Optimal Short Run Electricity Supply in India : Rationing and Pricing Options

UMA VISHVANATHAN

Thesis submitted to the Indian Statistical Institute in partial fulfillment of the requirements for the award of PhD

April 1992

Planning Unit
Indian Statistical Institute
New Delhi-110016

Optimal Short Run Electricity Supply in India : Rationing and Pricing Options

UMA VISHVANATHAN

Thesis submitted to the Indian Statistical Institute in partial fulfillment of the requirements for the award of PhD

April 1992

Planning Unit
Indian Statistical Institute
New Delhi-110016

Acknowledgement

During the course of the years it took to shaping this thesis to its present form, there have been several people who have proviided guidance, encouragement and support along the way. I must express my heartfelt gratitude to all of them.

Among my teachers, foremost, I owe a great deal to my thesis supervisor Prof. Atul Sarma, who introduced me to this area and always provided me with valuable help and guidance. To him goes the credit of seeing this thesis to its completion. Secondly, I am immensely indebted to Prof Amal Sanyal (formerly of JNU), who not only provided me with the problems taken up in Chapter 3 and Chapter 5, especially Chapter 5, but also allowed me the benefit of several hours of fruitful discussions. Prof. Dilip Mukherjee provided me with the theoretical base of the models of Chapter 5, advised me on the approach to the study and was kind enough to go through the preliminary draft of Chapter 5. For all this I am extremely grateful to him. Prof. G. Kadekodi of the Institute of Economic Growth took the trouble of going through the draft of the first four chapters and his observations and comments have helped in polishing the initial version of the thesis. Dr. Ranjan Ray of the Delhi School of Economics was kind enough to go through a part of the empirical model of Chapter 3. I acknowledge my gratitude to both of them.

Among my colleagues and friends, I must firstly thank Prabal Ray Choudhury with whom I have worked on a portion of the thesis. Chapter 5 is a revised version of our joint work. I thank Prabal for his patience in familiarising me with the theoretical basis of the existing literature and for often sorting out confused ideas. Working with him has been both fun and learning. I also wish to thank Saikat Datta who was always there to pull me up when things were going wrong, and without whose encouragement and support this work may have had difficulty in going to print. Thanks are also due to R.Sridhar who helped me in writing some of the programmes for the computation of the models of Chapter 3 and 4. I am also indebted to Hiranya Mukhopadhyay for his advice and help on matters ranging from empirical estimation to arranging appointments with well known specialists in the field. He has remained a constant support and I thank him for this.

There have been many more people who have helped me in getting access to government data and published reports, of which I can mention only a few. Roopa Joshi of BICP, Dr. Prabhat Mohan and Mrs. Vasa Suparna of NREB, Dr. V.N. Mishra and Mr. Vidhya Dhar of the Ministry of Agriculture, the officials of the Regional Power Survey Centre, the Central Electricity Authority Library, the Central Statistical Organization Library, and the Directorate of Economics and Statistics Library. Computer help from Mr. Naik, Mr. Ganesan, and Mr. Juyal is gratefully acknowledged.

Finally, I would like to thank my family and all my friends for all the encouragement and good cheer they have always kept me in.

Uma Vishvanathan

Planning Unit
Indian Statistical Institute
Delhi Centre.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

The supply of electricity to consumers in India is governed by the Electricity Supply Act (1948). Under the Act, electricity can be supplied from two sources:

(i) 'licensees' – that is, a person or body licensed under the Indian Electricity Act 1910 to supply energy, or a person who has obtained sanction under Section 28 of that Act to engage in the business of supplying energy.
(ii) The State Electricity Boards constituted under various State Governments and charged with the general duty of promoting the coordinated development of the generation, supply and distribution of electricity within the State in the most efficient and economical manner with particular reference to such development in areas not for the time being adequately served by any licensee.

In common parlance, 'licensees' supplying electricity constitute the private sector. The State Electricity Boards (SEBs) are in the public sector, but under the control of the respective state governments. Besides the above two suppliers, there are several large public sector electricity generating units which are directly under the control of the Central government. These Central units, as they are called, comprise mainly the National Thermal Power Corporation (NTPC), National Hydel Power Corporation (NHPC), Damodar Valley Corporation (DVC) and some others. They have been set up as generating units with the main purpose of supplying electricity to the SEBs (which are usually in short supply in relation to the demand they face), in turn for distribution to the final consumers of the respective states.

It is estimated that by the end of the Seventh Plan (1985 - 1990), the share of the State Electricity Boards, the Centre and the private sector may be 45662 MW (70%) , 16488 MW (25%) and 2673 MW (5%), repectively, in a total installed capacity of about 64823 MW[1]. It is clear that the SEBs along with the Central units take the responsibility of supplying power in the country, and it is the functioning of the two that is important in ensuring the efficient, economical and reliable generation and supply of electricity.

But ensuring efficient generation and supply is not without its problems. Since the generation of electricity has to depend on natural resources like coal, oil, gas, and to a lesser extent on enriched uranium, which once depleted are non-renewable, there is a problem of conserving these resources. Generation also takes place from different technologies – which implies that, given the cost of alternative technologies and the issue of conserving these fuels, determining the appropriate technology mix is an important area of research. Then again, huge capital investments for plants have to be made based on ex-ante projections of demand. Since capital is indivisible and generally has a low elasticity of substitution, there is also the question of determining long-term as well as least-cost investment. India is a capital-scarce developing country and the available resources are inadequate to meet the growing demand for electricity.

The demand for electricity itself has features that make every issue of generation and supply important. Considered a public utility along with gas, water, telephone etc., electricity has certain characteristics that are unlike the other services. Electricity is used both, for direct consumption as in heating and lighting, and indirectly as a drive force in the production of commodities. Like the demand for telephone services, the demand for electricity too varies throughout the day, with identifiable peaks when consumption is the highest. A distinguishing feature of electricity is that it is a non-storable good and can

[1] Report of the Sub-Group on Energy Pricing, SEB Finances and Related Issues [1989].

be produced only on demand. Neither is transfer or resale possible among the users. These two factors would mean that at any point of time there has to be enough supply generated ***at that point of time*** to meet the demand. If demand has to be met at all times, then the capacity of electric power plants is to be decided on a certain projection of the maximum demand occuring at any point of the day. As demand varies throughout the day this means that at all points below the maximum on the load curve (where demand or load is plotted against time measured in hours of the day), there will exist some idle capacity. On the other hand, if the capacity is built to meet the base load demand, as is sometimes the case, then during periods when the actual demand exceeds the capacity built to meet it, there would be a situation of too little demand at certain points of the curve and too much at all other points.

The solution advocated to this kind of strain on capacity is an appropriate price strategy which consists of devising a vector of differential prices. Put simply, it means charging a very low off-peak price in order to induce more consumption in that period, and charging a very high price (above marginal cost) in the peak period not only to lower consumption in that period, but also induce consumption to shift to the off-peak periods. This would not only eliminate the excess demand problem in the peak hours, but also improve the overall utilisation of capacity. If a suitable demand or load-management scheme coupled with an efficient supply is followed, then the problem of excess demand can be minimised to a large extent.

However, in India most of the SEBs which are the main distributors of electricity do not actually follow any efficient demand or supply management scheme. Effective demand management will mean charging appropriate prices in order to smoothen or flatten the load curve. An efficient supply means the generation of electricity at minimum cost and ensuring the supply over distances with the minimum distribution and transmission losses. But since the SEBs are under the control of the State governments the devising of an appropriate pricing strategy is denied to them for political and social reasons. Prices are fixed on an ad-hoc basis, often below the marginal cost of supply. As a result, misleading signals about the availability of electricity are transmitted to the consumers and demand swells beyond the supplying limit of the SEBs. Since prices fail to reflect the scarcity of the good, the next best option is to augment supply to meet the demand. This can, among other options, be done by (i) managing the plant mix or the technology mix of each SEB more efficiently, (ii) by purchasing from the Central units when there is a power shortage, (iii) by cutting down the line losses which are the result of poor-quality transmitting lines. This is again not achieved due to a lax administration which manages the supply, and the points of conflict between the SEBs and other Central generating units over the price of purchase of electricity. The result is :

(i) A poor plant availability which is due to the long delays in getting maintenance repairs done and the poor working condition of the plants.

(ii) A poor plant load factor i.e., capacity utilisation of the SEBs and the Central units.

(iii) A persistent situation of excess demand.

The purpose of this study is to examine some of the problems that beset efficient electricity supply in India. Certain key issues, highlighted below, regarding demand and output, are taken up and an attempt is made to suggest optimal responses or actions for the SEBs in situations of excess demand, high cost of production and high cost of purchase. The emphasis of this work will be on optimal electricity supply, and on load management schemes. Two issues are considered :

(1) A purely short term strategy of allocating supply in a situation of excess demand, fixed capacity and rigid prices, The first issue consists of determining optimal supply to various consumers through the derivation of an appropriate rationing scheme when available supply is short in relation to the demand.

(2) A short term solution where the objective is to augment supply through purchases from outside at minimum cost. We consider the following cases :

(a) We initially relax the assumption of fixed supply, so that the objective is to meet the whole demand through an optimal mix of own output and outside purchase ; and determine the purchase price for augmenting the firm's own production with purchases from an outside firm where the costs of the two firms are asymmetric.

(b) We then relax the assumption of fixed supply and the assumption of fixed prices, where the objective is now to determine the output mix, the purchase price that induces the choice of the optimal output mix, as well as the price that the consumers pay.

The plan of the thesis is as follows :

Chapter 2 presents a survey of the literature covering both rationing of a single good in a partial equilibrium analysis, and public utility pricing in a second best situation. Chapter 3 deals with the question of optimal supply and consists of (a) the theoretical formulation of the derivation of the optimal rationing scheme when supply and prices are fixed and there exists an excess demand situation ; (b) the first part of the empirical excercise for the rationing scheme, which comprises determining the agents behavior in a no-rationing situation. Chapter 4 is concerned with the working of the main rationing model with the submodels derived from appropriate restrictions. Chapter 5 deals with the relaxation of the supply constraint, and considers the optimal prices under which supply to consumers from the SEB can be increased by purchases from other generation units which have different marginal costs of supply. Chapter 6 discusses the current scenario in the country with some policy implications, and presents the conclusions of the work.

Chapter 2

Theoretical Review

This chapter presents the theoretical background to the issues that have been taken up for this thesis. It focuses on two issues relating to the field of public enterprise:

(a) The quantity rationing of limited supply of the good as an immediate allocative measure when an excess demand exists and prices are fixed.

(b) The pricing policy that would need to be in force in order to ensure an efficient and continuous supply that meets demand at all times.

A survey of the literature will be the thrust of this chapter and will focus on both rationing as well as pricing; both of these issues will be dealt with in this thesis. The survey on rationing will first briefly focus on macroeconomic disequilibrium and later on the analysis of disequilibrium in a partial equilibrium framework. The review of the literature on pricing deals with the question of pricing of public utilities, with specific reference to pricing in electric utilities.

2.1 Disequlibrium markets and quantity rationing : An overview

Central to the theory of neoclassical markets is the Walrasian paradigm of prices adjusting instantaneously to bring about an equilibrium between supply and demand. The Walrasian auctioneer starts the trading process by announcing an arbitrary price vector, which includes all prices. Agents then indicate how much they are willing to buy and sell at the announced prices. If the buying and selling decisions are inconsistent the auctioneer adjusts the price vector according to the rule that prices will be raised in the case of an excess demand and lowered in the face of an excess supply. The agents then renew their bidding and the process continues until the simultaneous consistency of the buying and selling decisions in all markets is acheived. It is after this that actual trading takes place.

In this world, any situation of excess is considered temporary, and prices move rapidly to clear the excess. This is of course not true of many markets like the primary goods sector or the labour market, where instantaneous price adjustment does not take place at all or where prices are slow to react. Goods are traded of course, but at levels other than Walrasian equilibrium levels. The presence of price and wage rigidities, leading to the Keynesian concept of unemployment, or underemployment of factors necessitated the analysis in a disequilibrium framework.

In his work on the microfoundations of Keynesian theory, Robert Clower [1965] assumed that households under non-market clearing prices would recognize that there are restrictions on their trading possibilities and explicitly take this into account in their utility maximizing process. To explain his analysis, we consider a twice continuously differentiable and strictly quasi-concave utility function :

$$U = U(D_i, l_i^s, M_i/p + m_i^d)$$

where D_i = demand for goods by household i.
L_i^s = supply of labour by household i
M_i/p = household i's initial holdings of real balances
$m_i^d = M^d/p - M_i/p$ = household i's flow demand for real balances.
Under the assumptions of neoclassical theory this utility function is maximized (with respect to D_i, L_i^s, and m_i^d) subject to the budget constraint :

$$pD_i + pm_i^d = wL_i^s + \pi_i$$

(where π is nominal profit income in the current period), leading to the household's demand for goods function, the labour supply function and the saving function:

$$D_i = D_i(p, w, \pi_i, M_i/p)$$
$$L_i^s = L_i^s(p, w, \pi_i, M_i/p)$$
$$m_i^d = m_i^d(p, w, \pi_i, M_i/p)$$

The level of transactions implied by the above functions can be carried out provided that aggregate demand does not exceed aggregate supply and that aggregate labour supply does not exceed labour demand i.e., $\sum D_i \leq Y$ and $\sum L_i^s \leq L$. Clower calls demand functions derived from the maximization of utility subject to only a budget constraint as 'notional demand functions'.

Suppose that there is an excess supply in the labour market and that, households, being on the long side of the market expect to face quantity constraints on their labor supply. Clower then argues that the household would take account the perceived restrictions in the labour market when it expresses its demand in the market for goods. Such a demand, known as the effective demand would be found by maximizing

$$U = U(D_i, L_i^s, M_i/p + m_i^d)$$

subject to the budget constraint

$$pD_i + pm_i^d = wL_i^s + \pi_i$$

as well as the perceived restrictions in the labour market:

$$L_i^s \leq \bar{L}_i$$

The effective demand functions then are :

$$\hat{D}_i = \hat{D}_i(w/p, \pi_i/p, M_i/p, \bar{L}_i)$$
$$\hat{m}_i^d = \hat{m}_i^d(p, w, \pi_i, M_i/p)$$

Thus effective demands depend on both prices and quantities. But Clower was not very clear on the issue of how trade takes place outside the Walrasian equilibrium. This was to some extent explained by Axel Leijonhufvud [1968].

