price would decrease over time. This means that under active regulation, the regulators would be successful in passing on the benefits of technological progress to the consumers. Although the regulators would ensure a fair rate of return to the investors of the firm. Comparing (4.28) with (4.11) shows that the regulatory price under active regulation would be lower than the monopoly price under no regulation. In the absence of regulation, a monopoly would charge increased prices from its consumers. By restricting expected output the monopolist would raise prices for its product and would earn more than fair returns for its investment. Under active regulation, the product prices would decrease faster if the returns to scale increase and if the output elasticity of labor increases.

Comparing (4.27) with (4.12), it is evident that the monopolist would make lower investment than the actively regulated firm. The monopolist restricts output and, therefore, also restricts investment. (4.29) shows that under conditions of technological progress, the investment of an actively regulated firm increases over time. The reason being that the decrease in prices, increase expected demand. The increase in expected demand requires more capital, even though, there is technological progress.

The equation (4.25) ensures that an actively regulated firm would make investment to a point where the decrease in the CEQ(labor) is equal to the increase in the cost of financing. This means that the firm would make efficient capital input decisions. The rate of technical substitution for the certainty equivalent of factor inputs is equal to the factor price ratio.

(4.24) implies that an actively regulated firm would earn a zero certainty equivalent of excess returns in each period. Even when the technology of the firm is improving the firm would not be able to improve its value. This implies that the firm would be indifferent to the adoption of the improved technology.

It was shown that active regulation is possible when the regulators have complete and current information about the firm technology and demand conditions. An actively regulated firm would have no incentive to improve its technology. The regulators would always be successful in eliminating the firm excess value by reducing the product prices. It was shown that price regulation could be achieved, when the fair rate of return is determined through the capital market equilibrium.

If the regulators are not current in their information, it would not be possible to actively regulate the firm. In that case the regulators would act on stale information. Or in other words regulation would be passive. The regulators may lag the firm in terms of the firm information. The next section develops a model of the passive regulation of the firm. It is shown that the existence of the regulatory lag provides an incentive for the firm to improve its technology. The firm would use the passive regulation to improve its value.

4.5 Passive Regulation

Passive regulation implies an existence of regulatory lag. The regulatory lag means that the regulators do not have complete and current information about the firm's production function.

The regulators may not be able to exactly forecast the demand and cost conditions of the firm for present or the future periods. Procuring this information may involve excessive costs. Budget constraint may restrict the regulators to conduct research about future firm conditions. However, it is assumed that the firm has complete knowledge of the opportunities for technological improvements available to it in the future. Also, the firm may not willingly like to provide such information to the regulators. Rather than to increase the probability of faulty decision through erroneous forecast, the regulators prefer to base their decisions on the cost and demand conditions of the previous period. The information about the demand and cost conditions of the previous period is publicly available to the regulators. Thus the regulators make the decisions for the present period, assuming that the cost and demand conditions of the previous period would continue into the present period and all future periods. Therefore, a lagged regulation considers a passive behavior on the part of the regulators. Although, the firm knows the future anticipated changes in the cost and demand conditions.

While making the decision for the present period, the regulators determine a price level that would provide a fair return to the firm at the technology of the previous period. Given a price level, the firm would now determine an exante investment level that maximizes the value of the firm.

The behavior of the regulatory body is passive in nature. The firm, knows the information lag[1] of the

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1 The phenomenon of information lag analyzed here is different from the analysis of regulatory lag by Bailey and Coleman (4). Bailey and Coleman (4) analyze the delays in regulatory reviews. The regulators know all the information about the firm, when the review is performed, but do not consider the changes that might take place in the next period. In their study, the regulation is conducted by providing a fair rate of return constraint to the firm, and demand and production conditions are assumed to be certain. Under above conditions Bailey and Coleman have shown that a delay in the regulatory reviews can improve the production efficiency of the firm.

regulators and sets out to use it for increasing the present value of the firm.

The present study assumes that price regulation is done every period but with stale information.

The following presents a model of lagged regulation, when the firm horizon is T periods long.

4.51 T Period Problem

The excess value of the firm at any point in time is the sum of the discounted CEQ(Future Excess Returns). In every period the firm determines an exante investment level that maximizes its value. Therefore, while making the decision for the present period, the firm needs to know the effect of present investment levels on all future excess returns.

To make the decision for the present period the firm would first determine optimal decision rules for all future periods. The firm would first determine a decision rule for the T th period (based on the information set available at the end of period T-1). Having done this, the firm would move one period backward, and based on the information set available at the end of period T-2, an optimal decision rule for the period t-1 is determined. The decision rule for T-1 is made after considering that irrespective of the outcome or the decision for T-1, optimal decisions would be made for the T th period.

In this way, recursively solving for one period at a time and moving backward; the firm solves its problem for the present period.

In each period, the firm maximizes its value subject to a regulatory constraint. The regulatory constraint determines a price that provides a fair rate of return to the firm (under the previous period conditions). Using the regulatory price, the firm determines an optimal investment level.

Under the above conditions the problem for the T period can be written as:

$$\underset{K_{L,T}}{\text{MAXIMIZE}} \quad \phi_{L,T+1}\left[(P_{L,T}: K_{L,T}) \;\middle|\; I_{T-1}\right] \tag{4.30}$$

$$\text{S/T} \quad \phi_{L,T+1} \; (P_{L,T}: K_{L,T-1}) = 0 \tag{4.31}$$

Subscript L, denotes the existence of regulatory lag. $\phi_{L,T+1}$ is the certainty equivalent of excess return for period T received at the beginning of period T+1. I_{t-1} is the information set available at the end of period T-1. (4.31) is the regulatory constraint for the period T. The regulators determine a price level $P_{L,T}$ (By using the capital $K_{L,T-1}$ and technology B_{T-1} of the previous period) that would provide a zero CEQ(Excess Return) or provides a fair return to the firm. Taking P_{LT} as the price for the T period, and considering the anticipated changes in the technology the firm plans investment levels K_{LT}. $K_{L,T}$ is the level of investment that maximizes the net present value of the firm.

Having determined a decision rule for the period T, the firm would set to solve the problem at the beginning of period T-1.

Similarly, T-1 period problem can be written as:

$$\underset{K_{1},T-1}{\text{Max}} \left[\phi_{L,T} \; (P_{L,T-1};\; K_{L,T-1}) \;\Big|\; I_{T-2} + \phi^{*}_{T+1}/(1+i) \right] \tag{4.32}$$

$$\text{S/T} \qquad \phi_{L,T} \; (P_{L,T-1};\; K_{L,T-2}) = 0 \tag{4.33}$$

where ϕ^{*}_{T+1} is the optimal CEQ of excess return for the period T. The problem given in (4.32) states that the firm would plan to set a capital level in the beginning of period T-1 that maximizes the excess value of the firm at the beginning of period T. The excess value at the beginning of period T represents the sum of CEQ(Excess Return) for period T-1 and the discounted CEQ(Excess Return) for period T. (4.33) is the regulatory constraint.

4.52 t'th Period Problem

Based on the above discussion, the problem can be generalized as:

$$\underset{(K_{L,t})}{\text{Max}} \left[\phi_{L,t+1} \; (P_{Lt}\text{:}K_{Lt}) + \sum_{k=t+2}^{T+1} \phi_{L,K}/(1+i)^{K-t-1} \right] \tag{4.34}$$

$$\text{S/T} \qquad \phi_{L,T} \; (P_{L,t};\; K_{L,t-1}) = 0 \tag{4.35}$$

(4.34) represents the value of the firm at the beginning of t+1. (4.35) represents the regulatory constraint for the period t.

$\sum_{K=t+2}^{T+1} \phi_{L,K} / (1+i)^{K-t-1}$ is the value of the firm in the beginning of period t+1 and will be denoted by $V^*_{L,t+1}$. It is the sum of the discounted CEQ(Excess Returns) for periods beyond t+1. The problem can now be written as:

$$\underset{K_{L,T}}{\text{Max}} \left[\phi_{L,t+1} (P_{L,t}, K_{L,t}) + V^*_{L,t+1} \right] \tag{4.36}$$

$$\text{S/T} \qquad \phi_{L,T}(P_{L,t};\ K_{L,t-1}) = 0 \tag{4.37}$$

Passive regulation can be considered as a duopolistic game between the firm and the regulators. The firm acts as the leader and knows the reaction function of the regulators. The firm maximizes its value by considering that the regulators would follow their reaction function. The reaction function of the regulators is to provide a fair rate of return to the firm, at the investment levels of previous period. The regulators behave passively and do not analyze whether or not the investment levels of the previous period are necessary for this period also.

After substituting for $P_{L,t}$ from the regulatory constraint into the objective function, (because $K_{L,t-1}$) is known the firm objective function can be written as:

$$\underset{K_{L,t}}{\text{Max}} \left[\phi_{L,t+1} (K_{L,t}) + V_{L,t+1} (K_{L,t}) \right]$$

The optimal solution must satisfy the following necessary condition.

$$\frac{\partial \phi_{L,t+1}}{\partial K_{L,t}} + \frac{\partial V_{L,t+1}}{\partial K_{L,t}} = 0 \qquad (4.38)$$

For a three-period problem it is shown later that the optimal solution would be an interior solution.

Let $K_{L,t}$ be the solution to (4.38). This represents the optimal capitalization of the firm. K_{Lt} maximizes the net present value of the firm.

Let us assume that $K^*_{L,t}$ is the efficient level of capital for the firm for the period t, or $K^*_{L,t}$ is the level of capital where $\frac{\partial \phi_{L,t+1}}{\partial K^*_{L,t}} = 0$. This is the point where the CEQ(Excess Return) for the period t is maximized and the CEQ(Total Cost) at the expected supply is minimum.

If at the optimum point $\frac{\partial V_{L,t+1}}{\partial K_{L,t}} > 0$

(4.38) is satisfied when $\frac{\partial \phi_{L,t+1}}{\partial K_{L,t}} < 0$. Given the concave nature of $\phi_{L,t+1} (K_{L,t})$, it is evident that $K^*_{L,t} < K_{L,t}$ or the optimal capital decision $K_{L,t}$ is higher than the efficient levels $K^*_{L,t}$. In this case the firm would over-capitalize. When the firm expects that the discounted sum of future CEQ(Excess Returns) can be increased by increasing capital levels, the firm would prefer to overcapitalize.

Similarly, if at the optimal point $\frac{\partial V_{L,t+1}}{\partial K_{L,t}} < 0$; the sum of the future discounted CEQ(Excess returns) is decreased by increasing the capital level, the firm would prefer to undercapitalize in the present period. In this case $\frac{\partial \phi_{L,t+1}}{\partial K_{L,t}} > 0$ and $K_{Lt} < K^*_{Lt}$.

Therefore, the efficiency of factor inputs in the present period depends upon the firm's expectations of "How the future excess returns would be affected by the present decisions."

The formulation given above is general in nature, and no specification has been made about the demand and production conditions. And hence, it is not possible to determine whether the firm would overcapitalize or undercapitalize.

The next section solves the above problem when the firm horizon is three periods long.

4.53 THREE PERIOD PROBLEM

The following analyzes the effect of information lag of the regulators on the firm input efficiency when the firm horizon is three periods long. The firm production function is homogeneous; which may have increasing, decreasing or constant returns to scale. The firm has an isoelastic demand function. The regulators lag the firm with regard to information about the firm technology and the investment level.

For the regulators to be able to give a price decision for the beginning period, the following assumes that the starting conditions are similar to the perfectly competitive environment. In the beginning period the firm is assumed to earn a zero CEQ(Excess Return) and the firm makes efficient factor input decisions. Perfectly competitive starting conditions provide an unbiased starting environment for the firm. It would provide a point of reference and comparison for future decision of the firm. In addition to above, the perfectly competitive starting conditions provide easy algebraic tractability. The effect of starting conditions, different from the perfectly competitive case, on the future firm decisions would be studied through computer simulation. The simulation results for different starting conditions are given in the next chapter.

The following presents the passive regulation for a 3 period firm horizon. First the perfectly competitive starting conditions are analyzed. Then the firm behavior in the last period (3rd period) is discussed. Finally, the firm's decision making for the second period is discussed. The subscript L, for the regulatory lag, has been omitted.

PERFECTLY COMPETITIVE STARTING CONDITIONS

It is assumed that in the first period the firm behaves as if it is working in a perfectly competitive environment. The firm is given a price level, that at the efficient capitalization, provides a fair rate of return to the firm.

The first period problem is to choose an excess return function, that at the efficient capital levels is zero.

The above can be represented by:

$$\max_{K_1} \quad \phi_2(P_1, K_1) \tag{4.39}$$

and

$$\phi_2 \quad (P_1, K_1) = 0 \tag{4.40}$$

The necessary conditions are:

$$\frac{\partial \phi_2}{\partial K_1}(P_1, K_1) = 0 \tag{4.41}$$

$$\phi_2 \; (P_1, K_1) = 0 \tag{4.42}$$

where $\phi_2 = P_1^{1-n}L_1 - A_1L_2gWK_1^{-\beta/\alpha}\; P_1^{-n/\alpha} - iK_1$

Substituting for ϕ_2, (4.41) and (4.42) can be written as below:

$$\beta/\alpha \; A_1WL_2gK_1^{-c/\alpha} \; P_1^{-n/\alpha} - i = 0 \tag{4.43}$$

$$P_1^{1-n} \; L_1 - A_1L_2gWK_1^{-\beta/\alpha} \; P_1^{-n/\alpha} - iK = 0 \tag{4.44}$$

(4.43) represents the marginal change for the CEQ (Excess Return) with respect to exante capital change should be zero. This also implies that the capital input levels should be efficient and the CEQ of the total cost be minimum. A simultaneous solution of (4.43) and (4.44) provides the following optimal solution.

$$P_1 = \left[\frac{S A_1^{\alpha/c}}{L_1}\right]^{\frac{c}{c-nc+n}} ; \quad K_1 = \left[\frac{G^{-\alpha/c}\ S^{-n}\ A_1^{\alpha(1-n)}}{L_1^{-n}}\right]^{\frac{1}{c-nc+n}} \qquad (4.45)$$

When the starting conditions are perfectly competitive, (4.45) gives the values of P_1 and K_1 that would exist for the first period. The firm would earn a zero CEQ(Excess Return); or

$$\phi_2(P_1 K_1) = 0$$

Based on the capital level for the starting period, the regulators would now determine P_2(P_2 is the price level for the second period). Hence the regulatory constraint for the second period is:

$$\phi(P_2, K_1) = 0 \qquad (4.46)$$

Comparing (4.40) and (4.46), it is evident that $P_2 = P_1$. This simplification was made possible by the perfectly competitive starting conditions assumed in this section.