Leijonhufvud's contention is that quantity adjustments take place faster than price adjustments. In his version of the tatonnement process, the auctioneer starts by announcing an arbitrary price vector which is fixed in the short run. When the firms announce their notional supply and demand, the auctioneer in the second stage now informs the agents of the *quantities* willing to be traded as against prices in the Walrasian market. The resulting quantity constraints along with the first round of prices are then used to generate effective demands for goods and labour and the corresponding perceived transactions. In the next round of recontracting, the household and the firm are informed about the new restrictions. This process continues(no trade takes place until the process is complete) until the perceived transactions of labour and goods converge toward the effective demands generated when perceived constraints are used together with the fixed prices as restrictions on the decision problems of the household and the firm. This point of convergence is the fixed point of the tatonnement process which maps effective demands into effective demands.

Barro and Grossman [1971] set up the general equilibrium version of the model, where consistent trading can take place at fixed, non-market clearing prices. A simple three market, one household, one firm economy is considered and two disequilibrium situations are analysed. One, an excess demand in both labour and goods market and two, an excess supply in both markets. The fix-price equilibrium (i.e., the point where the actual trading occurs) is then analysed for both of the above situations.

Of interest especially, is Jean.P.Benassy's [1982] contribution where he generalised the Barro-Grossman model and presented conditions under which a fix-price equlibrium exists. Benassy showed that, given certain rationing rules, the effective demands would be translated into perceived restrictions on trade, which would, in turn, determine the transactions taking place. Then a fix-price equlibrium is defined as the effective demands, perceived constraints, and optimal transactions fulfilling the following conditions.

(i) $\bar{\bar{x}}_{hn} = f(\tilde{x}_{1n} \cdots \tilde{x}_{H+Fn})$

i.e., the perceived constraints on trade are continuous functions of the effective demands, for H households and F firms.

(ii) $\tilde{x}_{hn}$ is the h^{th} agent's effective demand when his choice set is constrained by his initial endowments, the fixed prices and the perceived constraints.

(iii) $\bar{x}_{hn} = F(\tilde{x}_{1n} \cdots \tilde{x}_{H+Fn})$

i.e., actual transactions coincide with the net effective demands obtained from maximization subject to the perceived constraints.

Conditions (i) and (ii) take care of the fixed point property of the above equilibrium. The purpose of (iii) is to generate the actual transactions. Rationing functions (F) and the functions expressing the perceived restrictions on trades (f) in combination with the optimization by individual agents (which generate the effective net demand vectors $\tilde{x}$) map effective demand vectors into effective net demand vectors. The fix price equilibrium is the fixed point of this scheme. Under suitable concavity assumptions on the maximization problems and assuming the functions F and f are continuous, Benassy showed that a fix-price equilibrium exists. It was also shown that a fix-price equilibrium maximizes the utility of every agent given all the restrictions he perceives. In other words, the fix-price equilibrium is the best possible one for the agent under the circumstances of completely inflexible prices.

The definition of equilibrium emphasizes one important point: the vector of excess demands and equilibrium trades depends on the particular rationing scheme that is assumed to prevail in the economy. Changing the rule will alter the resource allocation and the ultimate consumption vectors in the fix-price equilibrium.

In Benassy's analysis therefore, the rationing rules act the part of the Walrasian auctioneer. The presence of the rules is to inform the agents during the tatonnement process of their actual trading possibilities. The rationing functions are usually assumed to have the following properties:

$$\bar{x}_{hn} \leq \tilde{x}_{hn} \text{ and } \bar{x}_{hn}\tilde{x}_{hn} \geq 0 \text{ for all } h \text{ and } n$$

$$\tilde{x}\tilde{x}_{hn} \leq 0 \Longrightarrow \bar{x}_{hn} = \tilde{x}_{hn} \text{ for all } h \text{ and } n$$

. The first means that no agent can be forced by the rationing function to trade more than his demand(supply). The second means that the short side of the market can always realize its effective demand.

It is clear that the equilibrium levels will depend a good deal on the rationing rule in practice. An inefficient rationing scheme will mean a distortion in the allocation of resources, and will consequently send wrong signals to the consuming agents about the quantities actually tradeable. In the absence of market-clearing prices, it is the quantity constraints that shape the choice set.

2.2 A survey of the theory of rationing

Long before general equilibrium and macroeconomic models were used to model quantity constraints, rationing of quantities was studied following the institution of rationing in Great Britain immediately after World War Two. The motive was to incorporate rationing into the the general theory of consumer choice [Tobin 1952] and examine the consequences of imposing further multiple constraints in addition to the budget constraint on the maximization of utility by an individual consumer.

Rationing is viewed, not strictly as a quantity constraint, but in the form of a ration currency, as different from money. There are thus ration incomes when labour supply is on the long side of the market, and ration expenditures when consumption of goods is restricted. The general approach to consumer behavior under rationing, worked out by Samuelson and Graaf, conceives of the consumer as maximizing a utility function, $u(x_1 \cdots x_n)$ subject to the multiple constraints $\sum p_j x_j = R_j (j = 0, 1, ..m)(m + 1 < n)$ where x_i is the amount consumed of the i^{th} good; p_{ji} its price in the j^{th} currency ($j = 0, 1..m$), and in particular, p_{0i} its price in money; R_j the consumer's income in the j^{th} currency, and R_0 his income in money. The conditions for a maximum are the budget constraint and the following equations.

$$u_i - \sum_j \lambda_j p_{ji} = 0, \ i = 1, 2..m$$

where u_i is the marginal utility of good i and λ_j the marginal utility of the j^{th} type of income. The system of $n + m + 1$ equations got from above gives rise to nx_i's and $m + 1$ λ's being functions of each of the p_{ji} and R_j. The results are analogous to the case when the consumer faces a single currency and a single budget constraint.

The above results have generally, in the theory of rationing, been applied to two kinds of problems: (i) the slopes of the demand functions under the rationing regime (ii) the slopes of the demand functions under the rationing regime compared to those in a free market non-rationing regime. Aggregation over all consumers with differing ration levels has also been studied. Malmquist, in his study of the demand for liquor in Sweden, derived expressions for collective income, price and ration elasticities of demand for the good rationed. These relationships depend on certain assumptions regarding the distribution of individuals by income and by a random variable representing 'tastes'.

Regarding the allocation of a scarce factor of production under rationing, Tobin argues that there are two dimensions to the problem : (i) to achieve equality among consumers in their indirect use of the scarce factor, through the consumption of consumer goods. (ii) to allocate the factor among the various uses in production to suit consumer's preferences. But this would mean that, the relative price ratio of the rationed goods will differ among producers and consumers for the same goods. A rationing scheme or mechanism will have to be devised, which brings about a more 'desirable' allocation of quantities - desirable, not only from the consumer's side, but also from the producer's point of view.

When demand exceeds capacity, supply interruptions become necessary. Brown and Johnson [1969] studied this problem for a welfare maximizing monopolist facing a stochastic demand. They assumed that when excess demand occured then the available supply would be costlessly rationed to those consumers who value supply the most. Subsequently, (Turvey [1970]; Visscher [1973]; Meyer [1975]; Crew & Kleindorfer [1976], [1978]) have modified and extended the Brown and Johnson results with regard to pricing and rationing practices. Tshirhart and Jen [1979] introduce interruptible service pricing as a formal rationing procedure. When an excess demand occurs, service to consumers is interrupted in a predetermined order and consumers are charged differential prices depending on their position in the priority ordering. Since consumers confront different reliabilities of supply, the influence of these reliabilities on demand is taken into account. The supplier will then choose the prices, the reliabilities and the capacity that maximizes his expected utility.

In a similar line of argument, Wilson [1989] discusses priority service rationing as one that will induce efficiency in allocation. Given a menu of service options of supply along with the associated prices, the consumers will select according to their valuation of the service. Compared to random rationing of scarce supplies, priority service provides efficiency gains by serving customers in the order that conforms to the costs that they incur from interruption.

The theory of quantity rationing and its implications on the demand behavior of households has been studied using the concept of 'virtual prices'– first defined by Rothbarth [1940-41] as those prices that would induce a household to demand through its maximizing behavior, exactly the amount rationed, while remaining at the same utility level. In a classic paper Neary and Roberts [1980] have demonstrated how it is possible to relate the unrationed expenditures to the rationed expenditures by the use of 'virtual prices'. This relation can also be used to measure the welfare effects of a good under rationing. For a section of our rationing model we shall use the concept of virtual prices in order to estimate the effect of electricity rationing on households.

The above then represents a brief survey of the general as well as partial equilibrium approaches to rationing. We shall now present a survey of the research literature in public utility pricing.

2.3 Pricing in Public Utilities

The working and decision-making of public enterprises and utilities has been a major part of the theory of welfare economics. Due to economies of scale, which results in utilities being formed as natural monopolies, government policy decrees that these be nationalised or atleast regulated in order that monopoly excesses are curtailed. Policy tools include not only pricing, but also using these prices for taxation or promoting income distribution.

2.3.1 Ideal Pricing

Interest in the regulation of public utilities can be traced back to Jules Dupuit's pioneering work in 1847 [reprinted in 1969] where he worked out the tolls to be paid for the use of public works such as roads and bridges. Nearly a hundred years later came Harold Hotelling's [1938] pathsetting article on the charges that were to be levied for the use of railways. Since public utilities are natural monopolies that are assumed to operate under increasing returns to scale, a pricing policy has to be devised that will best meet the conditions of Pareto-optimality. The principle of price equal to marginal cost will prove inapplicable in such a case. Hotelling argued that the price be set equal to marginal cost and the resulting deficit be met by taxation, and went on to prove that a direct income-tax would have less distortionary effect on welfare than a tax on commodities. Several writers who followed up provided variations of the same idea.

But Hotelling left certain questions unanswered. For, a tax on income would destroy the balance between income and leisure which would mean that the price of labour is torn away from the marginal cost of labour. So any kind of tax (where ever imposed), would in effect, produce some kind of distortion to bring an imbalance between price and marginal cost.

2.3.2 Second-best Pricing

Faced with the problem of non-fulfillment of first-order conditions of basic maximisation principles, this brings one to the realms of the second best where now maximisation has to be done in the presence of an added constraint. Second best theory basically owes its origin to the deviant of price from marginal cost. The main proposition of second best states that,"if there is introduced into a general equilibrium system a constraint which prevents the attainment of one of the Paretian conditions, the other Paretian conditions, though still attainable, are, in general no longer desirable. In other words, given that one of the Pareto optimum conditions cannot be fulfilled, then an optimum situation can be achieved only by departing from all other Paretian conditions".(Lipsey-Lancanster) The Lipsey-Lancaster [1956-57] theory in brief can be stated as: Suppose there exists a real-valued differentiable function,

$F(x_1 \cdots x_n)$

of n variables to be maximised subject to a constraint of the form ,

$G(x_1 \cdots x_n) = 0$

which is also real-valued and differentiable.

Then the usual Pareto conditions are,

$$\frac{\partial F/\partial x_i}{\partial F/\partial x_n} = \frac{\partial G/\partial x_i}{\partial G/\partial x_n}$$

Lipsey - Lancaster construct a second best problem by introducing the following constraint

$$\frac{\partial F/\partial x_1}{\partial F/\partial x_n} = K\frac{\partial G/\partial x_1}{\partial G/\partial x_n}; \qquad K > 1$$

as a constraint which represents a violation of the Paretian conditions. Now if the objective function is maximised subject to both constraints, then conditions for a maximum show that $\hat{x}_m$ (maximum attained) is a lower value than that attained in the unconstrained case. This can only be remedied if there is a constraint for each of the x, a condition that means that everywhere in the economy there should be a departure from the Paretian conditions.

First best theory assumes that there is perfect substitution between all factors which implies the equality between the ratio of marginal productivities and the ratio of prices. But in large monopolies this cannot be so – there is heavy capital investment where substitution is not possible. Besides, public enterprises or utilities also act as instruments to achieve national goals such as growth or income distribution. To achieve these an appropriate tax or subsidy scheme will have to be undertaken. In all these cases, second best theory comes into force. Second best theory is thus oriented towards problems of policy. One position holds that second best problems are caused by restrictions on policy and that problems are incomplete unless restrictions are specified, with the implication that policy must be made in context of a general equilibrium model. But views on this point differ. The fact that a general equilibrium analysis requires more information like exact knowledge of individual utility functions and firm productions makes it difficult to work with. So a piecemeal approach is needed.

Perhaps the best approach to second best theory is given by Marcel Boiteux in his 1956 article [also 1971] where he introduced a budget constraint into the maximisation problem. He studied an economy consisting of two sectors: a competetive sector where marginal cost is set equal to the market price; and a public sector where marginal cost is equal to a shadow price that need not correspond to the market price, but must satisfy the budget constraint of the firm. Boiteux studied the first order conditions of constrained Pareto optimality for such an economy. More importantly, he studied the rules of operation of the second sector when profits are fixed. Determining optimal behavior of public sector firms is equivalent to determining vectors of fictitious prices on the basis of which each firm in the public sector ought to maximise profits. Boiteux's results are as follows:

(a) If there is a single overall budgetary constraint to be satisfied for the whole sector, with no constraint on each other's profits, then the set of fictitious prices should be the same for every firm.

(b) On the other hand, if there is a separate budget constraint for each firm, then a set of fictitious prices is associated with each firm. These set of prices are inter related by the condition that the differences between the real and fictitious prices for the same two goods must have the same ratio for all firms in the sector.

A major departure of Boiteux's paper from earlier solutions lies in the use of shadow prices for inputs as well as outputs. Since his firms adopt a profit maximising criteria, his analysis is different from the original consumer surplus approach and is independant of any interpersonal comparison.

Baumol and Bradford [1970] have discussed the problem of departures from marginal cost pricing, where in the presence of a profit constraint and a production constraint, a proportional deviation from marginal cost is necessary for Pareto optimality. Prices are set such that the deviation from marginal cost is inversely proportional to the good's elasticity of demand. Social welfare will be served more effectively by causing unequal deviations in such a way that the more elastic commodity is priced closer to marginal cost and goods with inelastic demands have prices that diverge from their marginal costs by relatively wider margins. Baumol and Bradford call such a solution quasi-optimal because it is a second best solution forced upon the planner due to the added constraint.

Most work on the pricing of public utilities assumes that deficits can be financed by taxation or transfers without any deadweight loss, and that the distributional effects of such taxation are irrelevant. The first of these problems has been dealt with by assuming a constraint on the deficit or surplus of a public enterprise. Feldstein [1972] tackles the second of these problems, namely that of distributional considerations, in an argument that tries to integrate equity and efficiency in prices.

Feldstein considers a good that is not only sold to consumers as final output, but also as an intermediate good. He defined a 'distributional characteristic'- i.e., a weighted average of the marginal utilities (welfare being defined as the sum of individual utilities), each marginal utility weighted by the consumption of the particular good. Optimal pricing in the case of public goods for both firms as well as households requires that price be inversely proportional to the derived input elasticity of demand and the distributional characteristic. Optimal pricing therefore means price discrimination between households and firms.

A major work in the field of efficient public utility pricing in a second-best situation is that of Frank Ramsey [1927]. Efficient public utility pricing is defined as the following: Given a regulated firm that must break even and which serves M markets, the efficient set of prices $P_1, P_2, \cdots P_m$ is that set which maximizes total surplus subject to the constraint that the firm earns zero profit.

The most efficient uniform second-best prices are those which

$$\text{Max}_{p_1..p_m}[CS + PS] \ \text{ s.t } \ PS = F$$

where CS and PS are consumers surplus and producers surplus respectively, and where F represents the fixed cost of the firm. The Ramsey pricing rule or the Inverse Elasticity Rule(IER) derived from the above is

$$[\frac{p_i - c_i}{p_i}]\epsilon_i \ = \ [\frac{p_j - c_j}{p_j}]\epsilon_j \ = \ \lambda$$

In other words, for any pair of markets served by a regulated firm, the percentage deviations from marginal cost, weighted by the price elasticities of demand, should be equal for both markets to the markup λ.

The analysis is broadened to include those price structures where prices can not only vary across markets but also between consumers in the same market. This is done by means of a non-linear price schedule. The simplest type of a non-uniform price schedule is the two-part tariff. Under a two-part tariff, the consumer must pay an entry fee E in order to buy any positive amount at an usage charge p which does not vary with the quantity purchased. Willig [1978] showed that, from an initial uniform price p, which exceeds the firm's marginal cost, it is always possible to construct a nonuniform price which hurts no consumers, helps some and makes the firm more money.

2.3.3 Peak Load Pricing

Since the specific commodity chosen is electricity, which has time varying demands, particular attention has to be drawn to the peak load pricing models which, beginning with Steiner [1957] and Boiteaux [1949], inspired a vast body of research in the seventies and eighties.

The first contribution to the theory of peak load pricing came independantly from Steiner and Boiteux. Williamson [1966] and Hirshleifer [1958] also concurred with the results of the above two. Steiner adopts a welfare maximising approach, welfare being defined as the total sum of consumers surplus minus the cost of resources used for supply. There are two equal length periods, each having its own demand curve, $D_1(p)$ and $D_2(p)$. The peak load problem arises from the fact that one of these curves lies everywhere above the other. Costs are assumed linear, b is the operating cost per unit per period ; β is the capacity cost per unit. Thus, if there is existing capacity to supply quantity demanded in period 1, then $p_1 = b$; if additional capacity has to be installed to meet quantity demanded in period 2, then $p_2 = b + \beta$. p_1 is the off-peak price and p_2 the peak price. Optimal capacity is $q =$ Max (q_1, q_2) because at the optimum, quantity demanded cannot exceed capacity.

Williamson had similar results for peak and offpeak loads with the usual assumptions of a perfectly divisible plant. His analysis considered the case of a total shift in the demand curve - under what conditions was it optimal to add a new capacity unit ? Whereas Steiner and Hirshleifer sum the periodic loads vertically in order to find the optimum capacity, Williamson uses a weighted average of subperiod demands to obtain an effective demand for capacity curve. This demand for capacity curve is now fitted into the analysis to determine the longrun optimal plant size .

His basic principles for dealing with periodic demands are :

A. Optimal plant size is given by the intersection of the longrun marginal cost

curve (LRMC curve) and the effective demand for capacity curve .
B. Optimal price in every subperiod is given by the intersection of the short run marginal cost (SRMC) curve and the subperiod demand curve .
C. In a fully adjusted, continuously utilized system with only two periodic loads,
(a) Peak period price always exceeds LRMC .
(b) Off peak price is always below LRMC .
(c) Only when off peak load fails to use plant to capacity when priced at SRMC does peak load bear the entire burden of capacity costs .

Demands so far are assumed to be certain and known. But many public utilities face demands that have a strong random component. Interest in stochastic demand in public utility economics sprung up after a paper by Brown and Johnson [1969] regarding pricing under risk and uncertainty. A year earlier Turvey [1968] had pointed out the nature of stochastic electricity demand. B-J's paper produced some unusual results. The introduction of risk into the analysis required the authority to choose levels of price and output simultaneously. Optimal price was below LRMC and driven to SRMC because of the nature of $D = D(p, u)$ where u was the random element . Apart from this odd behavior of B-J's optimal price, another unusual aspect of their developments was the possibility of frequently occuring excess demand at the indicated solution. This low level of reliability was criticised by Turvey as implausible. Carrying on from here, Meyer [1975] reformulated the model by adding reliability constraints to it. This brought in the issue of how the optimal levels of such constraints was to be determined. An issue which was taken up later by Carlton [1977] and Crew and Kleindorfer [1978].

The question of pricing and capacity determination has been brought about in two very illuminating papers of Wenders [1976] and Crew and Kleindorfer [1976].
Wenders assumes three generation technologies available to meet demand - base, intermediate and peak, each having different annual capacity and energy costs per KW; marginal capacity cost $B_1 > B_2 > B_3$ and marginal energy

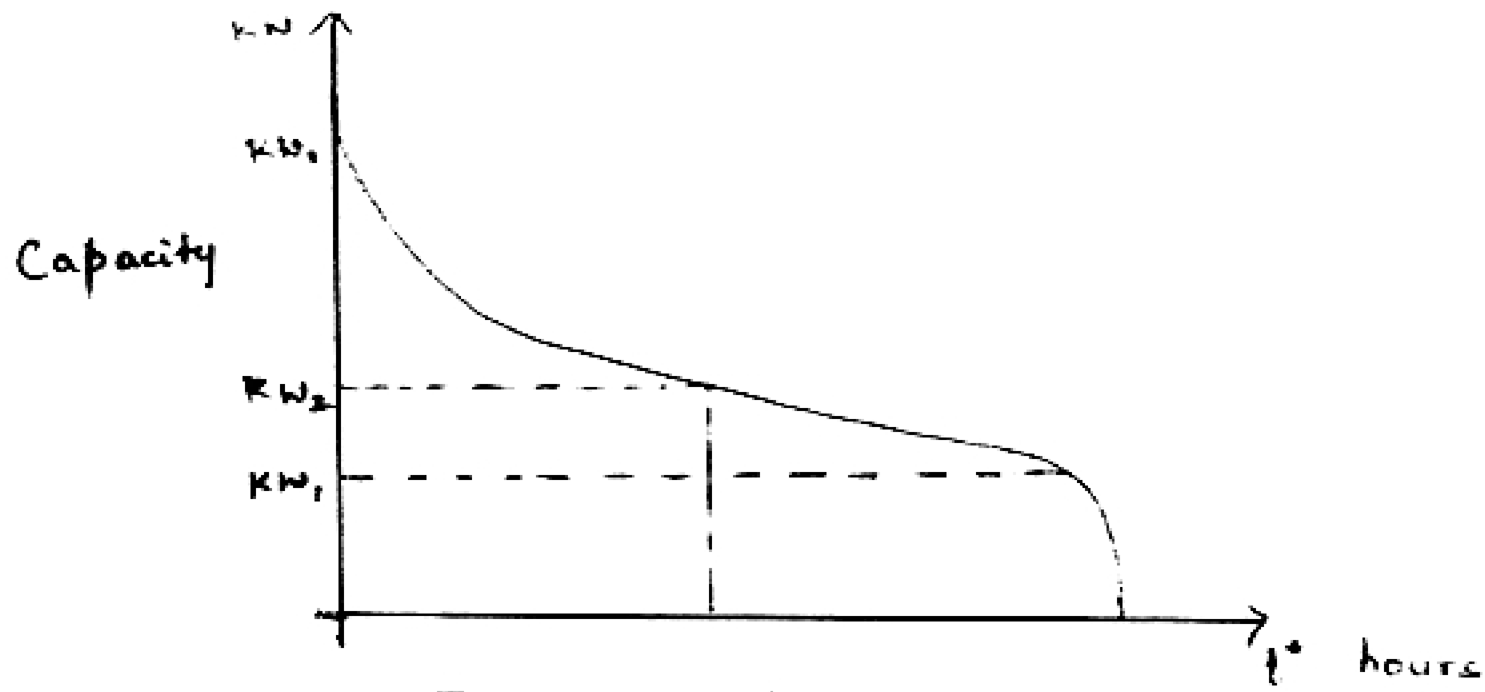


Figure 2.1: The load curve

cost $b_3 > b_2 > b_1$. The optimal mix of the three kinds of capacities depends on the pattern of load experienced by the utility. Define $w_1 = t_1/t^*, w_2 = (t_2 - t_1)/t^*, w_3 = (t^* - t_2)/t^*$. (See Figure 2.1). If the utility has already built KW_3 units of base load and wishes to increase this by 1 KW, it must consider the cost of one additional unit of intermediate capacity. Therefore the marginal cost of increasing base load must be weighed against the marginal cost of increasing intermediate load.

$$MC_3 = B_3 + (t_2/t^*)b_3$$

$$MC_2 = B_2 + (t_2/t^*)b_2$$

If $MC_3 < MC_2$, base load should be added until $MC_3 = MC_2$ or $t_2/t^* = w_1 + w_2 = (B_3 - B_2)/(b_2 - b_3)$

Similarly $t_1/t^* = w_1 = (B_2 - B_1)/(b_1 - b_2)$ This is how capacity mix should be adjusted to any fixed load duration curve. The problem now is to determine optimal prices to be charged. If the load duration curve can be divided into three pricing periods like,

z_1 fraction of the year demand is Q_1

z_2 fraction of the year demand is Q_2

z_3 fraction of the year demand is Q_3

$Q_1 > Q_2 > Q_3$

$z_1 = t'_1/t^*$, $z_1 + z_2 = t'_2/t^*$, $z_1 < w_1$ and $z_1 + z_2 < w_1 + w_2$
Total energy costs $C_o = b_3Q_3 + (z_1 + z_2)(Q_2 - Q_3)b_2 + z_1(Q_1 - Q_2)b_1$
Total capacity costs $C_k = B_3Q_3 + B_2(Q_2 - Q_3) + B_1(Q_1 - Q_2)$
Total welfare is now

$$W = \sum z_i \int_0^{Q_i} P_i dQ_i - C_o - C_k$$

Maximisation of W with respect to Q_i yields,

$$P_1 = b_1 + B_1/z_1$$

$$P_2 = \frac{(z_1 + z_2)b_2 - z_1 b_1 + B_2 - B_1}{z_2}$$

$$P_3 = \frac{b_3 - (z_1 + z_2)b_2 + B_3 - B_2}{z_3}$$

We see that capital costs now appear in the prices for offpeak periods This is a result of using different pricing periods and bringing in different technologies. Crew and Kleindorfer have a similar analysis for multi-period pricing with a diverse technology. They also assume linear costs
$C = b + \beta$.
The optimization in this case takes the form

$$\text{Max W } = \int_0^{X_i} \sum P_i(y)dy_i - \sum b_l q_{li} - \sum \beta_l q_l$$

s.t $\sum q_{li} = x_i$ for all i
$q_l - q_{li} \geq 0$ for all i,l
$x_i \geq 0, q_l \geq 0, q_{li} \geq 0$ for all i,l
where $P_i(y)$ is the inverse demand function.
x_i is demand in period i
q_l is capacity of type l,
q_{li} is output from plant l in period i
Welfare maximisation with respect to q_{li} will yield optimal prices by the first order conditions. The optimal prices here correspond to the long-run marginal cost.

There have been several studies advocating the use of long run marginal cost (LRMC) in electricity pricing. In calculating the LRMC, the important consideration is the amount of future resources used and saved by consumer decisions. In particular, with an appropriate choice of the peak period, structuring the tariffs based on LRMC by time of day generally leads to the conclusion that peak consumers should pay both capacity and energy costs, whereas off-peak consumers should pay only the energy cost. The objective of economic efficiency in setting tariffs is satisfied because the method of calculation is based on future economic resource costs rather than sunk costs. This method has been advocated for developing countries and Munasinghe and Warford [1982] have conducted studies for Indonesia, Pakistan, Philippines, Sri Lanka and Thailand.

The peak and off-peak prices are therfore, according to this approach, equal to LRMC and SRMC respectively. But as demand changes in between these two periods, the measure of marginal cost will keep fluctuating. In order to reduce the fluctuations, alternative methods of measuring marginal cost have been developed – Long Run Incremental Cost (LIC), Present Worth of Incremental System Cost (PWISC), and Average Incremental Cost (AIC). Some empirical studies based on these methods have been carried out for India too (Gellerson [1979]).

Using this vast literature as the background, this thesis attempts to address itself to basic issues relating to electricity.

(a) What is the optimal rationing scheme to be designed for a monopolist supplier of electricity in a situation of fixed prices, limited supply and excess demand ?

(b) If the supply constraint is relaxed to allow for increased supply through purchases from other generating units, but comes with a cost, what is the optimal tariff at which electricity should be purchased and sold in order to induce the socially optimal level of production?