From the equation (4.43) K_1 is given below:

$$K_1 = \left[G^{-\alpha}\ P_1^{-n}\ A_1^{\alpha}\right]^{1/c} \qquad (4.47)$$

where

$$G = \frac{i\alpha}{WgL_2\ \beta}$$

Substitution of K_1 in ϕ_2 provides ϕ_2 as a function of price. ϕ_2 is the certainty equivalent of excess return for the beginning period. It can be written as:

$$\phi_2 = P_1^{-n/c} \left[P_1^{1-n+n/c} L_1 - SA_1^{\alpha/c} \right] \tag{4.48}$$

(4.48) gives the CEQ(Excess Return) for the period one as a function of price only. When the price level is equal to the perfectly competitive levels ϕ_2 is zero. However, if the price is higher than the perfectly competitive levels ϕ_2 is greater than zero. A maximum ϕ_2 is achieved when the price is equal to the monopolistic levels. The monopoly price is given by:

$$P_1 = \left[\frac{n}{n-1} \quad \frac{A_1^{\alpha/c}}{L_1 C} \right]^{\frac{c}{c-nc+n}}$$

In this case the increased prices would necessitate a lower level of investment.

Hence if the starting conditions are that of a monopoly, the starting period price is higher and capital is lower than the perfectly competitive case. This means that with the monopolist starting conditions the second period price would be different than the first period.

The second period prices are fixed based on the first period capital levels. In the next section it is shown that any increase or decrease in price from the perfectly competitive levels raises the second period price.

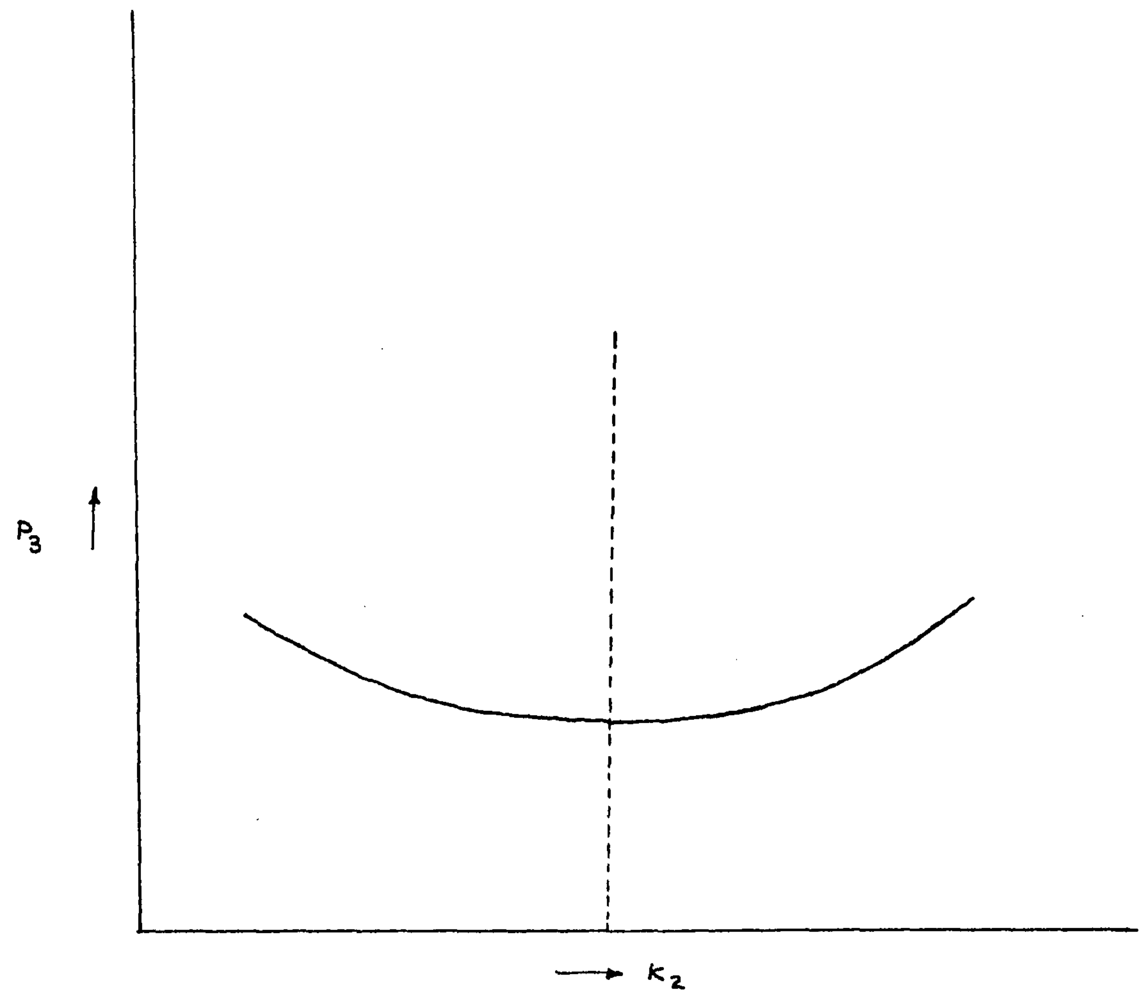


FIGURE 4.1

The above shows that different starting conditions would produce different firm conditions and regulatory constraints for the future periods. Therefore, the future firm conditions are affected by the starting conditions. How the starting conditions interact with the length of the firm horizon would be further studied through the simulations.

FINAL PERIOD PROBLEM

To solve the problem for the second period, the firm would first determine the optimal decision rule for the last period. Whatever are the decisions or outcome in the second period, the last period decisions must be optimal with respect to that.

In the third period, the firm maximizes the CEQ(Excess Return for the 3rd period. A price is given that provides a zero CEQ(Excess Return) at the technology and capital levels of period 2.

The problem in the third period is

$$\underset{(K_3)}{\text{MAX.}} \quad \phi_4\ (P_3,\ K_3,\ A_3) \tag{4.49}$$

$$\text{S/T} \quad \phi_4\ (P_3,\ K_2,\ A_2) = 0 \tag{4.50}$$

P_3 is determined from the regulatory constraint given in (4.50).

To decide a capital level K_2 for the second period, the firm needs to know the effects of K_2 on ϕ_4. This is done by first determining the effect of K_2 on P_3 and then the effect of P_3 on ϕ_4.

$$\frac{\partial \phi_4}{\partial K_2} = \frac{\partial P_3}{\partial K_2} \cdot \frac{\partial \phi_4}{\partial P_3} \tag{4.51}$$

$\frac{\partial \phi_4}{\partial K_2}$ is now determined by separately evaluating $\frac{\partial P_3}{\partial K_2}$ and $\frac{\partial \phi_4}{\partial P_3}$. $\frac{\partial P_3}{\partial K_2}$ denotes the effect of second period capital level on the third period price. The behavior of $\frac{\partial P_3}{\partial K_2}$ at different levels of K_2 will now be determined from the constraint given in (4.50)

$$\phi(P_3, K_2) = 0 \tag{4.50}$$

ϕ is an implicit function of P_3 and K_2. Denoting the partial derivatives by the corresponding subscripts such that

$$\frac{\partial P_3}{\partial K_2} = P_K; \quad \frac{\partial \phi}{\partial P} = \phi_P, \quad \frac{\partial \phi}{\partial K} = \phi_K$$

From (4.52) $$P_K = - \frac{\phi_K}{\phi_P} \tag{4.52}$$

Appendix (4.1) explains that P_3 is a convex function of K_2. (See Fig. (4.1)). Considering (4.52), $P_K=0$ when $\phi_K = 0$ and $K_2 = K_2^F$ small changes in K_2 from K_2^F would not change P_3.

An increase or decrease of K_2 from K_2^F would increase price, such that:

For $K_2 > K_2^F$; $P_K > o$ and for $K_2 < K_2^F$; $P_K < o$

P_3^F and K_2^F can be determined by simultaneously solving:

$$\phi_K^F = o$$
$$\phi^F = o$$

where: $\phi_K^F = A_2 L_2 Wg(K_2^F)^{c/\alpha} (P_3^F)^{-n/\alpha} - i$

Simultaneously solving for P_3^F and K_2^F gives

$$K_2^F = G^{-\alpha/c} \cdot \left[S/L_1\right]^{\frac{-n}{c-nc+n}} \cdot A_2^{\frac{\alpha(1-n)}{c-nc+n}} \qquad (4.53)$$

$$P_3^F = \left[\frac{S}{L_1} A_2^{\alpha/c}\right]^{\frac{c}{c-nc+n}} \qquad (4.54)$$

Figure (4.1) represents the regulatory constraint for period 3. K_2^F represents the efficient level of capital (at the lagged conditions) that satisfies the regulatory constraint. While P_3^F is the lowest price that can be imposed in the third period. The following intuitive explanation can be provided for the convexity of P_3-K_2 schedule.

Output remaining constant, when capital is increased from K_2^F CEQ(Total Cost) would increase. Change in cost from the efficient levels would increase the cost. Certainty equivalent of revenue and total cost would now equal at a lower expected output. In other words, the regulatory constraint would be satisfied at a lower level of expected output which implies higher prices. Hence the convex nature of P_3-K_2 schedule.

Let us now determine the effect of a given P_3 on the CEQ(Excess Return) for the third period. In the third period, when P_3 is given to firm by the regulators, the firm maximizes the CEQ(Excess Return) by choosing efficient K_3. The third period is the last period in the firm's horizon, the firm does not have to consider the effect of K_3 on future returns.

In the last period, the problem of the firm can be stated as: for a given price find an optimal level of capitalization that maximizes CEQ(ϕ_4):

$$\underset{K_3}{\text{Maximize}} \quad \phi_4 \; (P_3, K_3)$$

$$\text{or} \quad \underset{K_3}{\text{Maximize}} \quad P_3^{1-n} L_1 - A_3 W g L_2 K_3^{-\beta/\alpha} P_3^{-n/\alpha} - i\, K_3 \tag{4.55}$$

From the necessary conditions given in (4.43) an optimal K_3 is given as:

$$K_3 = \left[G^{-\alpha} \quad A_3^{\alpha} \quad P_3^{-n} \right]^{1/c} \tag{4.56}$$

Substitution of optimal value of K_3 from (4.57) in (4.56) provides optimal ϕ_4^* as a function of P_3.

$$\text{and} \quad \phi_4^* = P_3^{-n/c} \left[P_3^{1-n+n/c} \; L_1 - S A_3^{\alpha/c} \right] \tag{4.57}$$

The $\phi_4 - P_3$ schedule is given in Figure (4.2).

From (4.58) the following can be derived $\phi_4 = o$ at aA

$$\text{and } P_3^{A} = \left[\frac{S A_3^{\alpha/c}}{L_1} \right]^{\frac{c}{c-nc+n}} \tag{4.58}$$

$$\phi_4 \text{ is Max. at B; } P_3^{B} = \left[\frac{n s A_3^{\alpha/c}}{(n-1) L_1 c} \right]^{\frac{c}{c-nc+n}} \tag{4.59}$$

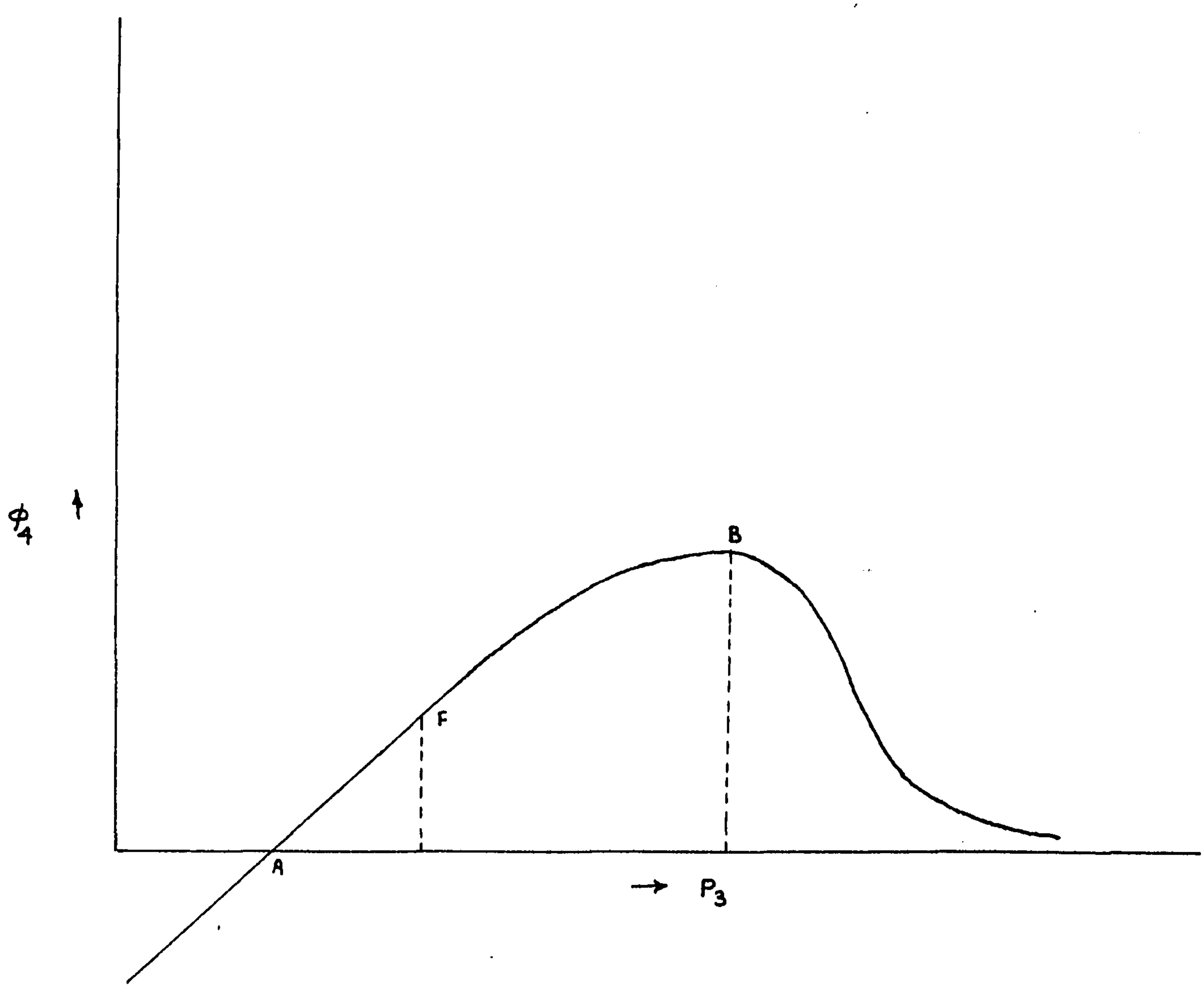


Figure 4.2

and also for $P_3 < P_3^B$, $\partial\phi_4^*/\ \partial P_3 > o$

for $P_3 > P_3^B$ $\partial\phi_4^*/\ \partial P_3 < o$

ϕ_4-P_3 schedule; given in Fig. (4.2) is the schedule achieved when the firm is provided a price level that it must charge while it is free to choose its capital levels. It was shown before that P_3^F is the lowest price that can be imposed for the third period.