The next three chapters are devoted to answering these two main issues.

Chapter 3

The Welfare Loss

3.1 Introduction

The question of the welfare implications of the quantities supplied and traded when supply is on the short side of the market is a very pertinent one when it addresses itself to developing countries. Here, the economy being in the growing stage, is characterised by a chronic shortage or excess demand in the goods market and an excess supply in the labour market. The prime reason for the former is the relatively slower growth in basic infrastructural sectors to meet the economy's growing needs. Shortages are therefore frequent, following underproduction which is due to non-availability of certain basic inputs.

In developing economies, most public utilities are owned by the government and therefore production is based more on social objectives than economic. Since public utilities supply certain essential goods, the government chooses to administer the prices to ensure stability. Therefore, in order to counter any kind of inflationary impact, there is a total or partial control over prices. While this may serve one important purpose, it is clear that in the absence of any other informational mechanism, administered prices fail to inform producers and consumers of the scarcity of the good. In the presence of fixed prices, demand is just a function of other prices and parameters which include own prices, tastes and incomes. It might well be, and indeed it is so in a country like India, that this would lead to a situation of excess demand. Since prices fail to clear the market, an excess demand necessitates an appropriate rationing scheme to allocate the available supply. From the viewpoint of development, a suitable rationing scheme will acquire special significance in view of the fact that it has to allocate scarce resources to the right agents which would have important impacts on growth and development.

The problem then is to devise a suitable rationing mechanism, or a load-shedding scheme, for a monopolist supplier of electricity, when faced with an excess demand situation. It is assumed that the supplier knows the demand at various points of the day, but has a fixed capacity to meet the demand at all times. The supplier is further constrained by the fact that the price of electricity is fixed institutionally, and does not change in response to the demand in the market. We assume that an arbitrary and non-optimal rationing is already in force. The optimal rationing mechanism will be seen as a two way decision making process by the supplier. Since any kind of rationing is bound to affect consumers' welfare, the first stage consists of determining or measuring the actual loss to welfare arising from rationing. Armed with this information, the second stage deals with the actual derivation of a now 'optimal' mechanism, through programming techniques, by choosing to minimise such a welfare loss. In effect, the supplier steps into the consumer's role in the first stage, goes through the corresponding maximizing decisions, then feeds this knowledge into a programming model and then goes through the second stage of minimizing the welfare loss subject to its overall resource constraints.

This chapter will deal with the first of the questions the thesis is addressed to, viz., rationing. Section 3.2 formulates the rationing model theoretically and states the main result. We then illustrate the above theoretical model empirically using data from the state of U.P. Sections 3.3, 3.4, 3.5 are concerned with the first stage of the programming problem, where the loss to welfare arising from rationing is determined. Section 3.6 presents the summary of the chapter.

3.2 The Model

The actual mechanism is viewed in an over-simplified model. Suppose the objective function defined as the Welfare Loss function, arising from the constraining of electricity consumption is given by

$$WL = U(Q) - U(S)$$

where $U(Q)$ is the utility level when consumption equals demand; i.e., $Q = (Q_1, \cdots Q_n)$ is the n vector of the unconstrained levels of goods. $U(S)$ is the utility level when only electricity is constrained, leading to new consumption levels of the other goods. That is, $S = f(S_e, S_2(S_e), \cdots S_n(S_e))$. Two main types of electricity users are defined.
(i) There are $i = 1, 2 ... k$ consumers using electricity as an intermediate good.
(ii) There are $i = k+1, k+2, ... n$ consumers using it as a final good and deriving direct benefit from it.
Assuming that the utilities are additive, the objective function now is

$$WL = \sum_{i=1}^{n} [U_i(Q_i) - U_i(S_i)]$$

where Q_i and S_i vectors have analogous interpretations.
The supplier's role in the objective function is through the manipulation of S_{ei}, i.e., the supply of electricity to any type i. In reality however, ration levels of electricity are not directly fixed. What is actually in control of the decision making electricity supplier is the hours of supply, or analogously, the hours of ration. We assume that there are $t = 1 \cdots T$ periods when demands are made. The hours of ration are decided on the basis of the load curve (that is, demand plotted against time measured in hours of the day), which is known to the supplier.

Therefore r_i^t is really the choice variable in the whole model, where r_i^t is the number of hours of ration in period t applicable to each type i. Two cases are now made:

Case 1 : Supply to any type i is a function of the ration hours applicable to only that type, and is independant of the hours of ration to other consumer types. Therefore,

$$S_{ei} = \sum_t s_{ei}^t \text{ where } s_{ei}^t = f(r_i, D, K)$$

where K is the total capacity which is fixed, D is the maximum demand on the capacity during the day, aggregated over all consumers, The following assumptions are made:

(i) s_{ei}^t is continuous and decreasing in r_i^t,

$$\frac{\partial s_{ei}^t}{\partial r_i^t} < 0, \ \forall i, \ r_i^t \geq 0$$

(ii) If a certain consumer type's hours of rationing during a certain demand period are increased, then some other consumer type's ration hours are relaxed for that period.

(iii)

$$\frac{\partial U_i}{\partial S_{ei}} > 0 \text{ where } S_{ei} = \sum_t s_{ei}^t$$

(iv) $p_{ei}^t = p_{ei}^{t+1}$. The price of electricity p_{ei}^t for consumers $i = 1, \cdots, n$ remains the same for all $t = 1, \cdots T$. This assumption imitates the actual situation in India, where there are no period-wise prices charged from the consumers.

(v) The rationing imposed for any consumer type i in a period t has no bearing on the rationing imposed on i in period $t + 1$. This is governed purely by the demands made in that period.

Before any optimization is done, let us specify what exactly is meant by utility loss to the two types of users. Since electricity is used both for direct consumption and indirectly in production, the definition of utility will differ in both cases. For those types $i = k + 1 \cdots n$, where electricity is used for direct consumption, the following specification is adopted.

Assume that the consumer maximizes his utility $U(x)$

subject to the budget constraint $px \leq M$

where x is the n vector of consumption levels of goods,

p is the price vector and M is the income of the consumer.

Suppose the solution to the above problem is $\overline{u}$.
Consider the dual, i.e., the expenditure or cost minimization problem of the consumer:

$$\text{Min } c(p, \overline{u}) = \text{Min } px \quad \text{s.t} \quad u(x) \geq \overline{u}$$

The solution is $\overline{c}(p, \overline{u})$ where $\overline{c}$ is the minimum expenditure to reach utility level $\overline{u}$, given price vector p and income M.
Suppose the consumption of one good say electricity x_e, is now restricted to $\tilde{x}_e$ where $\tilde{x}_e = \sum_t \tilde{x}_e^t$. Then the expenditure minimization problem is :

$$\text{Min } [p_e \tilde{x_e} + \tilde{p}\tilde{x}] \quad \text{s.t} \quad u(\tilde{x_e}, \tilde{x}) \geq \overline{u}$$

where p_e is the price of electricity, and $\tilde{p}$ is the price vector of all the other $n-1$ unrestricted goods, with the corresponding consumption vector $\tilde{x}$. Suppose the solution is now $c^*(\tilde{p}, \tilde{x_e}, \overline{u})$ where c^* is the minimum expenditure to reach utility $\overline{u}$, when $x_e = \tilde{x_e}$.
Since x_e is fixed, the problem reduces to

$$\begin{aligned} c^*(\tilde{p}, \tilde{x_e}, \overline{u}) &= p_e \tilde{x_e} + \min_{\tilde{x}} \; [\tilde{p}\tilde{x} \;\; \text{s.t} \;\; u(\tilde{x_e}, \tilde{x}) \geq \overline{u}] \\ &= p_e \tilde{x_e} + \phi(\tilde{p}, \tilde{x_e}, \overline{u}) \end{aligned}$$

where $\phi(\tilde{p}, \tilde{x_e}, \bar{u})$, the Hicksian demand vector of the unrationed goods, is independent of p_e. Following Rothbarth [1940-41], define 'virtual prices' or shadow prices as those prices that would induce a consumer to purchase exactly the restricted level $\tilde{x_e}$, while remaining at his utility level $\bar{u}$. That is, at some prices p_e^*, even in the absence of a quantity constraint or a supply restriction, and given that the other prices do not change, the consumer will demand only $\tilde{x_e}$. Neary and Roberts [1980] show that such prices will always exist if:

- The preferences are convex.
- The preference ordering is continuous.
- The preference ordering is strictly monotonic.

Since p_e^* is defined as that price at which just $\tilde{x}_e$ is demanded,

$$\frac{\partial \bar{c}(p_e^*, \tilde{p}, \bar{u})}{\partial p_e} = \tilde{x}_e$$

where $\tilde{x}_e$ is the Hicksian demand function, obtained as a derivative of the unrestricted cost function.
p_e^* is the solution to the above derivation.
We therefore have,

$$p_e^* = \psi(\tilde{p}, \tilde{x}_e, \bar{u})$$

In the case when the restriction on the rationed good is not enforced, the minimum expenditure function becomes

$$\overline{c}(p_e^*, \tilde{p}, \overline{u}) = p_e^* \tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \bar{u})$$

Now,

$$c^*(\tilde{p}, \tilde{x}_e, \overline{u}) = p_e \tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \bar{u})$$

and

$$\overline{c}(p_e^*, \tilde{p}, \overline{u}) = p_e^* \tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \bar{u})$$

Since the rationed demand functions $\tilde{x}$ will depend only on the level of the restricted good, and not on the price of electricity, $\phi(\tilde{p}, \tilde{x}_e, \bar{u})$ will be the same in both cases. The relation between the restricted and the unrestricted cost functions can be seen from the following expression [1].

$$\overline{c}(p_e^*, \tilde{p}, \overline{u}) = (p_e^* - p_e)\tilde{x}_e + c^*(\tilde{p}, \tilde{x}_e, \overline{u})$$

The above relation can be used to measure the welfare effects of a change in the level of restriction of $\tilde{x}_e$.

1

$$\begin{aligned} \overline{c}(p_e^*, \tilde{p}, \overline{u}) &= p_e \tilde{x}_e + (p_e^* - p_e)\tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \bar{u}) \\ &= (p_e^* - p_e)\tilde{x}_e + c^*(\tilde{p}, \tilde{x}_e, \overline{u}). \end{aligned}$$

From the concavity of the cost function in prices, we know that p_e^* is a negative function of $\bar{x}_e$. A rise in $\bar{x}_e$ will cause a fall in p_e^* and consequently a fall in the minimum expenditure required to maintain the consumer at the utility level $\overline{u}$. The extent of the benefit or loss resulting from a change in $\bar{x}_e$ can be measured by the above expression. It is not however, a welfare loss, in the sense of utility loss, since the consumer is constrained to remain on the same utility level $\overline{u}$. We will define the loss from the restriction of electricity consumption to all those consumers who use it as a final good as the following 'economic loss' :

$$(p_e^* - p_e)\bar{x}_e$$

i.e., the difference between the minimum expenditure required to reach utility level $\overline{u}$ when the consumer is not subject to any restriction and the minimum expenditure to reach utility $\overline{u}$ when there is a supply restriction.

For all those users who use electricity as an intermediate good, i.e., in production, welfare loss from restricting consumption is defined as follows. Assume that the representative user or producer has a technology that defines the production function as: $Y = f(x)$ where $f(x)$ is concave, x is a vector of inputs, electricity being one of them. The profit-maximizing programme of the firm is set out as :

$$\text{Max}_x \quad pf(x) - wx \quad \text{s.t} \quad f(x) = Y$$

where p is the price of the output which is determined by the market, and w is the price vector of all the inputs. The first order conditions for a maximum give :

$$pf'(x) = w$$

and $\hat{Y}$, i.e., the profit-maximizing level of output is determined at the point where

$$f'(x) = w/p$$

When electricity input is constrained to the level $\overline{x}_e$ (distinguishing the rationing to the producing sectors from $\tilde{x}_e$ – the rationing to the final consumers), then the profit maximizing problem becomes

$$\text{Max} \quad pf(x) - wx \quad \text{s.t} \quad f(x) = Y \quad \text{and} \quad x_e = \overline{x}_e$$

The neccesary conditions for an optimum give $f'(x) = \frac{w+\mu}{p}$ where μ is the shadow price of the constraint on the ration level. Let the restricted profit maximizing output be called $\tilde{Y}$.

The loss in welfare from the restriction of electricity input is then measured as the fall in the profit-maximizing output due to the restriction. This is nothing but $\hat{Y} - \tilde{Y}$. Aggregating over all users who fall in this category it is easier to talk in terms of the value of output rather than actual physical output. Since the price of output is independant of the cost of electricity input(by our assumption), we have

$$WL = p\hat{Y} - p\tilde{Y}$$

where $\tilde{Y}$ is a function of $\tilde{x}_e$ the supply of electricity input.

The Constraint Set : We assume that the supplier, with the knowledge of the welfare loss functions now proceeds to determine the optimal supply to consumers through the variable that he controls, i.e., r_i the number of hours of ration. In doing so, he is constrained by the following two main arguments: (i) The supply to all the consumers in any period cannot exceed the total capacity that he is assumed to hold. This is written in the form

$$\sum_{i=1}^{n} s_{ei}^{t} \leq K \;\forall t$$

In expressing the constraint in this form, we assume that capacity which is a stock concept is converted into flow terms. In other words, capacity in megawatts (MW) is converted into the capacity to supply during any period, a certain amount of kilowatthours given the plant load factor[2]. Though we

[2]This is nothing but the percentage of capacity utilization. A formal definition of the PLF is given on page 125 (Chapter 5).

have earlier talked in terms of restricted consumption, the terms 'supply' and 'consumption' of electricity will be used synonymously.