As price is increased from Fig. (4.2) the increases in price decrease the CEQ(Revenue) less than the CEQ (Cost). Hence there is a net increase of CEQ of excess return. At B, the CEQ (Excess Return) is the highest and the change of CEQ of revenue and cost with respect to price are equal.

However, if the price is increased more than P_3^B the CEQ(Revenue) falls much quicker than the fall in the CEQ (Costs). Hence the excess revenue decreases.

To know the effect of K_2 on ϕ_4^* Fig. (4.1) and (4.2) have to be combined. This would now be analyzed when there is technological progress. Technological progress implies that $A_3 < A_2$. From P_3^F given (4.54) and P_3^A given in (4.58) it is evident that $P_3^F > P_3^A$.

Through the convex nature of the regulatory constraint, the P_3^B can be arrived at from two different capital levels i.e.

K_2^{B1} and K_2^{B2}; where $K_2^{B1} < K_2^F < K_2^{B2}$

By combining figures (4.1) and (4.2), the following can be derived:

	Figure (4.1)	Figure (4.2)	Figure (4.3)	
(1) $K_2^{B1} < K_2 < K_2^F$	$\partial P_3/\partial K_2 < 0$	$\partial \phi_4/\partial P_3 > 0$	$\partial \phi_4/\partial K_2 < 0$	
(2) $K_2 < K_2^{B1}$	$\partial P_3/\partial K_2 < 0$	$\partial \phi_4/\partial P_3 < 0$	$\partial \phi_4/\partial K_2 > 0$	(4.60)
(3) $K_2^F < K_2 < K_2^{B2}$	$\partial P_3/\partial K_2 > 0$	$\partial \phi_4/\partial P_3 > 0$	$\partial \phi_4/\partial K_2 > 0$	
(4) $K_2 > K_2^{B2}$	$\partial P_3/\partial K_2 > 0$	$\partial \phi_4/\partial P_3 < 0$	$\partial \phi_4/\partial K_2 < 0$	

The signs for the second derivatives have been derived in Appendix (4.2).

For the conditions given in (4.60) the $\phi_4 - K_2$ schedule is bi-modal and is shown in Figure (4.3). At K_2^F the ϕ_4 function is convex downward while at K_2^{B1} and K_2^{B2}, ϕ_4 has the highest value and is concave downward. The values of ϕ_4 are equal at B_1 and B_2 as it corresponds to the same price P_3^B.

K_2^{B1} and K_2^{B2} can be determined from the following regulatory constraint:

$$P_3^{1-n}L_1 - WL_2gA_2K_2^{-\beta/\alpha} P_3^{-n/\alpha} - iK_2 = 0 \qquad (4.61)$$

P_3^B is given in (4.59).

An intuitive explanation for the bimodal $\phi_4 - K_2$ schedule is as follows: Increase or decrease of capital levels from K_2^F would require a higher P_3 to satisfy the regulatory constraint. Increases in P_3 raises CEQ(Excess

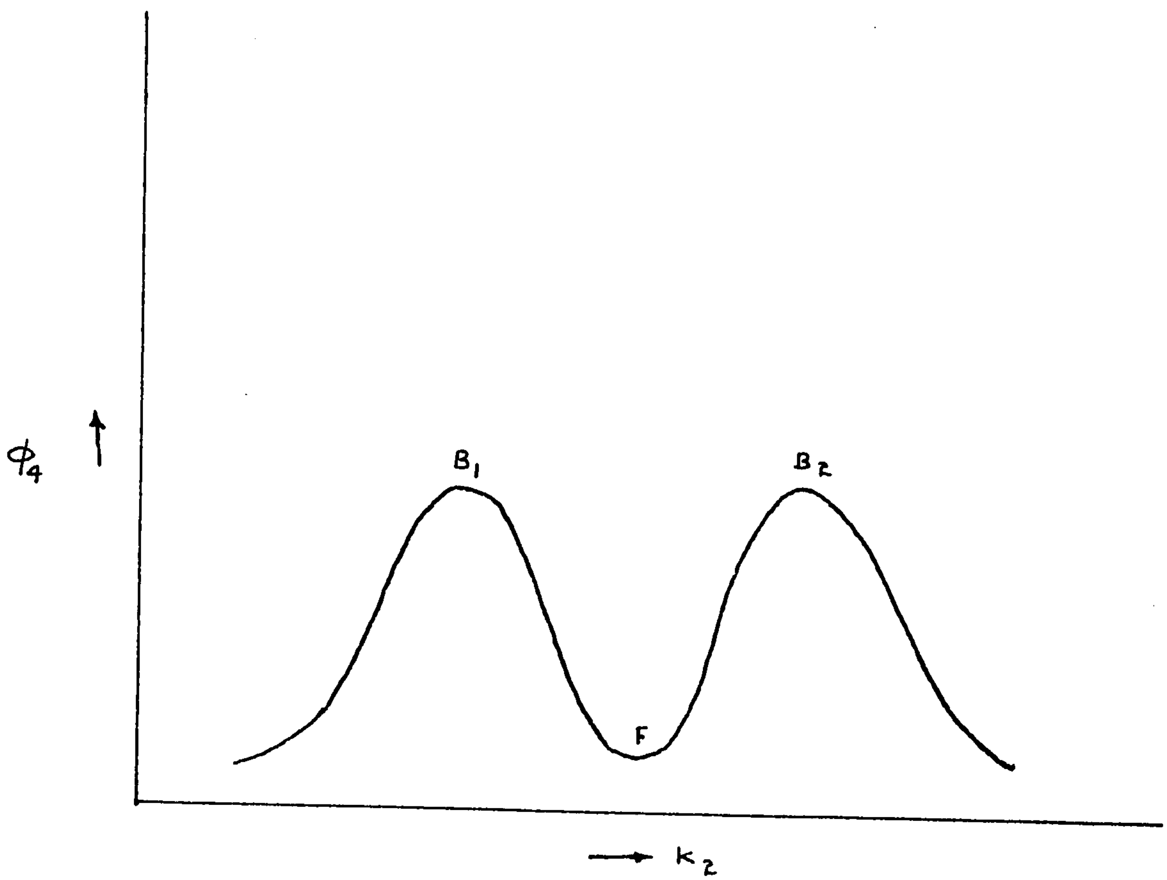


FIGURE (4.3)

Return) until it reaches an optimum at P_3^B and then declines. The behavior of ϕ_4 ,as K_2 is increased or decreased from K_2^F ,is similar. This provides ϕ_4^* as a bi-modal function of K_2. If capital levels are increased or decreased from K_2^F, ϕ_4 would increase.

The following discusses the effect of technological change in $\phi_4 - K_2$ schedule. The $\phi_4 - K_2$ schedule is given in Figure (4.3).

Under technological progress, (from (4.59)) P_3^B would decrease. The maximum ϕ_4 would take place at a lower price. Considering the $P_3 - K_2$ schedule, this implies that technological progress would contract the two wings of ϕ_4 (in figure (4.3)) towards the center. On the other kand, K_2^F given in (4.53) would increase with technological progress. Hence, technological progress would contract $\phi_4 - K_2$ schedule but shift K_2^F to the right.

EFFECT OF K_2 ON SECOND PERIOD CEQ(EXCESS RETURNS

As discussed before, the firm exante capital decision for the second period considers to maximize the CEQ (Excess Return) for the second period plus the discounted CEQ(Excess Return) for the third period. The effect of second period capital on the third period CEQ(Excess Return) is given in Figure 4.3.

The following now discusses the effect of K_2 on CEQ(Excess Return) for period 2 i.e. ϕ_3.

The certainty equivalent Excess Return for period 2 (taken at the beginning of period 3) is:

$$\phi_3 = P_2^{1-n}L_1 - WL_2 gA_2 P_2^{-n/\alpha} K_2^{-\beta/\alpha} - iK_2 \quad (4.61)$$

For the starting conditions assumed in this study (Perfectly competitive), the price for the second period is the same as in the first period.

Substituting from (4.45) and that $P_2 = P_1$

$$P_2 = \left[\frac{SA_1}{L_1}^{\alpha/c} \right]^{\frac{c}{c-nc+n}}$$

$\frac{\partial^2 \phi_3}{\partial K_2^2} < 0$ This ensures that ϕ_3 is a concave function of K_2.

ϕ_3 is a maximum at K_2^1

where

$$K_2^L = G^{-\alpha/c} A_2^{\alpha/c} \left[\frac{SA_1}{L_1}^{\alpha/c} \right]^{\frac{-n}{c-nc+n}} \quad (4.62)$$

ϕ_3 is CEQ(Excess Return) achieved by the firm when the firm must charge P_2 and it is free to vary its capital input. Providing a price level fixes the CEQ(Revenue) for the firm. However, the firm can change its CEQ(Cost) by changing the capital investment. At the efficient level of capital input CEQ(total cost) would be minimum and CEQ(Excess Return) would be maximum. K_2^L provides

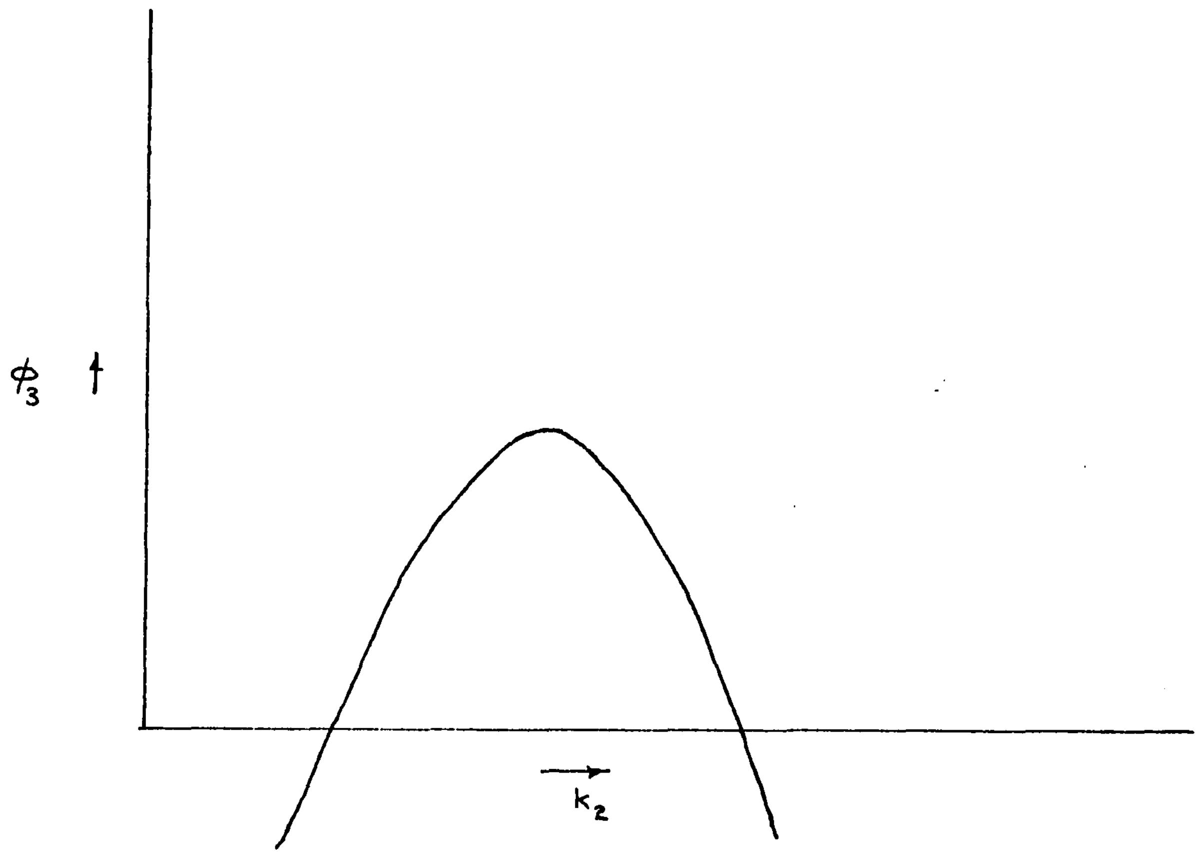


FIGURE 4.4

the maximum ϕ_3. If the firm had only a two period long horizon and if it were not to consider the effect of the second period capital levels on the third period returns the firm would choose an efficient capital level of K_2^L. Figure (4.4) shows ϕ_3 as a function of K_2.

Technological progress implies $A_2 < A_1$ and it would ensure that optimal $\phi_3 > 0$. Under technological progress ϕ_3 and ϕ_4 have been graphed against K_2, Figure (4.5).

From (4.53)

$$K_2^F = G^{-\alpha/c} A_2^{\alpha/c - \frac{n}{c(c-nc+n)}} \frac{S}{L_1}^{\frac{-n}{c-nc+n}}$$

Comparing K_2^F and K_2^L

For technological progress $K_2^F > K_2^L$

and for technological regression $K_2^F < K_2^L$

OPTIMAL K_2 UNDER TECHNOLOGICAL PROGRESS

The second period capital decision by the firm maximizes the CEQ(Excess Returns for the second period) plus the discounted CEQ(Excess Return for the last period).

The firm maximizes $\left[\phi_3 + \phi_4/(1+i)\right]$ (4.63)

The necessary condition is:

$$\frac{\partial\phi_3}{\partial K_2} + \frac{\partial\phi_4}{\partial K_2(1 + i)} = 0 \qquad (4.64)$$

The effect of technological progress is to shift the ϕ_3 function to the left of F, (Figure 4.5).