(ii) For all those consumers who use electricity in production, the supplier is faced with a constraint that the restricted output resulting from the non-availability of electricity should be atleast greater than a predetermined level of output as stipulated by a central authority. Formally,

$$\tilde{Y} \geq Y_0 \quad i = 1, 2, \cdots k$$

(iii) $r_i^t \geq 0$, $s_{ei}^t > 0$, $WL \geq 0$

The problem can now be stated as :

$$\text{Min}_{r_i^t} \quad WL = \sum_{i=1}^{n} [U_i(Q_i) - U_i(S_{ei}(r_i^t), S_{2i}(S_{ei}) \cdots S_{ni}(S_{ei}))] \tag{3.2.1}$$

$$\text{s.t} \quad \sum_{i=1}^{n} s_{ei}^t \leq K, \quad t = 1, \cdots, T \tag{3.2.2}$$

$$\tilde{Y}_i \geq Y_0, \quad i = 1, 2, \cdots k \tag{3.2.3}$$

$$\text{and} \quad r_i^t \geq 0, \; S_{ei} > 0, \quad i = 1, 2 \cdots n \tag{3.2.4}$$

Minimizing the Lagrangean expression for some $m \in i = 1, 2, \cdots k$,

$$\begin{aligned} \frac{\partial L}{\partial r_m^t} &= [-\frac{\partial U_m}{\partial S_{em}} S'_{em} - \frac{\partial U_m}{\partial S_{2m}} \frac{\partial S_{2m}}{\partial S_{em}} S'_{em} - \cdots - \frac{\partial U_m}{\partial S_{nm}} \frac{\partial S_{nm}}{\partial S_{em}} S'_{em}] - \lambda_t s_{em}^{t'} \\ &+ \lambda_m [\frac{\partial \tilde{Y}_m}{\partial S_{em}} S'_{em} + \frac{\partial \tilde{Y}_m}{\partial S_{2m}} \frac{\partial S_{2m}}{\partial S_{em}} S'_{em} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{nm}} \frac{\partial S_{nm}}{\partial S_{em}} S'_{em}] \end{aligned} \tag{3.2.5}$$

Since an increase in the ration hours of the m^{th} consumer means a fall in the ration hours applicable to type $j \neq m$, by our assumption, the effect of a change in r_j^t should be simultaneously taken into account. Assume that both m and j belong to the set $i = 1, 2, \cdots k$

$$\begin{aligned} \frac{\partial L}{\partial r_j^t} &= [-\frac{\partial U_j}{\partial S_{ej}} S'_{ej} - \frac{\partial U_j}{\partial S_{2j}} \frac{\partial S_{2j}}{\partial S_{ej}} S'_{ej} - \cdots - \frac{\partial U_j}{\partial S_{nj}} \frac{\partial S_{nj}}{\partial S_{ej}} S'_{ej}] \\ -\lambda_t s_{ej}^{t'} &+ \lambda_j [\frac{\partial \tilde{Y}_j}{\partial S_{ej}} S'_{ej} + \frac{\partial \tilde{Y}_j}{\partial S_{2j}} \frac{\partial S_{2j}}{\partial S_{ej}} S'_{ej} + \cdots + \frac{\partial \tilde{Y}_j}{\partial S_{nj}} \frac{\partial S_{nj}}{\partial S_{ej}} S'_{ej}] \end{aligned} \tag{3.2.6}$$

Setting both the equations to 0 for a minimum, and eliminating λ_t, by noting that $s^{t'}_{em} = \sum_t s^{t'}_{em} = S'_{em}$ because of assumption (v), (that is, the change in supply to type m in period t, is equal to the change in supply to type m in all periods, which is nothing but S'_{em}), we have,

$$\begin{aligned}[\frac{\partial U_m}{\partial S_{em}} + \cdots + \frac{\partial U_m}{\partial S_{nm}}\frac{\partial S_{nm}}{\partial S_{em}}] \quad - \quad \lambda_m(\frac{\partial \tilde{Y}_m}{\partial S_{em}} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{nm}}\frac{\partial S_{nm}}{\partial S_{em}}) \\ = [\frac{\partial U_j}{\partial S_{ej}} + \cdots + \frac{\partial U_j}{\partial S_{nj}}\frac{\partial S_{nj}}{\partial S_{ej}}] \quad - \quad \lambda_j(\frac{\partial \tilde{Y}_j}{\partial S_{ej}} + \cdots + \frac{\partial \tilde{Y}_j}{\partial S_{nj}}\frac{\partial S_{nj}}{\partial S_{ej}})\end{aligned} \qquad (3.2.7)$$

Consider now the cost minimization programme of m in the constrained case, i.e., the minimum cost of producing the restricted output $\tilde{Y}_m$.

$$\text{Min}_S \quad p_{em}S_{em} + wS_{wm} \quad \text{s.t } \tilde{Y}_m[S_{em}, S_{wm}] \geq Y_0 \qquad (3.2.8)$$

where p_{em} is the price of electricity that consumer m pays, S_{wm} is the vector of all other goods, and w is the corresponding price vector. Minimizing with respect to S_{em} gives,

$$p_{em} + wS'_{wm} - \lambda[\frac{\partial \tilde{Y}_m}{\partial S_{em}} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{wm}}S'_{wm}] = 0 \qquad (3.2.9)$$

λ is the shadow price of the constraint on a unit reduction of the supply. $[\frac{\partial \tilde{Y}_m}{\partial S_{em}} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{wm}}S'_{wm}]$ measures the marginal change in the output due to the unit reduction of electricity input. λ is therefore value of the marginal product. From duality we know that the corresponding profit maximization problem gives $p[\frac{\partial \tilde{Y}_m}{\partial S_{em}} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{wm}}S'_{wm}] = p_{em} + wS'_{wm}$ from the first order conditions.(i.e., marginal value product = marginal cost). Quite clearly, λ corresponds to λ_m in our Lagrangean, and $\lambda_m[\frac{\partial \tilde{Y}_m}{\partial S_{em}} + \cdots + \frac{\partial \tilde{Y}_m}{\partial S_{wm}}S'_{wm}]$ is equal, at the margin, to the cost reduction due to the restriction of electricity consumption.

Through a similar cost minimization programme for j, we have,

$$p_{ej} + wS'_{wj} - \lambda[\frac{\partial \tilde{Y}_j}{\partial S_j} + \cdots + \frac{\partial \tilde{Y}_j}{\partial S_{wj}}S'_{wj}] = 0 \qquad (3.2.10)$$

Therefore,

$$U'_jS'_j - U'_mS'_m \quad = \quad (p_{ej} + wS'_{wj}) - (p_{em} + wS'_{em}) \qquad (3.2.11)$$

where $U_j' = [\frac{\partial U}{\partial S_{ej}}, \cdots, \frac{\partial U}{\partial S_{nj}}]$ and $U_m' = [\frac{\partial U}{\partial S_{em}}, \cdots, \frac{\partial U}{\partial S_{nm}}]$;
and where $S_j' = (1, \frac{\partial S_{2j}}{\partial S_{ej}}, \cdots, \frac{\partial S_{nj}}{\partial S_{ej}})$ and $S_m' = (1, \frac{\partial S_{2m}}{\partial S_{em}}, \cdots, \frac{\partial S_{nm}}{\partial S_{em}})$
We now specify U_m and U_j as $p_m\tilde{Y}_m$ and $p_j\tilde{Y}_j$ respectively, where p_m and p_j are the prices of the output of m and j. Then we have,

$$p_m(\tilde{Y}_m'S_m') - (p_{em} + wS_{wm}') = p_j(\tilde{Y}_j'S_j') - (p_{ej} + wS_{wj}') \quad (3.2.12)$$

$$\text{or } (p_{em} + wS_{wm}') - p_m(\tilde{Y}_m'S_m') = (p_{ej} + wS_{wj}') - p_j(\tilde{Y}_j'S_j') \quad (3.2.13)$$

$p_m\tilde{Y}_m'S_m'$ is the loss in the marginal value product while $p_{em} + wS_{wm}$ measures the cost savings from a unit reduction in the consumption of electricity. The above result says that the fall in the marginal value product net of the cost savings for type m, has to be matched, ***at the margin***, with the increase in the marginal value product less the increased cost of consumption to any other $j \neq m$.

Suppose now it was the ration hours of a certain l type of consumer that is, final consumers was now reduced, $l \in [k+1, \cdots, n]$,

$$\frac{\partial L}{\partial r_l^t} = \frac{\partial[U_l(Q_l) - U_l(S_l)]}{\partial r_l^t} - \lambda_t S_l' \quad (3.2.14)$$

Then (3.2.7) implies once again that

$$-U_m'[S_m'] + \lambda_m\tilde{Y}_m = -\frac{\partial[U_l(Q_l) - U_l(S_l)]}{\partial r_l^t} \quad (3.2.15)$$

But as stated earlier,

$$\frac{\partial[U_l(Q_l) - U_l(S_l)]}{\partial r_l^t} = (p_{el}^* - p_{el})S_l' + p_{el}^{*'} \quad (3.2.16)$$

$$\text{Therefore, } p_m\tilde{Y}_m'S_m' - (p_{em} + wS_{wm}') = (p_{el}^* - p_{el})S_l' + p_{el}^{*'} \quad (3.2.17)$$

Again the above result says that the change in the marginal value product net of the change in cost from restricting of electricity supply to type $m \in [1, 2, \cdots, k]$ i.e., an intermediate consumer, should be balanced at the margin, by the increase in income to type $l \in [k+1, k+2 \cdots, n]$ i.e., a final consumer which is reflected in the fall of p_{el}^* in the expression $(p_{el}^* - p_{el})S_l' + p_{el}^{*'}$.
Note that WL is convex in S_{ei} for $i = 1, 2, \cdots k$ as $p\tilde{Y}$ is concave in S_{ei}, and $(p_{el}^* - p_{el})S_{el}$ is convex in S_{el} and for $i = k+1, k+2, \cdots, n$ as $(p_{el}^* - p_{el})S_{el}$ is

nothing but $\bar{c}(p_e^*, \tilde{p}, \tilde{x}_e, \overline{u}) - c^*(\tilde{p}, \tilde{x}_e, \overline{u})$ where $\bar{c}$ and c^* are convex. Also S_{ei} is decreasing in r_i^t for all $i = 1, 2, \cdots, n$. WL is therefore quasiconvex in r_i^t and so the first order conditions are necessary and sufficient for optimality.

The condition for optimum therefore states that the hours of ration should be decided at the point where supply leads to a proportionate change in welfare to different consumer types. Welfare loss will be minimised at this point of equality.

Case 2: Supply to any type i is a function of the ration hours applicable to all the consumer types. This is a straightforward extension of the earlier case. We have now, $S_{ei} = S_{ei}(r^t)$, $i = 1, 2 \cdots n$
where $r^t = (r_1^t ... r_n^t)$ The first order conditions now are :

$$\lambda_t \sum_{i=1}^{n} S'_{ei} = \sum_{i=1}^{n} U'_i S'_i - \sum_{j=1}^{k} \lambda_j U'_j S'_j \tag{3.2.18}$$

where j refers to those consumers who use electricity as an intermediate input and for whom the corresponding constraint λ_j holds. λ_t is the shadow price of a unit supply in period t. Consider the expenditure minimization programme of the supplier: Assume that his cost consists of a per unit fixed cost β of capacity installed and an average variable cost of b_t per unit of output in period t.

$$\text{Min } C = \sum_{i=1}^{n} \sum_{t=1}^{T} b_t s_i^t + \beta K \ \text{ s.t} \sum_{i=1}^{n} s_i^t \leq K \ \ \forall \ t \tag{3.2.19}$$

Minimising with respect to s_i^t gives,

$$b_t = \lambda_t \tag{3.2.20}$$

Therefore λ_t is the marginal cost of a unit supply to i in period t. But $\sum_{i=1}^{n} S'_{ei} = 0$ for what is really taking place is only a redistribution of a fixed supply. So,

$$\sum_{i=1}^{n} U'_i S'_i = \sum_{j=1}^{k} \lambda_j U'_j S'_j \tag{3.2.21}$$

Substituting for U_i and U_j correspondingly by their actual values gives the same result as in the first case.

The condition for equilibrium is therefore that the ration hours are adjusted such that the marginal percentage change in the welfare loss is equal for all types.
The optimal rationing mechanism is that which equates for all types, at the margin, the valuation of a unit of electricity. The next step is to illustrate this mechanism by means of an empirical example.

3.3 The Empirical Exercise

This section deals with the empirical estimation of the welfare loss to each of the electricity users. Electricity being a good used both for intermediate consumption as well as final consumption, the determination of welfare loss needs a different treatment for both kinds of users. Electricity is used in the production of both manufactured goods and primary goods, for domestic uses for heating and lighting and other appliances, as well as for commercial purposes, for public lighting and waterworks, for transport as in railway traction, and other miscellaneous activities. Since the benefit of using electricity for commercial and public lighting would be difficult to quantify and since they form a very small portion of the total electricity consumption[3], we will concentrate only on electricity used for production and domestic consumption.

In order to deal with the rationing mechanism empirically, it is neccessary to specify which data is taken and in what form it is used. For the entire analysis we take the state of Uttar Pradesh (U.P.) as the subject under study. The concentration here had to be on a state-wise analysis because the available supply varies across states, and each state has its own rationing scheme according to its capacity and hence the effects of rationing will be different in each state. Uttar Pradesh is a state which has, over the past fifteen years, shown a consistent divergence between the peak demand and peak supply. Power cuts are therefore frequent, and that is why this exercise is aimed at determining an

[3]The All-India proportion in 1982-83 was 10 % .

optimal power rationing scheme. But this will be taken up in greater detail in the next chapter. This chapter will deal only with the estimation of the welfare loss due to the rationing of electricity consumption.

So, the supplier of electricity is the Uttar Pradesh State Electricity Board (UPSEB) which is faced with a supply constraint. The consumers who demand electricity are of three categories - aggregate industry of the state[4], aggregate agriculture of the state[5], both of whom use electricity as an input in the production process, and the entire domestic or household sector which uses electricity for direct consumption. Each one of these consumers is subject to some kind of load-shedding over the day or month, in order that the available supply is shared among all the consumer types. The Board has control over the hours of supply but not the price of electricity which is effectively decided by the state government. The entire analysis of the rationing mechanism will be for the year 1983-84 as this was the most recent year compatible with the data for all the sectors.

To those who use it in production, welfare is defined as the loss in the value of output due to the rationing of electricity. Since electricity which is an input is restricted, it is reasonable to suppose that in the short run the output of the producing firm will be affected. However, we are dealing with many such firms all of whom may be producing different goods. The supplier of electricity does not know the type of output each firm is producing, rather he looks upon all such firms as one sector. Aggregation of the physical outputs of various such firms will not be possible. It is to circumvent this problem that we choose to take the aggregate value of output as a measure of welfare for the intermediate users.

The loss in the value of output is defined as the difference in the value of output when electricity is not restricted and the value of output when it

[4]Which means the organized manufacturing sector classified under the Annual Survey of Industries bulletin.

[5]The entire agricultural sector as recorded in the Agricultural Statistics Bulletin of the Directorate of Economics and Statistics of the Ministry of Agriculture.

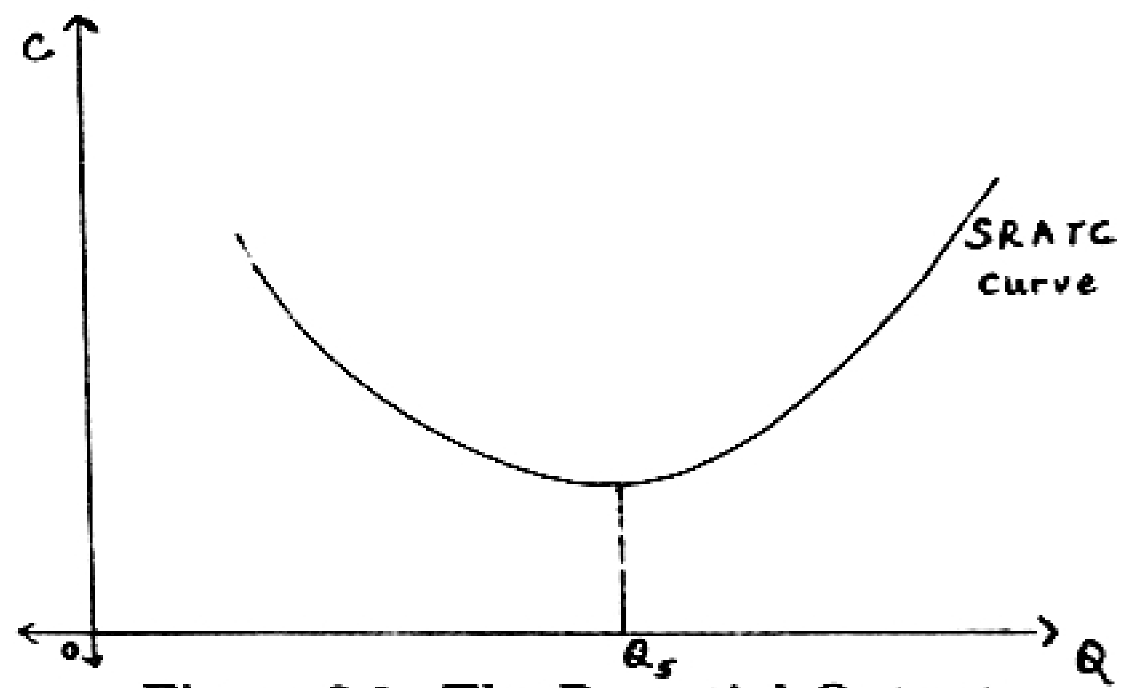


Figure 3.1: The Potential Output

is restricted. The actual restricted value of output is the observed value of output. The observed value of output and the corresponding input values are the values that have already been subjected to rationing. But determining that value of output which we call the 'unrestricted' output, is not straightforward, for there is no way of establishing from the published records what the true value of output in the absence of rationing would be. A technique has to be devised to determine the 'unrestricted value of output'.

For this purpose, we have adopted the methodology from Nelson [1989] who empirically estimated the extent of capacity utilisation in the electric power industry. The methodology that he has used is expained in detail below.

Capacity utilisation is normally referred to as the ratio of the achieved level of output to the total capacity. In order to measure capacity utilisation in an alternative way, Nelson uses Hickman's [1935] definition of 'potential output' as, that output which corresponds to the minimum point of the firm's short-run average total cost curve.(See Figure 3.1).

The minimum point is what the firm *should* have achieved given that the firm was a profit maximiser in the short run. The actual output is then divided by this 'potential' output to determine the capacity utilised. We have used this same method to determine the 'potential output' of industry and agriculture. In doing so, we apply the following reasoning. Under the assumption that a representative firm maximizes profits in the short-run, the minimum point of its short run average total cost curve is the point at which it should optimally produce, ***in the absence of any constraints.*** In other words, when we do not allow for any constraints on inputs operating on output (and when we do not allow for inefficient production or demand related constraints), then such a firm should be producing at the lowest point of the short run average total cost curve. Recall that $U(Q)$ in our model was defined as the utility level when all consumption equals demand. We will define $U(Q)$ for industry as the 'potential output'– the minimum point of the industry's short run average total cost curve. The output level at this point will then enter into the first expression of the welfare loss arising from electricity consumption in our model for industry.

Why the firm has not managed to operate on the lowest point of the short-run average total cost curve (if the capacity utilisation was less than 1) will probably be difficult to determine, unless the structural constraints are known and can be appropriately modelled. But it will be our assumption in this exercise that the ***only*** reason the firm was not producing at this point was due to the restriction on electricity consumption and its effect on other inputs and the output. We will ignore all other constraints on production treating them as negligible. Keeping only one restriction makes the problem simpler and facilitates the analysis as a partial equilibrium study.

The first problem for the Board is then to determine the potential output of both industry and agriculture. We take the case of industry first, assuming that the entire industrial sector of U.P. can be seen as one representative firm.

3.3.1 The model for industry

Assume that the representative firm has a smooth wellbehaved production function of the form $Q = f(F, M, L, K, T)$ where F is the amount of fuel input,

M is the aggregate material input,

L is the labour used,

K is the stock of capital, and T is a measure of technical progress. Consider the short run cost minimisation problem, of producing a certain output Q conditional on a given fixed stock of capital K. Since K is fixed, this implies that in the short run, the firm actually minimizes the variable cost of producing Q, that is, $VC = f(p_f, p_l, p_m, Q, K, T)$ where p_f, p_l, p_m are the prices of fuel, labour, and materials respectively. Notice that the variable cost function has *capital stock* and not capital price as one of its arguments. Corresponding to the above production function, the variable cost function is also assumed to be continuous, concave, and linearly homogenous in input prices. However, in order to empirically estimate such a function we need a more flexible form. The translog form[6] is one such approximation which exhibits properties of any arbitrary, twice continuously differentiable cost function at least at the point of approximation[7]. We have,

$$\begin{aligned}
\log VC = \alpha_0 &+ \sum_{i=1}^{n} \alpha_i \log p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij} \log p_i \log p_j \\
&+ \beta_Q \log Q + \frac{1}{2}\beta_{QQ}(\log Q)^2 + \sum_{j=1}^{n} \beta_{Qj} \log Q \log p_j \\
&+ \gamma_K \log K + \frac{1}{2}\gamma_{KK}(\log K)^2 + \sum_{j=1}^{n} \gamma_{Kj} \log K \log p_j \\
&+ \gamma_{KQ} \log K \log Q + \delta_T T + \delta_{TT} T^2 \\
&+ \sum_{i=1}^{n} \delta_{Ti} T \log p_i + \delta_{TQ} T \log Q + \delta_{TK} T \log K \qquad (3.3.1)
\end{aligned}$$

Linear homogeneity in input prices imposes the following restrictions:

$$\begin{aligned}
1. \sum_{i=1}^{n} \alpha_i &= 1 \\
2. \sum_{i=1}^{n} \alpha_{ij} &= \sum_{j=1}^{n} \alpha_{ij} = 0 \\
3. \sum_{j=1}^{n} \beta_{Qj} &= 0
\end{aligned}$$

[6] Christenson, et.al [1971].

[7] For the existence of a second order approximation of the translog function to a cost function that is continuous, concave and linearly homogenous, see appendix A.3(1).

$$4. \sum_{j=1}^{n} \gamma_{Kj} = 0$$

$$5. \sum_{j=1}^{n} \delta_{Tj} = 0 \tag{3.3.2}$$

The technology is assumed to be operating under constant returns to scale. This imposes the following symmetry condition to be obeyed by the cost function: $\alpha_{ij} = \alpha_{ji}$ for all $i, j = 1....n$.

Minimization of the variable cost function with respect to the variable input prices yields the cost-share equations by the first order conditions.
By differentiation,

$$\frac{\partial \log VC}{\partial \log p_i} = \frac{p_i}{VC}\frac{\partial VC}{\partial p_i}$$

By Shephard's lemma[8], $\frac{\partial VC}{\partial p_i} = X_i$, where X_i is the demand function for input i. Multiplying with $\frac{Q}{VC}$ gives the cost share equations. Though the cost share equations are really the input demand equations, they are derived through the use of already restricted inputs and therefore cannot be called demand equations. For our analysis we will refrain from calling these input demands and prefer to use the term 'costshares'.

$$\frac{\partial \log VC}{\partial \log p_i} = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} \log p_j + \beta_{Qj} \log Q + \gamma_{Kj} \log K + \delta_{Tj} T \tag{3.3.3}$$

Define the short run total cost for the firm as

$$SRTC = VC + p_K K \tag{3.3.4}$$

where $p_K K$ is the cost of the fixed capital of the firm, p_K being the price of capital stock. The short run average total cost is then:

$$SRATC = \frac{VC}{Q} + \frac{p_K K}{Q} \tag{3.3.5}$$

Minimisation of the $SRATC$ function with respect to Q yields the following equilibrium condition

$$\frac{1}{Q}\frac{\partial VC}{\partial Q} - \frac{VC}{Q^2} - \frac{p_K K}{Q^2} = 0 \tag{3.3.6}$$

[8]See Appendix A.3(2) for the statement of the lemma.

Now,

$$\frac{\partial \log VC}{\partial \log Q} = \frac{Q}{VC}\frac{\partial VC}{\partial Q}$$

and

$$\frac{\partial \log VC}{\partial \log Q} = \beta_Q + \beta_{QQ}\log Q + \sum_{j=1}^{n}\beta_{Qj}\log p_j + \gamma_{KQ}\log K + \delta_{TQ}T \qquad (3.3.7)$$

By multiplying the above by $\frac{VC}{Q}$ we rewrite the equilibrium condition as

$$\frac{VC}{Q_s^2}\frac{\partial \log VC}{\partial \log Q} - \frac{VC}{Q_s^2} - \frac{p_K K}{Q_s^2} = 0 \qquad (3.3.8)$$

where Q_s is the solution to the equilibrium condition i.e., Q_s is the output corresponding to the output at the minimum point of the SRATC curve. Since both Q_s and $\log Q_s$ appear in the above, iterative methods must be employed to arrive at the solution.

3.3.2 Data and Estimation

The data chosen for the analysis is from the state of U.P for the time-period 1960-61 to 1985-86. Though the usage of state-wise data throughout the analysis would have greatly improved the work, non-availability of data due to poor records has sometimes forced the usage of data for certain series at the All-India level. The inputs chosen are labour, aggregate materials input and fuel input. The Q in the analysis is not the actual physical output but the value of gross output at constant prices. All the above data including the gross value of output has been taken from the Annual Survey of Industries(ASI) records published by the Central Statistical Organisation for the census sector for the state of U.P. Though the study is based on *given output price* there really exists no price for aggregate output. What is available instead, is an output price index for all commodities. Besides ASI publishes data which are in current prices. To enable estimation with a consistent set of data the value of gross output should be devoid of any price fluctuations. It has first to be normalized to some constant prices. In order to determine the gross value of output at constant prices we constructed two alternative deflators for this purpose: (i)The ratio of

the Net State Domestic Product(SDP) accruing from manufacturing at current prices, to the net SDP from manufacturing at constant prices (1970-71 taken as the base year), both being available from the State Statistical Abstracts published by the State Statistical Bureau of the Government of Uttar Pradesh. (ii) The Wholesale Price Index (WPI) of manufacturing commodities at constant prices (1970-1971 = 100) available from Chandhok [1990].
We have chosen the WPI deflator over the former as it yielded better results in estimation. Therefore the entire gross value of output series is deflated using 1970-71 as the base year, and henceforth will be called the value of output at constant prices.

Labour price is defined as total emoluments(wages and salaries) divided by the total number of employees(including skilled and non-skilled). Price for aggregate material input is taken as the aggregate price index for manufacturing as available in the WPI tables with base year as 1970-71. Unfortunately, neither ASI nor the State Statistical Abstracts give any year-wise detailed break-up of fuel input as electricity consumed and other fuel. The only data available on electricity consumption by the aggregate industry is from the State Electricity Board. But this data is inconsistent with the ASI data since it does not take into account the electricity consumed by the industry's own generating plants. So we have to use the value of aggregate fuel input as given in ASI records. However, this will not really matter in the determination of the potential output, which does not require the detailed break-up of fuel. We calculate the price for fuel input as a weighted average of the prices of the components of fuel where the weights would be the percentage share of each of these components in some representative year, preferably the base year, i.e., 1970-71. But we could obtain this percentage shares for only 1971-72. Accordingly, we have identified three basic components of fuel : coal, mineral oil and electricity. Price indices for coal, mineral oil and electricity are taken from the WPI(Chandhok 1990) at 1970-71 prices. The price of fuel is then calculated as a weighted average of these individual prices indices, the weights being the proportion of each of coal, mineral oil and electricity in relation to total fuel input in the year 1971-72.

We also need the cost of capital for the analysis. The cost of capital service[9] is defined as:

$$p_K = p_I(r + \delta)$$

where p_I is the price index of investment goods, which is a weighted average of the price of construction and the price of plant & machinery, (both available from WPI), the weights being the proportion of of these two capital components in the base year 1970-71.

The price of construction is prepared by taking the ratio of the value of output at current prices to the value of output at constant prices. The price for plant & machinery is taken from the wholesale price index of plant & machinery equipment(Chandhok 1990). r is the rate of interest on capital or the opportunity cost of capital. Prime lending rate is viewed here as an opportunity cost of capital. However, there is no unique lending rate. Therefore we have used bank rate as a proxy for the prime lending rate, because they always move together. The bank rate is published annually in the issues of the Reserve Bank of India Bulletin. δ is the rate of depreciation which is calculated by taking the ratio of actual reported nominal figures of depreciation and the nominal value of fixed capital.