From $\phi_4 - K_2$ and $\phi_3 - K_2$ schedule in Figure (4.5),

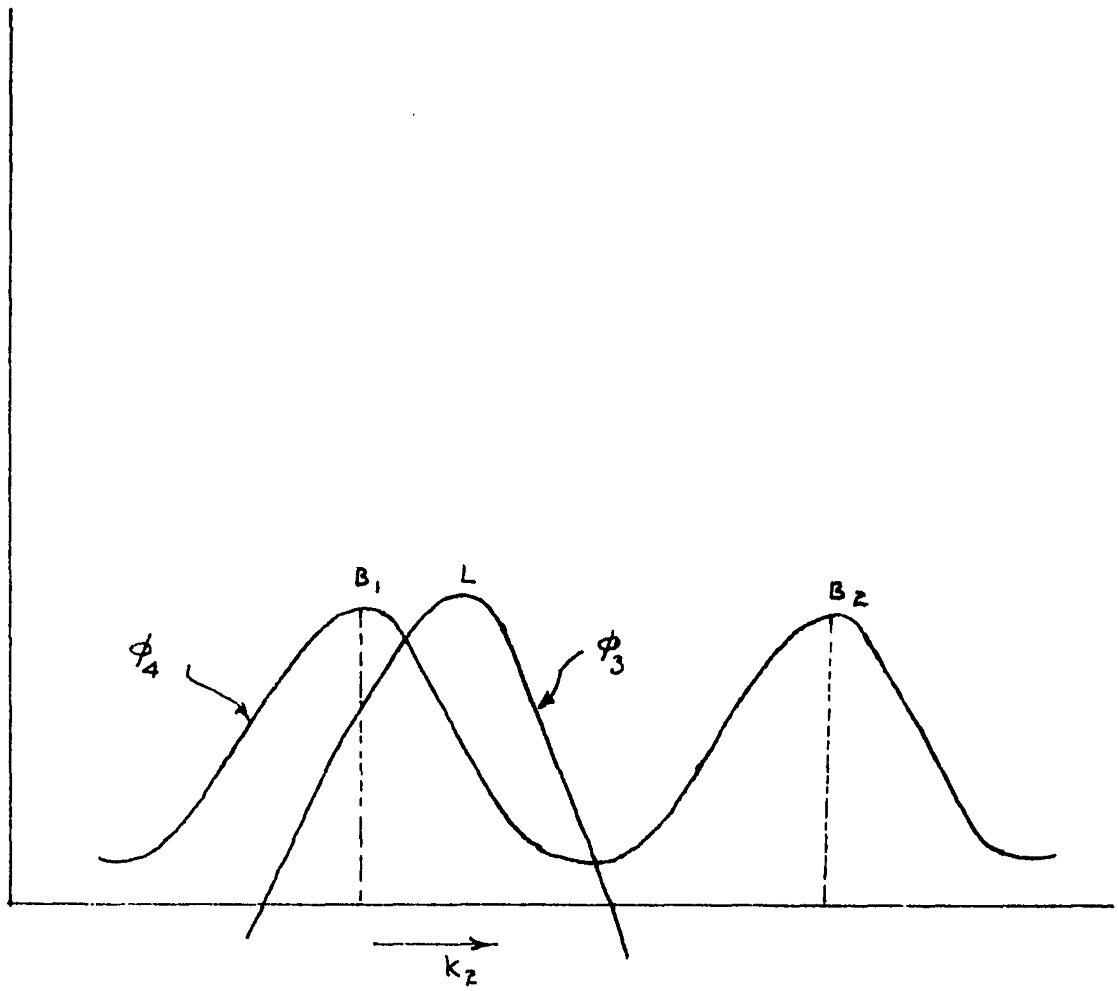


FIGURE 4.5

depending upon the rate of technological progress, two situations can result.

(A) $K_2^L > K_2^{B1}$

When the rates of technological progress are such that $K_2^L > K_2^{B1}$ there exists a K_2 where $K_2^L > K_2 > K_2^{B1}$

$$\text{and} \quad \frac{\partial \phi_2}{\partial K_2^*} = - \frac{\partial \phi_3}{\partial K_2^*(1+i)} \tag{4.65}$$

Hence K_2 would be less than efficient capital levels or the firm would undercapitalize.

In a situation of relatively slow technological progress, the decreased capital levels would increase the future excess returns more than the fall in present excess returns. Decreased present capital would allow future increases in the price that would increase excess returns. Hence the firm would find it beneficial to undercapitalize.

(B) If the rate of technological progress is such that $K_2^L < K_2^{B1}$, and if the combination of capital, demand and production elasticities provide a price that satisfies the regulatory constraint, then there would exist a K_2 such that

$$K_2^{B1} > K_2 > K_2^L$$

$$\text{and,} \quad \frac{\partial \phi_2}{\partial K_2} = - \frac{\partial \phi_3}{\partial K_2 \ (i+i)} \tag{4.66}$$

The necessary condition for optimization would be satisfied for $K_2 > K_2^L$ and overcapitalization would be the result.

When the rate of technological progress is very large, larger than efficient present capital levels would reduce future prices through the regulatory constraint. Reduced future prices increase future excess returns. Hence the firm would like to increase the capital levels from the efficient levels.

APPENDIX 4.1

The following develops the characteristics of the CEQ(Excess Return) earned by the firm when it is given a price P_t and it is free to determine an investment level K_t.

From equation (4.2)

$$\phi_{t+1} = P_t^{1-n} L_1 - W A_t g L_2 K_t^{-\beta/\alpha} P_t^{-n/\alpha} - i K_t \qquad \text{(I)}$$

For a given price P_t , Let us find an optimal K_t.

$$\frac{\partial \phi_{t+1}}{\partial K_t} = W A_t g L_2 \beta/\alpha \, K_t^{-c/\alpha} P_t^{-n/\alpha} - i = 0$$

An optimal K_t = $K_t^* = \left(\frac{i\alpha}{W g L_2 \beta}\right)^{-\alpha/c} P_t^{-n/c} A_t^{\alpha/c}$

when $G = \frac{i\alpha}{W g L_2 \beta}$

$$K_t^* = \left[G^{-\alpha/c} A_t^{\alpha} P_t^{-n}\right]^{1/c} \qquad \text{(II)}$$

Substituting (II) in (I) and considering that $S = \frac{G^{-\alpha/c}\, i\, c}{\beta}$

$$\phi_{t+1} = P_t^{-n/c}\left[P_t^{1-n+n/c} L_1 - S A_t^{\alpha/c}\right] \qquad \text{(III)}$$

From (III) $\phi_{t+1} = 0$

When $\left[P_t^{1-n+n/c} L_1 - S A_t^{\alpha/c}\right] = 0$

$$\text{or} \quad P_t = \left[S/L \; A_t^{\alpha/c}\right]^{\frac{c}{c-nc+n}} \qquad \text{(IV)}$$

After substituting to value of P_t

$$\frac{\partial \phi_{t+1}}{\partial P_t} = -\frac{n}{c} P_t^{\frac{-n-c}{c}} \left[P_t^{1-n+n/c} L_1 - S A_t^{\alpha/c}\right] + P_t^{-n/c}\left[(1-n+n/c) P_t^{-n+n/c} L_1\right] \qquad \text{(V)}$$

t+1 will be maximum, when (V) is equal to zero

(V) can be written as:

$$\frac{\partial \phi_{t+1}}{\partial P_t} = P_t^{-n/c}\left[-\frac{n}{c}\; P_t^{-n+\frac{n}{c}} L_1 + \frac{sn}{c} A_t^{\alpha/c-1} P + (1-n+\frac{n}{c}) P_t^{-n+\frac{n}{c}} L_1 \right]$$

or

$$= P_t^{-n/c}\left[(1-n) P_t^{-n+\frac{n}{c}} L_1 + \frac{sn}{c} A_t^{\alpha/c} P^{-1} \right] = 0 \qquad \text{(VI)}$$

or $$\left[(1-n) P_t^{-n+n/c} L_1 + \frac{sn}{c} A_t^{\alpha/c} P^{-1} \right] = 0$$

$$P_t = P_t^B = \left[\frac{ns}{(n-1)cL_1} A_t^{\alpha/c} \right]^{\frac{c}{c-nc+n}}$$

$$= \left[\frac{ns}{(n-1)L_1 c} \right]^{\frac{c}{c-nc+n}} A_t^{\frac{\alpha}{c-nc+n}}. \qquad \text{(VII)}$$

P_t^B is the optimal price for a monopolist for

$P_t < P_t^B$ $\quad \frac{\partial \phi_{t+1}}{\partial P_t}$.

and $P_t > P_t^B$ $\frac{\partial \phi_{t+1}}{\partial P_t} < 0$

The following evaluates $\frac{\partial^2 \phi_{t+1}}{\partial P_t^2}$.

$$\frac{\partial^2 \phi_{t+1}}{\partial P_t^2} = -\frac{n}{c} P_t^{\frac{-n-c}{c}} \left[(1-n) P_t^{-n+n/c} L_1 + \frac{sn}{c} A_t^{\alpha/c} P_t^{-1} \right]$$
$$+ P_t^{-n/c} \left[(1-n)(-n+n/c) P_t^{-n+\frac{n}{c}+1} L_1 - \frac{sn}{c} A_t^{\alpha/c} P_t^{-2} \right]$$

(a) When $P_t = P_t^B$

$$\frac{\partial^2 \phi_{t+1}}{\partial P_t^2} = P_t^{-n/c-1} \left[\frac{sn}{c} A_t^{\alpha/c} P_t^{-1} \left(\frac{nc-n-c}{c} \right) \right]$$

For a stable firm equilibrium, it is assumed that

$nc-n-c < 0$

Hence $\quad \partial^2 \phi_{t+1} / \partial P_t^2 < 0$

This means that for $P_t = P_t^B$, ϕ_{t+1} is a concave function and satisfies the second order conditions for an optimum.

(b) $$\frac{\partial^2 \phi_{t+1}}{\partial P_t^2} = 0 \qquad \text{(VIII)}$$

(VIII) would hold when $P_t = P_t^D$, and

$$P_t^D = \left[\frac{S\,(n+c)}{C\,L_1\,(n-1)\,c} A_t^{\alpha/c} \right]^{\frac{c}{c-nc+n}}.$$

P_t^D is represented in figure (4.2)

If $c < \frac{n}{n-1}$ (Feasibility condition for the firm)

$\frac{n+c}{c} > n$

and $P_t^D > P_t^B$. (Refer to figure 4.2)

The above implies that:

$$\frac{\partial^2 \phi_{t+1}}{\partial P_t^2} < 0 \quad \text{for } P_t < P_t^D.$$

And, $$\frac{\partial^2 \phi_{t+1}}{\partial P_t^2} > 0 \quad \text{for } P_t > P_t^D.$$

APPENDIX 4.2

The following shows that P_3 is a convex function of K_2.

The regulatory constraint is:

$$\phi(P_3, K_2) = 0$$

is an implicit function of P_3 and K_2. The regulators determine a price P_3 that provides a fair rate of return on capital K_2.

Denoting the partials with corresponding subscripts

$$P_k = -\frac{\phi_K}{\phi_P} \qquad \text{(I)}$$

It is shown in figure (4.4) and derived in Chapter 4 that for a given P_3, ϕ is a concave function of K_2.

Such that $\frac{\partial^2 \phi}{\partial K_2^2} < 0$

and for $K_2 \lesseqgtr K_2^*$; $\quad \phi_K \gtreqless 0 \qquad$ (II)

Where K_2^* provides an optimal level of capital for a given P.

For the firm equilibrium to be stable, it is well known that CEQ(Total Cost) curve should cut the CEQ(Revenue) from below.

This implies that when $\phi = 0$, , $\phi_P < 0 \qquad$ (III)

Substituting II, and III in I.

It is evident that

$P_k > 0$ for $K_2 < K_2^*$

$P_k < 0$ for $K_2 > K_2^* \qquad$ (IV)

and $P_k = 0$ for $K_2 = K_2^*$

Let us now analyze the second derivative of *I)

$$P_{KK} = - \frac{\phi_P \phi_{KK} - \phi_K \phi_{PK} P_K}{\phi_P^2} \qquad \text{(V)}$$

$$= - \frac{\phi_P \phi_{KK} + \phi_K \phi_{PK} \phi_K / \phi_P}{\phi_P^2}$$

$$= - \frac{\phi_P^2 \phi_{KK} + \phi_K^2 \phi_{PK}}{\phi_P^2} \qquad \text{(VI)}$$

Since $= P_3^{1-n} L_1 - A_2 WgL_2 K_2^{-\beta/\alpha} P_3^{-n/\alpha} - iK_2 = 0$

$$= (1-n) P_3^{-n} L_1 + A_2 WgL_2 K_2^{-\beta/\alpha} \left(\frac{n}{\alpha} P_3^{\frac{-n-\alpha}{\alpha}} \right)$$

$$= -A_2 WgL_2 \, \beta/\alpha \quad K_2^{-c/\alpha} \frac{n}{\alpha} P_3^{\frac{-n-\alpha}{\alpha}} \qquad \text{(VII)}$$

or $\phi_{PK} < 0$

The above discussion provides the following:

$\phi_{PK} < 0,$

$\phi_{KK} < 0,$

$\phi_P < 0,$

$\phi_K > 0$ (for $K_2 < K_2^*$)

and $\phi_K < 0$ (for $K_2 > K_2^*$)

Substituting above in (VI), it is evident that for

$K_2 < K_2^*$ or $K_2 > K_2^*$, $P_{KK} > 0$. (VIII)

From (IV), $P_K \gtrless 0$ for $K_2 \lesseqgtr K_2^*$ (IX)

(VIII) and (IX) imply that P_3 is a convex function of K_2 and is sketched in figure (4.1).

APPENDIX 4.3

The following discusses the second derivative of ϕ_4 with respect to K_2.

$$\frac{\partial \phi_4}{\partial K_2} = \frac{\partial \phi_4}{\partial P_3} \cdot \frac{\partial P_3}{\partial K_2}$$

Using the subscripts for the derivatives

$$\phi_K = \phi_P \cdot P_K$$

and $$\phi_{KK} = \phi_P P_{KK} + P_K^2 \phi_{PP} \qquad (I)$$

For $K_2 = K_{B1}$ or $K_2 = K_{B2}$, the following is provided in Appendices (4.1) and (4.2).

$P_{KK} > 0$

$p = 0$

$P_K^2 > 0$

and $\phi_{PP} < 0$

After substituting in (I), it is evident that $\phi_{kk} < 0$

for $K_2 = K_2^F$, it is shown in Appendices (4.1) and (4.2) that

$\phi_P > 0$

$\phi_{PP} < 0$

$P_k = 0$

and $P_{kk} > 0$

After substituting in (I), it is evident that $\phi_{KK} > 0$

Referring to figure (4.3), the above proves that a B_1 and B_2, ϕ_4 is a concave function of K_2, while, it is a convex function at F.

APPENDIX 4.4

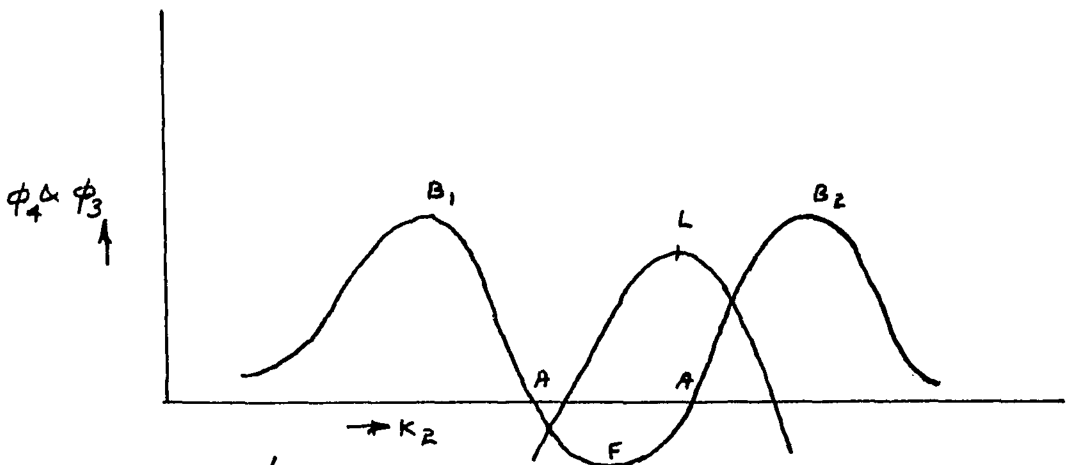
Under conditions of regulatory lag, the following discusses the technological regression. It considers a three period firm horizon and the starting conditions are assumed to be perfectly competitive.