Capital stock is then calculated by deflating the nominal value of fixed capital as given in the ASI records by p_K. The usual method of constructing a capital stock series is however, by the 'perpetual inventory' method. Seth and Mehta [1987] have calculated capital-output ratios for various states for the period 1960-1980. The capital stock used for this exercise was calculated by the perpetual inventory method. Using the capital-output ratio calculated by

[9]A distinction is to be made between the cost of capital and the cost of capital service. The former is p_I which is the price of capital goods. We will use the cost of capital service to take into account the opportunity cost of capital invested as well as the depreciation on the existing capital stock. Investment goods refer to plant & machinery, construction(including material, workers) and other fixed assets like furniture (wood and steel), computing amchines, typewriters etc. But since plant & machinery and construction form the bulk of investment goods, we have chosen only the two.

them for 1962, we worked out a capital stock series for our data range by the same method[10]. But this procedure yielded insignificant results which led us to believe that the method which uses an arbitrary life span for different assets comprising capital stock is not really compatible with the value of aggregate output, for the purpose of regression. Besides, the 'perpetual inventory' method of calculating capital stock series is controversial and has several conceptual problems[11].

Table 3.3.2 gives the data that we have used for the analysis.

---

[10] For a detailed step by step analysis, see Seth and Mehta.

[11] See Ahluwalia [1985]

Table 3.3.2

The data for industry in Rs. lakh

Year	val of output	Cap Stock	Labour cost	Fuel Cost	Mat Cost
1960-61	25229.00	8372.87	3139.32	1027.91	16486.62
1961-62	28947.25	9467.06	3592.75	1211.76	18894.49
1962-63	29276.39	10452.25	4009.42	1307.44	19001.48
1963-64	32305.66	12987.66	4410.67	1827.23	19727.15
1964-65	38884.65	30236.52	5145.31	1967.42	24474.22
1965-66	46787.64	39990.42	6131.74	2330.37	28716.10
1966-67	49560.99	47804.88	5740.48	2804.94	31069.18
1968-69	61838.78	62502.03	6790.42	2696.88	38434.15
1969-70	73976.99	75470.52	7609.79	4870.56	43622.95
1970-71	84151.52	92968.55	9453.62	6316.88	49258.28
1971-72	91921.16	101510.78	10628.46	6933.00	54970.46
1972-73	115015.38	130112.93	14272.75	8150.84	67262.94
1974-75	149921.00	141783.00	20294.00	14133.00	80632.00
1975-76	171824.00	168006.00	22441.00	18074.00	93627.00
1976-77	201745.00	194337.00	21773.00	20881.00	105326.00
1977-78	221678.00	218042.00	27842.00	19451.00	124411.00
1978-79	248000.00	244923.00	30188.00	21929.00	138923.00
1979-80	281992.00	265782.00	35699.00	28180.00	153029.00
1980-81	319663.00	298813.00	42270.00	34314.00	177479.00
1981-82	495520.00	375626.00	48601.00	45429.00	255309.00
1982-83	640757.00	465819.00	63417.00	66763.00	375037.00
1983-84	701162.00	537117.00	74431.00	76173.00	423777.00
1984-85	864863.00	615037.00	87126.00	80360.00	555430.00
1985-86	881665.00	698028.00	87116.00	84544.00	571054.00

The cost share equations for our three input model of labour, fuel and materials are as below :

$$\frac{\partial \log VC}{\partial \log p_L} = \alpha_L + \sum_{j=L}^{F,M} \alpha_{Lj} \log p_j + \beta_{QL} \log Q + \gamma_{KL} \log K + \delta_{TL} T \qquad (3.3.9)$$

$$\frac{\partial \log VC}{\partial \log p_F} = \alpha_F + \sum_{j=F}^{L,M} \alpha_{Fj} \log p_j + \beta_{QF} \log Q + \gamma_{KF} \log K + \delta_{TF} T \qquad (3.3.10)$$

$$\frac{\partial \log VC}{\partial \log p_M} = \alpha_M + \sum_{j=M}^{L,F} \alpha_{Mj} \log p_j + \beta_{QM} \log Q + \gamma_{KM} \log K + \delta_{TM} T \qquad (3.3.11)$$

To facilitate empirical estimation, an additive disturbance term is appended to each of the cost share and the variable cost equations. The disturbance term is assumed to be identically and independantly normally distributed with the assumption of zero mean and variance σ^2 i.e.,

$$E(u) = 0$$

and

$$E(u'u) = \sigma^2$$

Since the cost shares must sum to unity, implying that

$$\sum_i u_i = 0$$

one cost share equation must be dropped in order to avoid a singular and non-diagonal residual covariance matrix. We dropped the material cost share equation for this purpose. The variable cost equation along with the labour cost share and the fuel cost share equations form a multivariate regression model which has to be estimated jointly in order to take into account the simultaneity between the equations. The method for estimation is the Iterative Seemingly Unrelated Regression (SURE) technique by Zellner [1962] which uses iterative methods in order to achieve convergence. The estimates are asymptotically also Full Information Maximum Likelihood (FIML) estimates which are invariant to the equation dropped.

3.3.3 Results

Estimation subject to the symmetry and linear homogeneity in prices restrictions (Equations 3.3.2) was done through Zellner's technique and convergence was achieved after seven iterations. The variable $\log K \log Q$ had to be dropped since it induced multicollinearity. The estimated coefficients along with their standard errors are given in table 3.3.31. For a cost function to be well-behaved we require that it satisfy the properties of monotonicity and concavity i.e., the first order and second order conditions of neoclassical production theory. Since the translog does not satisfy these conditions globally we have to check for monotonicity and concavity at each observation. Monotonicity is assured if the estimated cost share equations are positive. We conclude that this is indeed so at all data points. For concavity the Hessian matrix of the estimates of the coefficients of the input prices should be negative semi-definite[12]. We find that this is satisfied at 75% of the observations.

[12]See Appendix A.3(3) for the concavity condition.

Table 3.3.31

Estimates of the Translog Cost function

Coefficient	Estimate	Coefficient	Estimate
α_0	245.05538	β_{QQ}	1.1664055
	(246.31144)		(1.0106206)
α_L	1.7690426*	β_{QL}	−0.0546784*
	(0.4605805)		(0.0212417)
α_F	-0.1140660	β_{QF}	0.0317026
	(0.6712411)		(0.0321360)
α_{LL}	-0.0147041	γ_K	4.5541001
	(0.0088302)		(4.4573618)
α_{LF}	−0.0342846*	γ_{KK}	-0.2810342
	(0.0106206)		(0.2637763)
α_{FF}	−0.0663470*	γ_{KL}	−0.0211804*
	(0.0237304)		(0.0073881)
β_Q	-24.881162	γ_{KF}	-0.0255942
	(22.269144)		(0.0316306)
δ_T	0.8981040	δ_{TT}	0.0011978
	(1.7690498)		(0.0069906)
δ_{TL}	0.0063414*	δ_{TF}	0.0055961
	(0.0019011)		(0.0027321)
δ_{TQ}	-0.0918273	δ_{TK}	0.0655482
	(0.0787193)		(0.324457)

Degrees of freedom 5

Figures in parenthesis refer to standard errors.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

The estimation was conducted using the Time Series Package (TSP) version 6.53.

Table 3.3.32

Statistical results for the variable cost equation :

R-squared	0.996810	Sum of squared residuals	0.096549
Adjusted R-squared	0.981657	Standard error of regresion	0.155362
Durbin-Watson statistic	1.8635754	F-statistic	65.78310

Table 3.3.33

Statistical results for the labour cost share equation :

R-squared	0.698539	Sum of squared residuals	0.001866
Adjusted R-squared	0.614800	Standard error of regresion	0.010183
Durbin-Watson statistic	1.765998	F-statistic	8.341849

Table 3.3.34

Statistical results for the fuel cost share cost equation :

R-squared	0.818386	Sum of squared residuals	0.004172
Adjusted R-squared	0.767938	Standard error of regresion	0.015225
Durbin-Watson statistic	1.527292	F-statistic	16.22231

3.3.4 Analysis

These estimates were then fitted into the equation $\frac{\partial \log VC}{\partial \log Q}$ to yield the marginal variable cost function, and the resulting values used in conjunction with the variable cost determines the equilibrium value of output which is the solution to the condition,

$$\frac{VC}{Q_s^2}\frac{\partial \log VC}{\partial \log Q} - \frac{VC}{Q_s^2} - \frac{p_K K}{Q_s^2} = 0$$

which is the 'value of potential output' at the minimum point of the $SRATC$ curve. The result had to be established iteratively since both Q and $\log Q$ appear in the equation[13].

The resulting figure for the year 1983-84 is 3.693463×10^{10} compared to the existing figure for the value of the output as 2.7069×10^{10}. This indicates that the aggregate industry, has indeed, been receiving a lower value of output

[13]See Appendix A.3 (2) for the iterative method.

evaluated at 1970-71 prices, than it could have achieved at the same prices, had it been operating on the minimum point of its short run average cost curve. This departure from the ideal production level could have been to several reasons, but we have already explained that we assume that the reason for industry not operating at this point is *only* due to the restriction of the electricity input.

The fact that the achieved level of value of output is much lower than the potential output should not be surprising considering the empirical evidence that industry is subject to continuous rationing throughout the year, (See Chapter 4 for the empirical references) and the Board sometimes departs from the stated rationing schedule to impose random rationing which can only cause further loss. Welfare loss is therefore positive, and it should be the task of the electricity supplier whose aim is to decide upon an optimal rationing scheme to devise a scheme that tries to minimise such welfare loss.

3.4 The model for agriculture

Though agriculture has certain features unlike industry, we assume that every agricultural producer is a profit-maximizer. Therefore he works through a neoclassical production function where the choice of inputs is determined by his cost minimizing behavior. We use a similar model as we have used in the case of industry, with only the inputs varying. The results are however vastly different. Assume the representative producer has a production function of the following form.

$$Q = f(F, E, L, A, T)$$

where output Q is produced through inputs fertilizer F, energy E and labour L, given the fixed factor of area A under cultivation. T is again a measure of technical progress. Then, given that the farmer or producer already has certain area under cultivation, the short run cost minimization with respect to the variable inputs is as follows:

$$\begin{aligned}\log VC = \alpha_0 &+ \sum_{i=1}^{n}\alpha_i \log p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_{ij}\log p_i \log p_j \\ &+ \beta_Q \log Q + \frac{1}{2}\beta_{QQ}(\log Q)^2 + \sum_{j=1}^{n}\beta_{Qj}\log Q \log p_j \\ &+ \gamma_A \log A + \frac{1}{2}\gamma_{AA}(\log A)^2 + \sum_{j=1}^{n}\gamma_{Aj}\log A \log p_j \\ &+ \gamma_{AQ}\log A \log Q + \delta_T T + \delta_{TT}T^2 \\ &+ \sum_{i=1}^{n}\delta_{Ti}T\log p_i + \delta_{TQ}T\log Q + \delta_{TA}T\log A \end{aligned} \qquad (3.4.12)$$

where again linear homogeneity in input prices imposes the following restrictions.

$$\begin{aligned} 1. \sum_{i=1}^{n}\alpha_i &= 1 \\ 2. \sum_{i=1}^{n}\alpha_{ij} &= \sum_{j=1}^{n}\alpha_{ij} = 0 \\ 3. \sum_{j=1}^{n}\beta_{Qj} &= 0 \\ 4. \sum_{j=1}^{n}\gamma_{Aj} &= 0 \\ 5. \sum_{j=1}^{n}\delta_{Tj} &= 0 \end{aligned} \qquad (3.4.13)$$

Total cost is defined as

$$TC = VC + p_A A \qquad (3.4.14)$$

where p_A is the cost of the land under cultivation. Similar to the case of the aggregate industry above, the condition for the 'potential output' is the following equation.

$$\frac{VC}{Q_a^2}\frac{\partial \log VC}{\partial \log Q} - \frac{VC}{Q_a^2} - \frac{p_A A}{Q_a^2} = 0 \qquad (3.4.15)$$

where Q_a is the potential output for agriculture. Again iterative methods must be adopted to arrive at the solution.

3.4.1 Data

Again, estimation subject to the symmetry and linear homogeneity conditions was done through Zellner's iterative three stage least squares method. But the data we use is now vastly different. Firstly, it is now no longer a timeseries data set. The data set is described in greater detail below.

The data with regard to the agricultural sector in U.P. though rich in various aspects, fails to, unfortunately, give any long timeseries data on the costs associated with production. Instead crop-wise and season-wise output data is available. But the inputs going into each type of crop would then be very difficult to gather. What we have done here is to divide the entire data matrix in terms of division-wise total agricultural production. For purposes of agricultural statistics, the Agricultural Ministry in U.P. divides the 52 districts of U.P into 12 divisions. Most data can be then obtained from the figures for the districts and consequently for the divisions. We believe that this may be a better method of undertaking the study, since it would, for comparison bring out the differences between the divisions. For, U.P. is a large state and is extremely polarised as far as agricultural development is concerned. Western U.P. is the more prosperous region and has a higher output, and a high electricity consumption because of the presence of tubewells for irrigation, operated by pumpsets which can be run on electricity or diesel. Eastern U.P. in comparison is agriculturally poor in all respects, due to outdated methods of farming and irrigation. An analysis of this kind will also help the supplier of electricity, in a more detailed study, to understand the difference in the electricity consumption between the developed western divisions and the poorer eastern and hill divisions.

However, even this district-wise data is not available on a long time-series basis. It has only been possible to get data for four years from 1981-82 to 1984-85 for all the inputs. We have therefore pooled the data, used a time-series on a cross-section, thereby obtaining 48 observations.