It is shown in equations (4.53) and (4.59) that

$$P_3^F = \left[\frac{S}{L_1} A_2^{\alpha/c}\right]^{\frac{c}{c-nc+n}}$$

$$P_3^A = \left[\frac{S A_3^{\alpha/c}}{L_1}\right]^{\frac{c}{c-nc+n}}$$

For technological regression $A_2 > A_3$, therefore, $P_3^F > P_3^A$. This implies that $\phi_4^F < 0$, and $\phi_4^A = 0$. In accordance with above, the $\phi_4 - K_2$ schedule is sketched in the following diagram



The ϕ_3--K_2 schedule is sketched in Figure (4.4).

K_2^L is given in (4.62)

$$K_2^L = G^{-\alpha/c} A_2^{\alpha/c} \left[\frac{SA_1}{L_1}\right]^{\alpha/c \; \frac{-n}{c-nc+n}} \qquad (4.62)$$

also K_2^F is given in (4.53)

$$K_2^F = G^{-\alpha/c} \left[{}^{S}/_{L_1}\right]^{\frac{-n}{c-nc+n}} A_2^{\frac{(1-n)}{c-nc+n}} \qquad (4.53)$$

As $A_1 > A_2$; $K_2^L > K_2^F$

The rest of the discussion is similar to the case of technological progress discussed in Chapter IV. The technological regression shifts the ϕ_3 function to the right.

When $K_2^L > K_2^{B2}$, the decrease of capital from efficient levels increases the present value of future excess returns more than the decrease of present period CE (Excess Returns). In this case it is advantageous for the firm to undercapitalize.

When $K_2^L < K_2^{B2}$, the increase of capital from efficient levels increases the present value of future excess returns more than the decrease of present period CE (Excess Returns). In this case it is advantageous for the firm to overcapitalize when $K_2^L = K_2^{B2}$, efficient factor input decisions are made.

V_3 is the value of the firm at the end of period 2.

$$V_3 = \phi_3 + \phi_4/(1+i)$$

From the above figure, for $K_2^F < K_2 < K_2^A$, $\phi_4 < 0$ and in that case if $\phi_3 < -\phi_4/_{1+i}$, $V_3 < 0$. Although the firm would overcapitalize but it would have a negative net present value. The above shows that under technological regression, conditions may exist when the regulated firm would have negative net present value.

CHAPTER V

SIMULATION OF THE MODEL OF FIRM BEHAVIOR FOR ELECTRIC UTILITY INDUSTRY

5.1 INTRODUCTION

This chapter presents the results of the simulations of the models of firm behavior as developed in Chapter IV. The simulations have been performed for the electric utility industry. The firm behavior has been analyzed under different conditions of regulation and market structure. Section 5.2 presents the unique characteristics of the Electric Utility industry. Section 5.3 outlines the basic concepts and methodology used for the simulation. This is followed by the description of the algorithm and the mechanics of the decision making by the firm and the regulators. Finally, the results of the simulations are presented.

5.2 The Electric Utility Industry

In this study the simulations of firm behavior have been conducted on the electric utility industry. The characteristics of the electric utility industry have been extensively analyzed in the literature.* This is precisely the reason for its selection in this study.

*See Taylor (84)

The performance* of the last three decades shows that the electric utility production function is characterized by increasing returns to scale. While analyzing the effect of the regulation on the firm behavior, Courville (16) estimated the parameters of the production function for the Electric Utility Industry. His analysis has considered the generation aspect of the Electric Utility Industry. The transmission and distribution of electricity was not included because of the following reasons:

(1) They are probably characterized by a fixed proportion production function.

(2) The planning horizon is much longer than the generation of electricity. Transmission and generation is designed for a much larger capacity than immediately required.

(3) Some firms are net sellers to other firms while others are net buyers. Different firms need varying amounts of investment in the transmission and distribution of electricity.

To have included the transmission and distributional aspects into the analysis would have obscured his analysis of efficiency in production. By using a homogeneous production function, Courville (16) estimated the elasticities for different vintages of plants. He has

*See Courville (16)

confirmed that the Cobb Douglas production model could not be rejected for the electric utility industry.

The relation tested is given by:

$$Q_i = AK_i^{\beta} F_i^{\alpha} L_i^{\lambda} \quad \delta u_i \quad bc_i \quad \varepsilon i$$

where

Q_i = Output/rR. for plant i

K_i = Capital for plant i

F_i = Fuel input

L_i = Labor input

U_i = the capacity utilization of plant i

C_i = the capacity of plant i

ε_i = A random variable normally distributed with mean o and variance ^{2}.

Cross-section data for different plant vintages were used to estimate the parameters.

The following results were derived.

Vintage Group	$\hat{\text{Log A}}$	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\lambda}$	$\hat{\delta}$	$\hat{b}$	R^2	DF
1948-1950	-1:779 (2.60)	0·1674 (2.60)	1·04 (16·40)	-0·006 (0·12)	-·2929 (1·94)	-0·0009 (2·40)	0·995	20
1951-1955	-1·5549 (3.54)	0·1254 (2·99)	1·035 (24·71)	0·0632 (1·62)	0·0869 (0·88)	-0·0003 (2·62)	0·996	30
1960-1966	-1·0764	0·0772 (1·59)	0·9493 (16·53)	0·0403 (1·03)	0·2913 (2·47)	0·00009 (0·62)	0:993	31

From the above results Courville concluded:

(1) The output elasticity of labor is close to zero and is insignificant at 10% significance. This means that there is practically no substitution between labor and other inputs for electricity generation.

(2) The production function is increasing returns to scale.

For purposes of simulation the present study uses the output elasticities determined by Courville (16).

Taylor (84) has reviewed the literature on the demand for electric power. He has argued that the price elasticity for electric demand is different for short run than for the long run. He argues that the short run demand is constrained by the amount of capital stock that uses electricity, while the long run changes in the demand are correlated with the variation of capital stock that consumes electricity. He also contends that the electric demand is also affected by the block pricing practices followed in the industry. Different authors have estimated different price elasticities of demand. Taylor has summarized their estimates as below:

RESIDENTIAL	Short Run	Long Run
Houthakkar[1]	-0·89	
Houthakkar & Taylor	-0·13	-1·89
INDUSTRIAL		
Mount, Chapman & Tyrell	-0·22	-1·82
COMMERCIAL		
Mount, Chapman & Tyrell	-0·17	-1·36

The present study simulates a multiperiod model of firm behavior, therefore long run price elasticity estimates have been used.

In addition to the price and output elasticities mentioned above, the following parameters are used in the simulation of the model.

Cost of Fuel: The cost of fuel is $5.5/unit.

CERTAINTY EQUIVALENTS: The certainty equivalents for the firm revenue (L_1) and the firm fuel costs (L_2) are affected by the uncertainty in the revenue and the uncertainty in the costs. The uncertainty in the revenue and costs stem from the uncertainty in the demand. Considering that the systematic risk of electric demand is positive, then the certainty equivalent of the net revenue for the firm is less than one. Simulation was

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[1] See Taylor (84).

conducted by varying L_1 and L_2.

THE DEMAND DISTRIBUTION: It is assumed in Chapter IV that the demand = $\tilde{\theta}$ (Price)$^{-n}$. $\tilde{\theta}$ is the multiplicative stochastic element. $E(\tilde{\theta}) = 1$. Although depending upon the economic factors, the demand for electricity may vary from a year to year but the estimates for the uncertainty are not available. It is assumed that $\tilde{\theta}_t$ is independently and identically distributed overtime. The analysis in Chapter IV holds for any distribution of θ. If the certainty equivalents remain the same, the exante decision remains the same for any distribution of θ .

INTEREST RATE: Future CEQ(Excess Returns) are discounted at the risk free rate of return. The effect of change in the interest rates on the firm decision is given in Exhibit XII.

5.3 DISCUSSION OF METHODOLOGY PASSIVE REGULATION

The model of passive regulation is presented in Chapter IV. Passive Regulation of a utility results from the regulators not having the current firm information and, therefore, they determine the present prices based on the previous period technology and investment levels of the firm. On the other hand the firm knows its current environment and also knows the technological improvements that it expects into the future.

The firm would plan an investment level that maximizes its net present value, while it considers the regulatory constraint. The net present value of the firm is the sum of the discounted certainty equivalent of excess return for present and all future periods.

Assuming that the firm has a T period horizon, then the problem of the firm in any period t is given in (4.34) and reproduced below.

$$V^*_{t+1}\ (K_t) = \underset{K_t}{\text{MAX}} \left\{ \phi_{t+1}\ (P_t, K_t) + \sum_{K=t+2}^{T+1} \frac{\phi K}{(1+i)^{K-t-1}} \right\} \quad (5.1)$$

$$\text{S/T} \quad \phi_{t+1}\ (P_t, K_{t-1}) = 0 \quad (5.2)$$

If

$$V_{t+2/(1+i)} = \sum_{K=t+2}^{T+1} \frac{\phi K}{(1+i)^{K-t-1}} \quad (5.3)$$

then V_{t+2} is the value of the firm in the beginning of t + 2. It is the sum of discounted CEQ(future excess returns). The problem of the firm in any period t can be written as:

$$V^*_{t+1}\ (K_t) = \underset{K_t}{\text{MAX}} \left\{ \phi_{t+1}\ (P_t, K_t) + \frac{V^*_{t+2}}{1+i} \right\} \quad (5.4)$$

Subject to

$$\phi_{t+1}(P_t\ , K_{t-1}) = 0 \quad (5.5)$$

From the regulatory constraint given in (5.5), the firm knows P_t and proceeds to determine an optimal capital K_t. For every feasible value of K_t, there exists a stream of optimal excess returns $\phi_{t+1}, \phi_{t+2}, \ldots\ldots, \phi_{T+1}$.

These are determined after solving for the regulatory constraint in each period and determining the optimal capital levels for each future period.

Hence for every feasible value of K_t in period t, to determine whether it is optimal, the firm has to know the decision rules for all future periods. Out of the feasible region for K_t an optimal K_t is determined that provides the maximum (V_{t+1}) of the firm.

V_{t+1} (K_t) is the discounted sum of the optimal CEQ(excess returns) ϕ_{t+1} (K_t), ϕ_{t+2} (K_t),....., ϕ_{T+1} (K_t).

While analyzing a three period example, it was shown in Chapter IV section and sketched in Figure (4.3) that ϕ_4 is non-linear function of K_2. Moreover, ϕ_4 is bimodel with concave and convex regions. It is also proved in Chapter IV section and shown in Figure (4.4) that ϕ_3 is a strictly concave function of K_t. Hence V_3 is a sum of non-linear functions of K_2 which are concave and/ or convex over the region.

To maximize V_{t+1}, optimal values of ϕ_{t+2}, ϕ_{t+3}, ..., ϕ_{T+1} have to be determined. Therefore, to solve the problem in the present period, first, optimal decision rules for all future periods have to be determined. Contingent upon the information set available to the firm at the end of period T - 1, the firm would determine an optimal decision rule for the period T. Or, for each feasible value of K_{T-1}, the firm would determine an optimal K_T.

Similarly, based on the information set available to the firm at the end of period T-2, the firm would determine an optimal decision rule for T-1. For each feasible value of K_{T-2}, the firm would determine an optimal K_{T-1}. The feasible region of K_{T-2} satisfies the following constraint.

$$\phi(P_{T-1}, K_{T-2}) = 0$$

In other words, all values of K_{T-2} for which a P_{T-1} exists and satisfies the above constraint is a feasible region for K_{T-2}. After determining P_{T-1} the firm would solve for an optimal K_{T-1} that provides a maximum V_T.

In this way, starting with the last period, the firm would determine decision rules for all future periods and finally solve the problem for the present period. Hence the technique of Backward Recursive Dynamic Programming. While solving the problem for the present period, the firm needs to know the decision rules for all future periods. For any feasible value of K_t, there exists a set of optimal values for K_{t+1}, K_{t+2}, and K_T.

5.4 DESCRIPTION OF ALGORITHM FOR SIMULATION OF PASSIVE REGULATION

An algorithm for simulation of passive regulation must incorporate the following aspects of decision making:

(1) Based on any feasible value of capital for the previous period, the firm must determine a decision rule for the present period. The decision rule for the present period is determined after the decision rules for all future periods are known.

(2) Determination of the decision rules must start first with the last period. Through recursive decision making, and moving backward, finally the problem is solved for the present period. Finding an optimal decision for the present period also involves finding an optimal future decision path.

The following considers a T period firm horizon. First, the decision rule for the last period is determined. For each feasible value of K_{T-1} an optimal K_T is determined. The feasible region of K_{T-1} is the set of values of K_{T-1} for which a P_T exists and satisfies the following constraint.

$$\phi(P_T, K_{T-1}) = 0$$

To keep the number of decision alternatives within manageable limits only 100 equispaced values of K_{T-1} in its feasible region are considered. Corresponding to 100 feasible values of K_{T-1}, there are 100 optimal values of K_T. An optimal K_T maximizes $\phi_{T+1}(P_T, K_T)$. (5.6) represents the optimal decision rule for each feasible value.

Decision Rule	Feasible K_{T-1}	Price	Optimal K_T	MAX ϕ_T	
1	$K_{1,T-1}$	$P_{1,T}$	$K_{1,T}$	$\phi_{1,T+1}$	
2	$K_{2,T-1}$	$P_{2,T}$	$K_{2,T}$	$\phi_{2,T+1}$	
3	$K_{3,T-1}$	$P_{3,T}$	$K_{3,T}$	$\phi_{3,T+1}$	(5.6)
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
99	$K_{99,T-1}$	$P_{99,T}$	$K_{99,T}$	$\phi_{99,T+1}$	
100	$K_{100,T-1}$	$P_{100,T}$	$K_{100,T}$	$\phi_{100,T+1}$	

An optimal $K_{j,T}$ denotes the optimal value of K_T when the previous period capital is $K_{j,T-1}$.

Having determined the decision rule for the last period, the firm determines a decision rule for the last but one period. For each feasible value of K_{T-2} an optimal K_{T-1} is determined that maximizes $\phi_{T-1} + \phi_T$. (5.7) represents the decision rule for each feasible value of K_{T-2}.

Decision Rule	Feasible value of K_{t-2}	Price	Optimal K_{T-1}	Maximum V_T
1	$K_{1,T-2}$	$P_{1,T-1}$	$K_{1,T-1}$	$V_{1,T} = \phi_T + \phi_{T+1}/1+i$
2	$K_{2,T-2}$	$P_{2,T-1}$	$K_{2,T-1}$	$V_{2,T} = \phi_T + \phi_{T+1}/1+i$
3	$K_{3,T-2}$	$P_{3,T-1}$	$K_{3,T-1}$	$V_{3,T} = \phi_T + \phi_{T+1}/1+i$
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
99	$K_{99,T-2}$	$P_{99,T-1}$	$K_{99,T-1}$	$V = \phi_T + \phi_{T+1}/1+i$
100	$K_{100,T-2}$	$P_{100,T-1}$	$K_{100,T-1}$	$V = \phi_T + \phi_{T+1}/1+i$

(5.7)

An optimal $K_{j,\ T-1}$ denotes the optimal value of capital for T - 1, when the feasible value of the capital for T - 2 is $K_{j,T-2}$.

Having solved (5.6) and (5.7). For a given value of $K_{J,T-2}$; an optimal K_{T-1} and K_T are determined as below. By using the decision rule reference for period T - 1, given in (5.7), corresponding to a given $K_{j,T-2}$; an optimal $K_{J,T-1}$ is determined. Then, from the decision rule reference for period T given in (5.6), an optimal K_T is determined.

Now, if the firm horizon is three periods long (T=3), and when 100 feasible values are considered, the firm has to solve 100 problems for period 3 and another 100 problems for period 2.

In total 200 possible solutions have to be evaluated.

If instead of backward recursive programming a forward decision making is applied, the process would be as follows:

Feasible Value	Price	Capital For T-1	Capital For T	(Excess Return)
$K_{1, T-2}$	$P_{1,T-1}$	$K_{1,T-1}$	$K_{1,T}$	$\phi_{1,T} + \phi_{1,T+1}/(1+i)$
			$K_{2,T}$	$\phi_{1,T} + \phi_{2,T+1}/(1+i)$
			$K_{3,T}$	$\phi_{1,T_1} + \phi_{3,T+1}/(1+i)$
			.	.
			.	.
			.	.
			$K_{99,T}$	$\phi_{1,T} + \phi_{99,T+1}/(1+i)$
			$K_{100,T}$	$\phi_{1,T} + \phi_{100,T+1}/(1+i)$
		$K_{2,T-1}$	$K_{1,T}$	$\phi_{2,T} + \phi_{1,T+1}/(i+i)$
			$K_{2,T}$	$\phi_{2,T} + \phi_{2,T+1}/(i+1)$
			$K_{3,T}$	$\phi_{2,T} + \phi_{3,T+1}/(1+i)$
			.	.
			.	.
			.	.
			$K_{99,T}$	$\phi_{2,T} + \phi_{99,T+1}/(1+i)$
			$K_{100,T}$	$\phi_{2,T} + \phi_{100,T+1}/(1+i)$
		$K_{3,T-1}$		
		.		
		.		
		.		

For a given value of $K_{j,T-2}$ there are 100 feasible values of K_{T-1} and for each feasible value of K_{T-1} there are 100 feasible values of K_T. Hence for each given value of $K_{j, T-2}$ there are 100 x 100 feasible alternatives. Hence, the firm must solve for 100^2 alternatives and determine the one that provides the highest firm value.

For a three period problem, a foreward decision making would involve evaluating 100^2 alternatives. On the other hand, the same problem could be solved by Backward Recursive Dynamic programming by solving for 200 alternatives only.

By applying the Backward Recursive Dybamic Programming a T period analysis is completed by solving for 100 (T - 1) problems. While the same problem would involve $100^{(T-1)}$ alternatives, if handled through forward decision making.

The simulations have been performed under the following conditions:

(1) By varying the starting conditions

(2) By varying the firm demand and production conditions, and

(3) By varying the firm horizon.

5.5 STEADY STATE CONDITIONS

The period in which the firm decision rule is unaffected by the firm starting conditions, the system is considered to have achieved the steady state conditions. Exhibit III shows the firm decision for different starting conditions. The effect of any starting conditions disappears from period five and onwards.

The period in which the steady state conditions are achieved is affected by the demand and production conditions of the firm. By comparing exhibits III and IV, it is evident that two different firms, while working under different demand and production conditions, would achieve steady state conditions in different periods.

5.6 EXISTENCE OF THE OPTIMAL DECISION RULE

The problem of the firm in period t is given by (5.4) and (5.5) and reproduced below:

$$\underset{K_t}{\text{Maximize}} \left\{ \phi_{t+1} (P_t, K_t) + \frac{V_{t+2}}{1+i} \right\} \qquad (5.4)$$

$$\text{S/T} \qquad \phi(P_t, K_{t-1}) = 0$$

Where

$$\phi(P_t, K_{t-1}) = P_t^{1-n} L_1 - WL_2 g A_{t-1} K_{t-1}^{-\beta/\alpha} P_t^{-n/\alpha} - iK_{t-1} = 0.$$

Where for any combination of demand and output elasticities (for a given K_{t-1} and A_{t-1}) a P_t does not exist that satisfies the regulatory constraint (5.5), the firm cannot be provided a fair rate of return. In such a case regulatory prices cannot be determined, and the firm cannot be ensured a fair rate of return. This can result when:

1. Due to technological regression, the certainty equivalent of total cost is higher than the certainty equivalent of total revenue at all

levels of output.

2. Because of a change in the demand elasticity the CEQ (total revenue) is lower than the CEQ (total cost).
3. A change in the rates, the interest rates, and the output elasticities makes the CEQ (total cost) higher than CEQ (total revenue).

Fig. (4.1) gives the regulatory constraint and shows that very high or very low values of capital make the total cost higher than the CEQ (Revenue).

5.7 DISCUSSION OF RESULTS

EFFECTS OF MARKET STRUCTURE

Exhibit I compares the firm decisions when the market structure is a monopoly, actively regulated monopoly and a passively regulated monopoly. The technology improves at the rate of 1.125% per period. The simulation results are given for a 9-year period. The results confirm the conclusions derived in Chapter IV. A monopoly charges the highest price. It restricts investment. The net present value of the firm is the highest. The monopolist makes efficient factor input decisions in each period.

As the technology improves, the monopolist finds it beneficial to decrease the product price and increase the capital investment. Improvement of the technology also increases the CEQ(Excess return) earned by the firm.

An actively regulated firm charges the lowest price. The exante investment of the firm is the highest in each period. The net present value of the firm is zero in each period. The product prices reduce overtime. The rate of reduction in prices is the same as that for an unregulated monopoly.

The prices charged by a passively regulated firm are higher than those charged by an actively regulated firm. Under passive regulation the regulatory price is based on the technology of the previous period; which is less efficient. This implies higher prices. The net present value of the firm is lower than if it were a monopoly. The investment made by the firm is less than the efficient levels. Under conditions of technological progress a passively regulated firm would under-capitalize.

FIRM HORIZON:

Exhibit II gives the results of passive regulation when the firm horizon is 3 - 9 periods long. The increase in the firm horizon increases the net present value of the firm. A longer firm horizon provides increased flexibility to the firm to increase the CEQ(Excess Return) in future periods. A passively regulated firm earns more than fair returns. As the firm horizon is increased, the inefficiency of production also increases. For technological progress a longer firm horizon results in increased undercapitalization by the firm. When the firm starting conditions are perfectly competitive, the firm investment levels decrease in the beginning periods and then increase. Fig. (5.1) gives the firm capital level at different points in time. It is shown that capital levels reach the lowest point when the firm horizon is longest. The efficient level of capital that the firm should have planned increases steadily over the firm horizon.

STARTING CONDITIONS

When the starting period capital is higher or lower than the perfectly competitive levels, the results of passive regulation are presented in Exhibit III. Exhibit I presents the results for the perfectly competitive starting conditions.

When the rate of technological progress is 1.25%, the effect of starting conditions disappears before the fifth period. In this case all starting conditions provide the same firm decision for periods 5 and beyond. Most of the adjustment for the starting condition takes place in the second period. For the third and the fourth periods, the adjustment for the starting conditions is small.

When the rate of technological progress is 2.5%, the firm decision for different starting conditions is identical for the 7th period and beyond. This implies that the greater is the rate of technological progress, the longer the time it takes for the firm to come over the effect of starting conditions.

Irrespective of the firm starting conditions, for technological progress, the firm undercapitalizes for all periods. For rates of technological progress of 1.25% and 2.5%, Exhibit III shows that the firm undercapitalizes in all periods except for the last period.

Exhibit IV presents the results when the demand elasticity is -1.94. Results are presented for a high and a very low starting capital. In this case, even when the starting conditions are different, the firm makes the same decision for periods four and beyond. The effects of starting conditions disappears before the fourth period.

TECHNOLOGICAL PROGRESS

Exhibit V shows that, when the rate of technological progress is 1.25%, the firm undercapitalizes in all periods except the last one. Undercapitalization is also confirmed when the rate of technological progress is 2.5%. When the rate of technological progress is increased, the degree of undercapitalization also increases, and the regulatory price falls faster. Increase in the rate of technological progress also increases the net present value of the firm.

For a three period horizon, the rates of technological progress were increased from 3.125% to 39.125%, and the results are shown in Exhibit VI. It is shown that the higher the rate of technological progress, the lower the price for the third period, and the higher the net present value of the firm. The firm makes efficient factor input decisions in the last period. In all situations the firm plans undercapitalization.

The following discusses the effect of changes in the demand or production conditions of the firm, while the technology progresses.

DEMAND ELASTICITY

Mount, Chapman and Tyrrell* have estimated the long run demand elasticity as -1.82. With -1.82 as the demand elasticity, Exhibit III provides the price and capital of a passively regulated firm. A starting capital of 0.75 is assumed. Anderson* has estimated the long run demand elasticity as -1.94. For a starting capital of 0.75, the decisions of a passively regulated firm are given below.

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* See Taylor (84)

TABLE 5.1

STARTING CAPITAL = 0.75   P = PRICE

DEMAND ELASTICITY = 1.94   OK = OPTIMAL CAPITAL

OKP = EFFICIENT CAPITAL

V = VALUE

PERIOD	P	OK	OKP	OK/OKP	V
2	4.61	0.360	0.509	0.707	0.018
3	4.52	0.375	0.520	0.721	0.016
4	4.44	0.385	0.529	0.728	0.015
5	4.37	0.395	0.537	0.735	0.013
6	4.30	0.405	0.546	0.741	0.011
7	4.23	0.425	0.554	0.767	0.008
8	4.16	0.465	0.564	0.824	0.006
9	4.08	0.575	0.576	1.000	0.003

The above results show that a decrease in the demand elasticity increases the product prices. The optimal capital investment is decreased. A change in the demand elasticity does not change the undercapitalization.

OUTPUT ELASTICITY:

Exhibit VII compares the price and capital investment of a passively regulated firm when the output elasticity of capital is varied. The exhibit shows that an increase in the output elasticity of capital increases the regulatory price and the level of capital input by the firm.

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* See Taylor (84)

The following provides an explanation of the above:

An increase in the output elasticity of capital increases the optimal capital-labor ratio for the firm. In this case, it also increases the total cost of the output. The increase in the total cost of output requires a higher regulatory price.

Exhibit VIII compares the passive regulation when output elasticity of fuel is changed. The exhibit shows that an increase in the output elasticity of capital increases the regulatory price and lowers the optimal level of capital. The results for increases in the output elasticity of fuel are opposite to the increases in the output elasticity of capital.

The increase in the output elasticity of fuel reduce the optimal capital - expected labor ratio. Hence, the optimal capital planned by the firm would decrease. In this case, it lowers the total cost of output and, would result in lower regulatory price.

MARKET RISK OF REVENUE

An increase in the market risk of the revenue decreases the certainty equivalent of a dollar of revenue. Therefore, an increase in the risk decreases the certainty of equivalent of total revenue. When the cost function remains the same and the CEQ(revenue) shifts downward, a fair rate of return is provided to the firm at higher prices. Hence, an increase in the revenue uncertainty would increase the regulatory prices. This is shown in Exhibit VI. Higher prices would mean lower expected supply, therefore reduced capital investments.

MARKET RISK OF FUEL COST

Exhibit X represents the results of passive regulation when the market risk of total fuel cost is changed. For the same expected fuel costs, a decrease in the uncertainty of fuel usage, would increase the certainty equivalent of the fuel cost. This shifts the total cost curve upward. Increased CEQ(total cost) would require increased regulatory price. Hence, the decreased market risk of fuel increases the regulatory price and reduces the expected output. Reduced expected output required a lower capital input level. Increase in market risk of fuel cost decreases the capital input levels.

FUEL RATES

Exhibit XI gives the results of a passively regulated firm when the fuel costs change from \$5.5 to \$6.5/ton. Increase in fuel rates increases the CEQ(cost) per unit of output. Demand conditions remaining constant, the regulators would have to provide a higher regulatory price. Increased prices imply lower expected demand and expected supply. This results in lower level of capital investment by the firm.

RISK-LESS RATE OF RETURN

Exhibit XII gives the results of a passively regulated firm when the interest rates are changed. A reduction in the interest rates lowers the regulatory price and increases the capital investment by the firm.

5.9 CONCLUSION

This chapter has presented the results of the simulation of the models of firm behavior by using the parameter's from the electric utility industry. The simulation tests confirm the analytically derived results of the previous chapters. In addition to above, the effect of firm horizon, firm starting conditions, and output and demand elasticities on the regulated firm decisions was determined. Increased firm horizon, provides greater flexibility to the firm to increase its net present value and also increases the inefficiency in the production decisions. The effect of starting conditions on the firm decisions disappears in the beginning few periods, and thereafter, the firm makes the same decisions for all starting conditions.

CHAPTER VI

SUMMARY, CONCLUSION AND COMMENTS

The results developed in the last three chapters are summarized below.

The single-period and multiperiod models of firm production behavior have been developed. The single period formulation considers the expected demand as function of price and quality. Price remaining constant, the expected demand should be an increasing function of quality. Consumers would be willing to pay a higher price for better quality product. For purposes of analytical tractability the multiperiod formulation considers the expected demand as a function of price only. Different conditions of market structure; e.g., a monopoly, an actively regulated monopoly and a passively regulated monopoly; have been considered.

Maximization of expected utility cannot be pursued as a valid firm objective as very often it is not clear whose expected utility should be considered. The management of the firm should make production decisions that maximize its net present value.

The returns to the stockholders must be consistent with risks in the revenue and costs of the firm. This must also be in line with the returns available for comparable risks elsewhere in the economy.

The net present value of the firm must be determined in context of the capital market equilibrium. The capital asset pricing model[1] provides a mean to determine an equilibrium present value of an uncertain net cash returns.

An unregulated monopolist would charge a higher price and restrict expected supply than the perfectly competitive industry. If the valuation of marginal quality increases with quality, the monopolist would supply a higher quality level than the perfectly competitive industry. The opposite would be true if the marginal valuation of quality decreases with quality. At the optimal point the expected marginal revenue is equal to the expected marginal cost and the marginal revenue product of quality is equal to the marginal costs due to quality.

The shareholders of a regulated firm must be provided a fair rate of return. The production decisions of a regulated firm are affected by the behavior of the regulators. The regulators may actively or passively seek to regulate the activity of the firm. It is proposed in the literature[2] that a firm may be regulated by imposition of a fair rate of return constraint. This is impractical because a firm may not abide by such a regulatory constraint. This study proposes regulation through price and quality controls. To eliminate the

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[1]See Sharpe (67).

[2]See Averch & Johnson (2).

monopoly excess returns, regulators must impose both the price and quality controls. Only price regulation would not eliminate the monopoly excess returns. By adjusting the product quality levels and thus restricting the expected demand, the regulated firm can increase its net present value and earn more than fair returns. Similarly, when only quality controls are imposed on the firm, the firm would raise the product prices, restrict the expected demand, and earn more than fair returns. When the regulated firm is given both the price and quality standards, the firm expected supply would be equal to the expected supply from the perfectly competitive industry, and the shareholders would earn a fair rate of return.

When the firm horizon is longer than one period, the new regulatory price must be determined after considering the changes in the technology of the firm. If the regulators determine a regulatory price for the next period, after considering the technology for the next period, the firm is regulated actively. The regulators impose a price that provides a fair rate of return at the efficient investment levels. On the other hand the firm determines an optimal investment that maximizes its net present value.

Active regulation is an ideal scheme for the regulation of the firm. It provides the lowest regulatory price and ensures highest level of expected supply by the firm. The firm makes efficient factor input decisions in each period.

The advantages of technical progress are passed onto the consumers in the firm of reduced prices. Under active regulation, the improvement in the technology does not increase the net present value of the firm. This implies that the firm has no incentive to improve its technology.

When the regulators do not have complete knowledge about the firm environment, passive regulation would result. In this case, the regulators determine prices for the present period based on previous period conditions of the firm. Passive regulation can be represented as a duopolistic game between the firm and the regulators. The firm acts as the leader while the regulators are the passive followers. Considering the technology and the investment levels of the previous period, the regulators determine a regulatory price. Using this as the price and the technology for the present period, the firm determines an optimal investment level for the present period. The regulated firm determines an investment level that maximizes its net present value. The net present value of the firm is the sum of discounted CEQ(Excess Return) for present and future periods. The above implies the existence of the regulatory lag.

Under conditions of regulatory lag, the firm has an incentive to improve its technology and earn more than fair returns. Passive regulation provides a higher regulatory price than active regulation. It is shown that under technological progress, conditions would exist where the firm would plan lower investment than the efficient levels. Hence passive regulation results in motivating the firm to produce inefficiently.

An increase in the rate of technological progress increases the inefficiency in the firm capitalization and also increases the net present value of the firm. The regulatory price decreases with the improvement in the technology of the firm. An increase in the rate of technological progress increases the rate of decline of product prices.

An increased firm horizon provides an increased flexibility to the firm for improving the future certainty equivalent of excess returns. Therefore, the longer the firm horizon, the greater the net present value of the firm and the higher the inefficiency in the capitalization. It is shown that the above results hold for an increasing, decreasing, or constant returns to scale production function.

The simulation of the model of passive regulation confirms the following:

The decrease in the demand elasticity increases the product prices and reduces the capital investment of the firm. However, it does not change the planned undercapitalization by the firm.

Similarly the change in the output elasticities of fuel and capital do not change the undercapitalization of the firm. Decrease in systematic risk of revenue reduces the regulatory prices and improves the firm expected supply.

Increase in the systematic risk of the total fuel costs increases the regulatory prices and, therefore, reduces the firm expected supply.

The increase in the fuel rates increases the regulatory prices. Similarly, the increase in the risk free rate increases the cost of financing and, therefore, increases the regulatory prices.

Views for Further Research

1. This study has analyzed a single period model of a firm with regard to quality when it is a monopoly and an actively regulated monopoly.

The demand is considered to be a function of price and quality, and so is the cost of the product. It was shown that price regulation is not sufficient to eliminate the monopoly excess returns.

The multiperiod model of firm behavior does not determine the quality of the product. To keep the algebraic tractability the demand is considered to be affected by price only.

In an inter-temporal context, the analysis of product quality could be conducted by assuming the following forms of production and demand conditions.

$$xq = BL^{\alpha} K^{\beta} \tag{6.1}$$

$$x = p^{-n}q^{s} \tag{6.2}$$

(6.1) gives an homogeneous production function. x and q are product output and quality levels respectively. Quantity and quality are considered to be perfect substitutes in production and are joint products. (6.2) is a demand function. Quantity demanded is affected by the product price and quality. n/s represents the price elasticity of quality demand. An increased quality would be valued more by the consumers. For $s < n$, the consumer's valuation of marginal quality will reduce.

Under the above conditions an inter-temporal model of a firm can be formulated and the following can be analyzed and compared:

(1) price controls only,

(2) quality controls only, and

(3) both price and quality controls.

The above can be compared for

(1) regulatory lag and

(2) no regulatory lag.

2. The inter-temporal analysis of firm behavior assumes a disembodied technical change. The same assets when rearranged according to a new technology would provide improved or increased output. The firm does not make investments for research and development. Although an exogenous source of technical innovations may be true for some industries (such as electrical utility industry and air transportation industry), it is not representative of all the industries (e.g.

telephone and telecommunication industry). Therefore, the model could be made more general by treating the technological change endogenously.

The cost of the technological change must be an increasing function of technological progress. Hicks-Neutral Technological progress implies increase in the technological coefficient B_t.

The total cost of output =

Cost of labor + cost of financing + cost of research and development.

$$= B_t^{-1/\alpha} W g L_2 K_t^{-\beta/\alpha} P_t^{-n/\alpha} + i K_t + D(B_{t+1} - B_t)^m \qquad (6.3)$$

where m $\geqslant$ 1 and D is the cost coefficient.

Under the above formulation the regulators determine the regulatory price and consider the cost of research and development in determining the fair price for the product. On the other hand, the firm would determine the capital investment levels and the level of the production technology. Under the above formulation the following can be determined and compared:

(1) The effect of regulatory lag on the technological innovations in the industry.

(2) The rate of technological innovations for a monopoly, actively regulated monopoly, and a passively regulated monopoly.

3. The multiperiod analysis of firm behavior assumes

perfection in the secondary real asset markets. At the end of each period, the firm maintains the optimal level of investment for the next period by buying or selling the assets. In real world, the firms have greater flexibility in adding to the assets, while they may not be able to sell the existing assets at the book value. To reflect the real world conditions the following constraint may be added to the problem of the firm:

$$k_t \geqslant (1 - \gamma)\, k_{t-1}$$

where γ is the rate of depreciation.

The problem of the firm in period t can be represented as:

$$\text{Maximize} \quad \left[\phi_{t+1}(P_t, k_t) + V_{t+1}(P_t, k_t)\right] \qquad (6.4)$$

$$\text{Such that} \quad \phi(P_t, K_{t-1}, A_{t-1}) = 0 \qquad (6.5)$$

$$K_t - (1-\gamma) K_{t-1} \geqslant 0 \qquad (6.6)$$

(6.4) is the net present value of the firm at the end of period t. (6.5) is the regulatory constraint for period t, while (6.6) represents the imperfection of the secondary real asset markets.

In this case the firm would have less flexibility in reducing the capital levels; therefore, it would be interesting to analyze whether a passively regulated firm would undercapitalize. Undercapitalization was shown to exist for a passively regulated firm when the real asset markets are perfect.

4. The present study analyzes the firm behavior when the technological progress is of Hicks-Neutral type. This implies that the marginal productivity of labor and capital improve in equal proportion. A logical extension of the above would be to analyze the factor augmenting technical change.

Harrod-Neutral technological progress is a special case of factor augmenting technological change. It is labor augmenting.

Let $x = f(ak, bL)$ be the production function.

Harrod-Neutral technological change implies that the marginal and average productivity of capital remains constant while the marginal productivity of labor improves. This means a remains constant, while b increases.

A capital augmenting technology means that the marginal productivity of labor remains constant while the marginal productivity of capital improves. In this case, b remains constant while a increases.

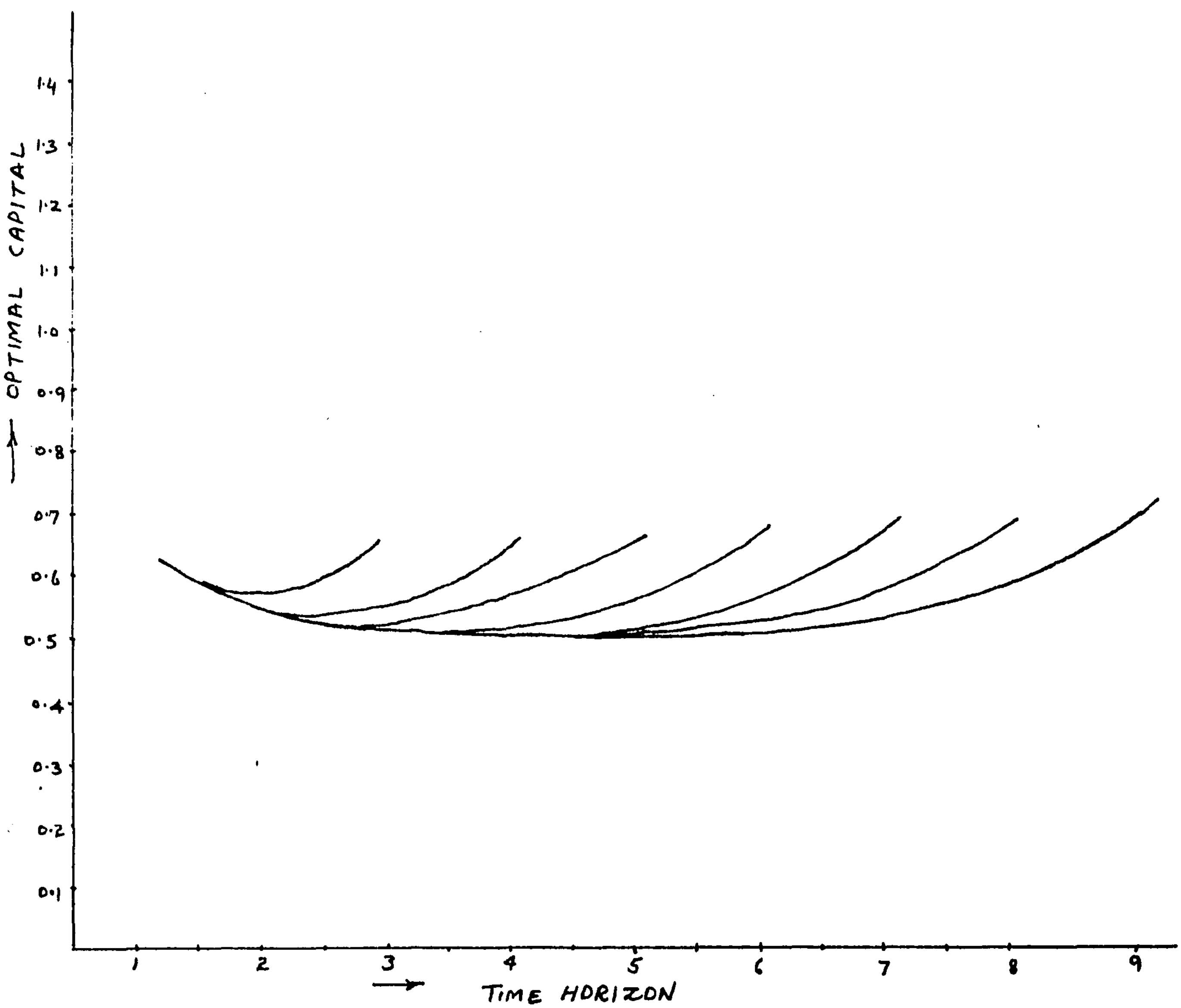
The behavior of a passively regulated firm, with regard to production efficiency under different conditions of technological progress, needs to be analyzed.

5. The present study assumes that the demand distribution is independently and identically distributed overtime, while the technology improves.

There may be situations where the technology does not improve significantly over the period, but significant shifts in the demand might take place. Growth in the population may provide slow but continuous shifts in the demand for the product. The changes in the expected demand may effect the investment planning by the firm and also the regulatory price.

When the product demand = $\tilde{\theta}_t P_t^{-\eta}$, demand growth implies that $E(\tilde{\theta}_t) < E(\tilde{\theta}_{t+1}), \ldots\ldots\ldots, < E(\tilde{\theta}_T)$.

In the above situation a model of a passively regulated firm could be developed on the same lines as done in this study.



OPTIMAL CAPITAL
1·4
1·3
1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
1
2
3
4
5
6
7
8
9
TIME HORIZON

FIGURE 5·1

EXHIBIT I

FIRM BEHAVIOR UNDER DIFFERENT CONDITIONS OF MARKET STRUCTURE

	Technology Improves at the Rate of 1.125% Every Period														
	Monopoly					Active Regulation					Passive Regulation				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
1	19.3	0.0707	0.0707	1.00	0.0521	4.41	0.6422	0.6422	1.00	0.0	4.41	0.6422	0.642	1.000	0.0179
2	19.0	0.0716	0.0716	1.00	0.0483	4.34	0.6502	0.6502	1.00	0.0	4.02	0.5250	0.653	0.804	0.0196
3	18.8	0.7250	0.7250	1.00	0.0442	4.28	0.6584	0.6584	1.00	0.0	4.27	0.5050	0.655	0.770	0.0189
4	18.6	0.0734	0.0734	1.00	0.0398	4.21	0.6664	0.6664	1.00	0.0	4.23	0.5000	0.661	0.756	0.0174
5	18.4	0.0743	0.0743	1.00	0.0350	4.15	0.6749	0.6749	1.00	0.0	4.17	0.5050	0.668	0.755	0.0154
6	18.1	0.0752	0.0752	1.00	0.0282	4.09	0.6834	0.6834	1.00	0.0	4.11	0.5150	0.676	0.761	0.0131
7	17.9	0.0761	0.0761	1.00	0.0217	4.03	0.6919	0.6919	1.00	0.0	4.05	0.5350	0.685	0.781	0.0105
8	17.7	0.0771	0.0771	1.00	0.0139	3.97	0.7006	0.7006	1.00	0.0	3.98	0.5800	0.695	0.834	0.0075
9	17.5	0.0781	0.0781	1.00	0.0071	3.91	0.7093	0.7093	1.00	0.0	3.91	0.70500	0.705	1.000	0.0039

P = Price

OK = Optimal Capital Planned by the Firm

OKP = Efficient Capital at Price P

V = Value

EXHIBIT II

PASSIVE REGULATION: THE EFFECT OF HORIZON

Rate of Technical Progress = 1.25%

Horizon Length

Horizon Length	3					4				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.570	0.653	0.872	0.005	4.324	0.550	0.653	0.842	0.008
3	4.273	0.660	0.659	1.00	0.003	4.278	0.560	0.658	0.851	0.006
4						4.213	0.665	0.666	1.00	0.003
Horizon Length	5					6				
2	5.325	0.535	0.653	0.819	0.010	4.325	0.530	0.653	0.811	0.013
3	4.283	0.525	0.656	0.800	0.009	4.286	0.515	0.656	0.785	0.011
4	4.225	0.555	0.663	0.837	0.006	4.230	0.525	0.662	0.793	0.009
5	4.154	0.675	0.673	1.000	0.003	4.165	0.560	0.671	0.834	0.007
						4.093	0.68	0.681	1.00	0.003

P = Price

OK = Capital Levels Planned by the Firm

OKP = Efficient Capital at Price P

V = Value

EXHIBIT II (Continued)

Rate of Technical Progress = 1.25%

Horizon Length	7					8				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.53	0.653	0.811	0.015	4.325	0.525	0.653	0.803	0.017
3	4.285	0.51	0.656	0.777	0.014	4.286	0.505	0.656	0.770	0.016
4	4.232	0.51	0.662	0.770	0.012	4.234	0.505	0.661	0.764	0.015
5	4.171	0.525	0.669	0.784	0.010	4.174	0.510	0.669	0.762	0.012
6	4.106	0.565	0.678	0.833	0.007	4.112	0.530	0.677	0.782	0.010
7	4.033	0.69	0.690	1.00	0.003	4.045	0.570	0.687	0.829	0.007
						3.974	0.700	0.698	1.00	0.004

Horizon Length	9				
2	4.325	0.525	0.653	0.803	0.019
3	4.286	0.505	0.655	0.770	0.018
4	4.233	0.500	0.661	0.756	0.017
5	4.176	0.505	0.668	0.756	0.015
6	4.114	0.515	0.676	0.762	0.013
7	4.051	0.535	0.685	0.781	0.010
8	3.986	0.580	0.695	0.835	0.007
9	3.914	0.705	0.705	1.00	0.003

P = Price
OK = Capital Levels Planned by the Firm
OKP = Efficient Capital at Price P
V = Value

EXHIBIT III

EFFECTS OF STARTING CONDITIONS

	Starting Capital Levels Lower than Perfectly Competitive									
	Rate of Technical Progress = 1.25%					Rate of Technical Progress = 2.5%				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.359	0.490	0.646	0.758	0.0211	4.359	0.435	0.639	0.680	0.0429
3	4.301	0.490	0.652	0.751	0.0196	4.274	0.420	0.645	0.651	0.0412
4	4.241	0.495	0.659	0.751	0.0177	4.168	0.420	0.656	0.640	0.0381
5	4.178	0.505	0.667	0.757	0.0156	4.054	0.425	0.671	0.633	0.0340
6	4.114	0.515	0.676	0.762	0.0131	3.939	0.445	0.686	0.649	0.0294
7	4.051	0.535	0.685	0.781	0.0105	3.817	0.480	0.705	0.680	0.0237
8	3.986	0.580	0.695	0.835	0.0075	3.690	0.550	0.727	0.756	0.0169
9	3.914	0.705	0.707	1.000	0.0039	3.554	0.755	0.753	1.000	0.0089

Starting Capital = 0.50

Perfectly Competitive Capital = 0.67

	Starting Capital Levels Higher than Perfectly Competitive									
	Rate of Technical Progress = 1.25%					Rate of Technical Progress = 2.5%				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.334	0.515	0.651	0.791	0.020	4.334	0.455	0.645	0.705	0.0417
3	4.290	0.500	0.655	0.763	0.019	4.261	0.430	0.648	0.663	0.0406
4	4.236	0.500	0.660	0.757	0.0175	4.160	0.425	0.658	0.646	0.0377
5	4.176	0.505	0.668	0.756	0.0154	4.050	0.435	0.672	0.647	0.0338
6	4.114	0.515	0.676	0.762	0.0131	3.931	0.450	0.688	0.654	0.0290
7	4.051	0.535	0.685	0.781	0.0105	3.813	0.480	0.706	0.680	0.0235
8	3.986	0.580	0.695	0.834	0.0075	3.690	0.550	0.727	0.756	0.0169
9	3.914	0.705	0.707	1.000	0.0039	3.554	0.755	0.753	1.000	0.0089

Starting Capital = 0.75

Perfectly Competitive Capital = 0.67

EXHIBIT IV

EFFECT OF STARTING CONDITIONS

	Starting Capital = 0.37 Lower than Competitive					Starting Capital = 0.705 Higher than Competitive				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.58	0.375	0.514	0.729	0.0179	4.58	0.380	0.515	0.737	0.0178
3	4.51	0.380	0.522	0.728	0.0164	4.51	0.385	0.523	0.736	0.0163
4	4.44	0.390	0.529	0.737	0.0148	4.44	0.390	0.530	0.735	0.0147
5	4.37	0.400	0.538	0.734	0.0129	4.37	0.400	0.538	0.734	0.0129
6	4.30	0.410	0.546	0.751	0.0109	4.30	0.410	0.546	0.751	0.0109
7	4.23	0.430	0.555	0.777	0.0088	4.23	0.430	0.555	0.777	0.0088
8	4.16	0.465	0.565	0.823	0.0062	4.16	0.465	0.565	0.823	0.0062
9	4.08	0.575	0.576	1.000	0.0033	4.08	0.575	0.576	1.000	0.0033

Demand Elasticity = -1.94

P = Price

OK = Optimal Capital

OKP = Efficient Capital

V = Value

EXHIBIT V

EFFECTS OF CHANGE IN RATE OF TECHNICAL PROGRESS

(Competitive Starting Conditions)

Horizon = 9 Periods

	Rate of Technical Progress = 1.25%					Rate of Technical Progress = 2.5%				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	4.325	0.460	0.647	0.710	0.041
3	4.286	0.505	0.655	0.770	0.0189	4.258	0.430	0.649	0.662	0.040
4	4.133	0.500	0.661	0.756	0.0174	4.160	0.425	0.658	0.645	0.037
5	4.176	0.505	0.668	0.755	0.0154	4.050	0.435	0.672	0.604	0.033
6	4.114	0.515	0.676	0.761	0.0131	3.931	0.450	0.688	0.654	0.029
7	4.051	0.535	0.685	0.781	0.0105	3.813	0.480	0.706	0.680	0.023
8	3.986	0.580	0.695	0.834	0.0075	3.690	0.550	0.727	0.756	0.016
9	3.914	0.705	0.705	1.00	0.0039	3.554	0.755	0.755	1.00	0.008

P = Price
OK = Optimal Capital
OKP = Efficient Capital
V = Value

EXHIBIT VI

THREE PERIOD HORIZON, EFFECT OF CHANGE IN RATE OF TECHNICAL PROGRESS

Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
	Rate of Technical Progress = 3.125%					Rate of Technical Progress = 7.125%				
2	4.339	0.505	0.640	0.789	0.014	4.339	0.450	0.620	0.725	0.032
3	4.199	0.655	0.655	1.000	0.008	4.051	0.650	0.649	1.000	0.019
	Rate of Technical Progress = 11.125%					Rate of Technical Progress = 15.125%				
2	4.339	0.415	0.601	0.690	0.049	4.339	0.395	0.584	0.676	0.065
3	3.912	0.645	0.644	1.000	0.029	3.778	0.640	0.640	1.000	0.039
	Rate of Technical Progress = 19.125%					Rate of Technical Progress = 23.125%				
2	4.339	0.375	0.568	0.660	0.081	4.339	0.365	0.545	0.667	
3	3.656	0.635	0.635	1.000	0.049	3.535	0.635	0.633	1.000	
	Rate of Technical Progress = 27.125%					Rate of TEchnical Progress = 31.125%				
2	4.339	0.355	0.538	0.660	0.111	4.339	0.350	0.524	0.668	0.126
3	3.423	0.630	0.630	1.000	0.069	3.31	0.630	0.628	1.000	0.078
	Rate of Technical Progress = 35.125%					Rate of Technical Progress = 39.125%				
2	4.339	0.345	0.511	0.675	0.140	4.339	0.345	0.499	0.691	0.154
3	3.212	0.625	0.627	1.000	0.088	3.112	0.625	0.626	1.000	0.097

Starting Capital = 0.795
Demand Elasticity = -1.82
P = Price
OK = Optimal Capital
OKP = Efficient Capital
V = Value

EXHIBIT VII

PASSIVE REGULATION

EFFECT OF CHANGE IN OUTPUT ELASTICITY OF CAPITAL

	β = 0.1674					β = 0.1506				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	4.290	0.415	0.593	0.699	0.042
3	4.286	0.505	0.655	0.770	0.0189	4.219	0.390	0.596	0.654	0.040
4	4.233	0.500	0.661	0.756	0.0174	4.120	0.385	0.606	0.635	0.038
5	4.176	0.505	0.668	0.755	0.0154	4.012	0.390	0.618	0.631	0.034
6	4.114	0.515	0.676	0.761	0.0131	3.899	0.405	0.632	0.640	0.029
7	4.051	0.535	0.685	0.781	0.0105	3.783	0.435	0.648	0.671	0.023
8	3,986	0.580	0.695	0.834	0.0075	3.661	0.500	0.668	0.748	0.017
9	3.914	0.705	0.705	1.000	0.0039	3.531	0.690	0.691	1.000	0.008

Starting Capital = 0.64

P = Price

OK = Optimal Capital

OKP = Efficient Capital

V = Value

β = Output Elasticity of Capital

EXHIBIT VIII

PASSIVE REGULATION

EFFECT OF CHANGE IN OUTPUT ELASTICITY OF FUEL

	α = 1.04					α = 1.00				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	3.773	0.530	0.747	0.709	0.048
3	4.286	0.505	0.655	0.770	0.0189	3.711	0.495	0.750	0.660	0.046
4	4.233	0.500	0.661	0.756	0.0174	3.630	0.490	0.760	0.644	0.043
5	4.176	0.505	0.668	0.755	0.0154	3.536	0.495	0.775	0.638	0.038
6	4.114	0.515	0.676	0.761	0.0131	3.440	0.510	0.792	0.643	0.033
7	4.051	0.535	0.685	0.781	0.0105	3.341	0.545	0.812	0.671	0.027
8	3.986	0.580	0.695	0.834	0.0075	3.237	0.615	0.835	0.736	0.019
9	3.914	0.705	0.705	1.000	0.0039	3.124	0.865	0.864	1.000	0.010

Starting Capital = 0.64

P = Price

OK = Optimal Capital

OKP = Efficient Capital

V = Value

α = Output Elasticity of Fuel

EXHIBIT IX

PASSIVE REGULATION

EFFECT OF CHANGE IN MARKET RISK OF REVENUE

			$L_1 = 0.95$					$L_1 = 0.90$		
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.019	4.69	0.405	0.572	0.708	0.037
3	4.286	0.505	0.655	0.770	0.018	4.60	0.380	0.576	0.659	0.036
4	4.133	0.500	0.661	0.756	0.017	4.50	0.375	0.584	0.642	0.033
5	4.176	0.505	0.668	0.755	0.015	4.38	0.380	0.596	0.637	0.030
6	4.114	0.515	0.676	0.761	0.013	4.25	0.395	0.610	0.647	0.026
7	4.051	0.535	0.685	0.781	0.010	4.12	0.425	0.626	0.679	0.021
8	3.986	0.580	0.695	0.834	0.007	3.99	0.490	0.645	0.759	0.015
9	3.914	0.705	0.705	1.000	0.003	3.84	0.670	0.669	1.000	0.007

Starting Period Capital = 0.64

P = Price

OK = Capital Levels Planned by the Firm

OKP = Efficient Capital at Price P

V = Value

L_1 = Certainty Equivalent of a Dollar of Expected Revenue

EXHIBIT X

CHANGE IN THE UNCERTAINTY FOR LABOR REQUIREMENT

	L_2 = 0.90					L_2 = 0.95				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	4.631	0.435	0.611	0.711	0.039
3	4.286	0.505	0.655	0.770	0.0189	4.557	0.405	0.614	0.659	0.038
4	4.133	0.500	0.661	0.756	0.0174	4.453	0.400	0.622	0.643	0.035
5	4.176	0.505	0.668	0.755	0.0154	4.335	0.405	0.635	0.637	0.032
6	4.114	0.515	0.676	0.761	0.0131	4.212	0.420	0.650	0.646	0.027
7	4.051	0.535	0.685	0.781	0.0105	4.085	0.455	0.667	0.682	0.022
8	3.986	0.580	0.695	0.834	0.0075	3.948	0.520	0.688	0.755	0.016
9	3.914	0.705	0.705	1.000	0.0039	3.804	0.715	0.713	1.000	0.008

Starting Capital = 0.64

P = Price

OK = Capital Levels Planned by the Firm

OKP = Efficient Capital at Price P

V = Value

L_2 = Certainty Equivalent of a Dollar of Fuel Costs

EXHIBIT XI

PASSIVE REGULATION

EFFECT OF CHANGE IN THE FUEL COSTS

	W = $5.5/Ton					W = $6.5/Ton				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	5.348	0.380	0.542	0.701	0.035
3	4.286	0.505	0.655	0.770	0.0189	5.256	0.360	0.545	0.660	0.034
4	4.133	0.500	0.661	0.756	0.0174	5.132	0.355	0.554	0.640	0.031
5	4.176	0.505	0.668	0.755	0.0154	4.996	0.360	0.565	0.637	0.028
6	4.114	0.515	0.676	0.761	0.0131	4.854	0.375	0.578	0.648	0.024
7	4.051	0.535	0.685	0.781	0.0105	4.705	0.405	0.594	0.681	0.019
8	3.986	0.580	0.695	0.834	0.0075	4.549	0.465	0.612	0.759	0.014
9	3.914	0.705	0.705	1.000	0.0039	4.381	0.635	0.635	1.000	0.007

Starting Capital = 0.64

P = Price

OK = Optimal Capital

OKP = Efficient Capital

V = Value

EXHIBIT XII

EFFECT OF CHANGE IN THE INTEREST RATES

	Interest Rate = 6%					Interest Rate = 5%				
Period	P	OK	OKP	OK/OKP	V	P	OK	OKP	OK/OKP	V
2	4.325	0.525	0.653	0.804	0.0196	4.194	0.530	0.793	0.668	0.045
3	4.286	0.505	0.655	0.770	0.0189	4.125	0.500	0.796	0.628	0.044
4	4.133	0.500	0.661	0.756	0.0174	4.030	0.495	0.808	0.612	0.040
5	4.176	0.505	0.668	0.755	0.0154	3.923	0.500	o.825	0.608	0.036
6	4.114	0.515	0.676	0.761	0.0131	3.813	0.520	0.843	0.616	0.031
7	4.051	0.535	0.685	0.781	0.0105	3.696	0.555	0.866	0.640	0.025
8	3.986	0.580	0.695	0.834	0.0075	3.576	0.625	0.892	0.700	0.018
9	3.914	0.705	0.705	1.000	0.0039	3.446	0.924	0.924	1.000	0.009

P = Price

OK = Optimal Capital Planned by the Firm

OKP = Efficient Capital at Price P

V = Value

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