Of all the material inputs that go into the production of agricultural output, fertilizers form the highest percentage[14], with the other inputs like pesticides and seeds forming a small proportion. Since data is not easily accessible for the latter two, and since fertilizer price really is the deciding factor in the material cost we have taken only fertilizer cost in the material input cost. Fertilizers are actually composed of three components, nitrogen, phosphorus and potassium (N,P,K). The Fertilizer Statistics Bulletin published by the Fertilizer Association of India (FAI), gives the physical amount of fertilizer in metric tonnes, used by each division. Fertilizer cost is obtained by multiplying the fertilizer input in tonnes by the price (All India) per tonne also given by the Fertilizer Statistics Bulletin. However, the price of fertilizer used in the variable cost function, is the All-India price index of fertilizers which is a weighted average of the All-India consumption of nitrogen, phosphorous, and potassium (using division consumption figures as weights does not improve the results in any way).

Energy input consists of diesel and electricity input. Electricity input from the figures of UPSEB is available only as a state-wise figure for agricultural production and not district-wise. However, data is available on the number of tubewells owned by each division. Since we know that the Board does not discriminate among districts and divisions in the matter of electricity rationing[15], it is not wrong to assume that the division with the higher number of tubewells has a higher electricity and diesel consumption. Total electricity cost for the state is assumed to be the 'revenue assessed from agriculture' as given in the accounts of UPSEB[16]. Using the percentage of electric tubewells(private and

[14]The average percentage share during the period 1980 to 1985 was 85 % .

[15]This is borne out by the schedule on power cuts of UPSEB.

[16]Revenue assessed from agriculture is determined on the basis of the meter readings of electricity connections given by the Board. However, incidences of theft are reported which means that actual electricity consumption is higher, but that some power is not paid for. This means that some quantity of electricity has been obtained free of cost, and therefore the only quantity paid for is shown by the meter readings. The cost of electricity input is therefore the revenue assessed.

state) in the total number for each division as weights, and multiplying by the revenue assessed we obtain the electricity cost for each division for each of the four years.

Diesel input figures are again not available for each division. Since pumpsets are operated using high-speed diesel oil (HSDO) mainly, we shall consider the amount of HSDO consumed as the diesel input.The Bulletin of Petroleum and Natural Gas Statistics published by the Ministry of Petroleum, only gives the All-India figure of the percentage of HSDO. The share of U.P. is then calculated as a proportion of this figure, the proportion being the population of U.P. in the All-India population. The Bulletin also gives the share of HSDO sold to agriculture and plantation. Assuming the same proportion for the state, we calculate the amount of HSDO sold to U.P. agriculture. Diesel cost is then calculated by multiplying the above amount with the price of diesel oil per tonne which is also available from the Bulletin. The total diesel cost is then distributed among the divisions in the proportion of the number of diesel pumpsets. The price of energy input is then taken as a weighted average of the price indices of electricity and HSDO from WPI using the percentages of the above calculated electricity cost and diesel cost in total energy cost as the weights.

The Directorate of Economics and Statistics of the Ministry of Agriculture publishes annually the bulletin 'Agricultural Wages in India', which gives the state and division-wise price of labour per day, by the type of work (i.e., as weeder, sower, plougher, reaper etc). For our analysis, since we only need total labour cost, we make no distinction among these various types and only take the average wage per day. The price of labour is then computed by calculating the wage per day for the whole year for the different divisions[17]. The Statistical Abstract of U.P. gives the total agricultural labour per division according to the 1981 census. It also gives the growth rate in the population division-wise for

[17]Since agricultural output is seasonal, labour input is also correspondingly seasonal, and so is the wage per day. But to compute the seasonal wage for labour makes the model complicated, which we have avoided.

the ten-year period from 1971-1981. Taking the average growth rate per year, the number of people working as labour in agriculture is computed division-wise for the four years. Labour cost is then the price of labour multiplied by the number of persons employed on land. Variable cost is the total of fertilizer, energy and labour cost.

Though capital stock does exist in agricultural production, as in the form of land, buildings, tractors, ploughs, threshing machines, bullocks, etc, there are severe computational difficulties in measuring the capital stock and the cost of capital. For one, there is no recorded data on the value of any of these components of capital– the census of livestock only gives the number of bullocks, machines etc. Two, there is a problem of aggregating all these components and the appropriate weights to be used for this purpose[18]. We believe that the exclusion of other forms of capital (other than land) will do less harm than the inclusion of an incorrect measure of capital. So we shall assume that the fixed factor in the short-run is the area, given in hectares for each division, available from the Agricultural Statistics Abstracts published by the Directorate of Economic Statistics and Crop Insurance of the government of U.P. However, this includes irrigated as well as unirrigated area. But we have excluded the unirrigated area from our analysis because firstly, the two cannot be aggregated due to differences in the quality of land, and secondly, it is irrigated land that is concerned with energy input and higher labour force in the peak season and higher use of fertilizer to improve productivity. The fixed factor in the short run is therefore only the area under irrigation.

Agricultural output (also available from the Directorate of Economics and Statistics), measured in tonnes, comprises of the broad categories : cereals, pulses, edible oils, sugarcane and others measured in bales like cotton, jute

[18]Tara Shukla [1965] has studied capital formation in Indian agriculture – capital being land, buildings, irrigation, bullocks, machinery and implements. These components in numbers have been converted into value figures using farm level National Sample Survey (NSS) retail price data. But this is only possible for a survey level study. Using the same method for the level of aggregation needed for our model is grrossly inaccurate.

etc. However, in order to avoid any problems in aggregation and measurement, we again assume Q to be the value of agricultural output, instead of physical agricultural output. The value of agricultural output is computed as follows:

In order to compute production from only irrigated area, we multiplied the Gross Irrigated Area (GIA) by the yield of irrigated area which is in kilograms per hectare (and available in the Bulletin 'Agricultural Situation In India'). Unfortunately, this was available only for crops like rice, wheat, gram and barley. For these four crops the above method was used. For the other 14 crops[19] that we have considered, we multiplied the GIA for each division, for each crop, for each year by the State average yield of that crop for that year. In this way we obtained the production under irrigated land for the 18 crops for the 12 divisions for each of the four years. The Bulletin of Agricultural Prices in India gives the price per quintal of all the crops at different centres of the state (except for sugarcane price, which is available from the Bulletin of Commercial Crops Statistics). Taking the average price of all these centres, we computed the value of the above determined output from irrigated area. Again in order to remove any kind of price fluctuationary effects, we deflated the value of output for each division (aggregated over all crops), by the price index for agricultural output at 1970-71 prices. This deflator was computed by using the percentage of food and non-food crops for each year as weights (for a medium level representative division), and multiplying by the repective WPI price indices for food and non-food agricultural outputs (Chandhok 1990).

The cost share equations for the three input model of labour, fertilizer and energy are as below :

$$\frac{\partial \log VC}{\partial \log p_L} = \alpha_L + \sum_{j=L}^{F,E} \alpha_{Lj} \log p_j + \beta_{QL} \log Q + \gamma_{KL} \log K \qquad (3.4.16)$$

$$\frac{\partial \log VC}{\partial \log p_F} = \alpha_F + \sum_{j=F}^{L,E} \alpha_{Fj} \log p_j + \beta_{QF} \log Q + \gamma_{AF} \log A \qquad (3.4.17)$$

[19]These are: jowar bajra, maize, arhar, urad, moong, masur, sugarcane, groundnut, potato, sesame, mustard, cotton and tobacco.

$$\frac{\partial \log VC}{\partial \log p_E} = \alpha_E + \sum_{j=E}^{L,F} \alpha_{Ej} \log p_j + \beta_{QE} \log Q + \gamma_{AE} \log A \tag{3.4.18}$$

3.4.2 Estimation and Results

Estimation subject to the linear homogeneity in prices (equations 3.4.13) and symmetry conditions was again done by Zellner's I3LS method. The variable T had to be dropped as none of the parameters associated with it were significant. Since this is a pooled data estimation, we have to test for crossectional heteroscedasticity and timeseries autocorrelation. The data did not exhibit any serial correlation. However, the Lagrangean multiplier test revealed heteroscedasticity.(See Appendix A.3(5) for the formal condition of the Lagrange multiplier test.). This is not surprising considering the fact which has been mentioned before, that there are vast variations in all respects between the divisions, especially the hill divisions have markedly lower figures for all the inputs and outputs. This problem could have been alleviated to some extent if the time series were long enough, but we only have an extremely wide and short data set.

The model was reestimated now using a transformed data set to remove the effects of variation between divisions. The fixed effects model was then used. All the figures within each division were now calculated as deviations from the mean values. The intercept had quite obviously to be dropped. Estimation subject to all the restrictions was performed using the SURE technique. Convergence was achieved after 5 iterations. The variable cost equation and the fertilizer cost share equations yielded estimates that were more significant now. All the statistical results for these two equations showed marked improvement, thereby pointing out that the fixed effects model was the more appropriate one for the analysis. Besides an F-test of the ratio of the standard errors of both the estimations was significant. A comparison of the statistical results is given in Tables 3.4.21, 3.4.22, 3.4.23. The estimated cost shares were all positive thereby satisfying the first order conditions. The estimates along with their standard errors are given in Table 3.4.24.

Table 3.4.21

Results for the Variable Cost equation

Results	Fixed Effects SURE Model	SURE model
R-squared	0.945851	0.874686
Adjusted R-squared	0.925147	0.821522
Standard error of regression	0.050888	0.411620
Durbin-Watson statistic	2.473494	0.606718
F-statistic	45.68470	16.45271
Sum of squared residuals	0.088048	5.591214

Table 3.4.22

Results for the fertilizer share equation

Results	Fixed Effects SURE Model	SURE model
R-squared	0.761361	0.101124
Adjusted R-squared	0.739162	0.017508
Standard error of regression	0.018161	0.082725
Durbin-Watson statistic	2.750376	1.031622
F-statistic	34.29708	1.209384
Sum of squared residuals	0.014339	0.294268

Table 3.4.23

Results for the energy share equation

Results	Fixed Effects SURE Model	SURE model
R-squared	0.235456	0.370148
Adjusted R-squared	0.164335	0.311558
Standard error of regression	0.008794	0.016706
Durbin-Watson statistic	1.353849	1.142694
F-statistic	3.310662	6.317514
Sum of squared residuals	0.03325	0.012002

Table 3.4.24

Estimates of the Translog Cost function

Coefficient	Estimate	Coefficient	Estimate
α_F	-.0014298	β_{QQ}	0.2448849**
	(.0019945)		(0.0756839)
α_E	0.0001103	β_{QF}	-0.0006135
	(0.0011959)		(0.00073066)
α_{FF}	0.1395212**	β_{QE}	0.0007496
	(0.0131462)		(0.0035440)
α_{FE}	0.0014020	γ_A	-1.3857596
	(0.0073159)		(3.1282832)
α_{EE}	0.0190480*	γ_{AA}	0.5161257
	(0.0072477)		(0.2694477)
β_Q	0.9770479*	γ_{AF}	0.0302386**
	(0.4187944)		(0.0093901)
γ_{AE}	0.0155739**	γ_{AQ}	−0.3366149**
	(0.0054793)		(0.1050962)

Degrees of freedom 34

Figures in parenthesis refer to standard errors.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

Estimation was done using the Time Series Package (TSP) version 6.53.

3.4.3 Analysis

To compute the 'potential output from irrigated area', we have to use a similar method as for the industry. The condition now is

$$\frac{VC}{Q_a^2}\frac{\partial \log VC}{\partial \log Q} - \frac{VC}{Q_a^2} - \frac{p_A A}{Q_a^2} = 0$$

where Q_a is the potential output in agriculture. $p_A A$ is the cost of the fixed factor in the short run. Ideally we should be using p_A as the rental value of irrigated area. But this information is not in published form and is diffcult to process from the raw data available with the Ministry of Agriculture. We have therefore used the value of irrigated area as the proxy. This is also available from the Ministry of Agriculture and collected from various *tehsils* of the districts of U.P.[20] It refers to the market value of the concerned irrigated area in each *tehsil*. This we were able to obtain only for the year 1984-85. From this information, as a first step, the figures for the *tehsils* were appropriately aggregated to conform to the twelve divisions of the data set. The irrigated area for a division was calculated as a weighted average of the irrigated area of each *tehsil*, and correspondingly the value of irrigated area was calculated. The value per hectare of irrigated area for each division was determined[21]. The difference in the ratio of net state domestic product at current and constant(1970-71 = 100) prices between 1984-85 and 1983-84 is 18 %. Assuming that this increase in state income *devoid of any price effects* will represent the increase in the value of an asset like land, we then assume that the value of irrigated area in 1984-85 deflated by the same index i.e., ratio of the net state domestic product at current and constant (1970-71) prices is 18 % higher than that in 1983-84. By this method we have calculated the value of irrigated area for each of the twelve divisions for the year 1983-84.

A similar exercise to the one for aggregate industry was carried out to find the 'potential output from irrigated area' for agriculture for the year 1983-84. The iterative method was employed again, this time twelve times in order to get potential output for twelve divisions.

The figures for potential output and observed output are given in Table 3.4.3.

---

[20] Comprehensive List of the Cost of Cultivation Data, Ministry of Agriculture.

[21] The List unfortunately omits figures for some *tehsils* and so the figures have a slight unavoidable margin of error.

Table 3.4.3

Agricultural Output: Observed & Potential

Division	Observed	Potential
Meerut	2.42×10^7	2.83×10^7
Agra	8.64×10^6	8.94×10^6
Bareilly	5.81×10^6	6.13×10^6
Allahabad	1.08×10^7	1.27×10^7
Varanasi	1.00×10^7	1.22×10^7
Gorakhpur	6.65×10^5	6.82×10^5
Lucknow	6.09×10^6	6.37×10^6
Faizabad	5.80×10^6	6.09×10^6
Moradabad	6.03×10^6	6.39×10^6
Jhansi	6.39×10^6	6.69×10^6
Kumaun	1.19×10^6	1.38×10^6
Garhwal	1.59×10^5	1.99×10^5

Though the potential output for each year is higher than the achieved level of output, notice that there is no set pattern to distinguish between the divisions. For instance one would expect that the more prosperous divisions would not lose much due to the rationing since diesel pumpsets are largely prevalent. But Kumaun, a poor hill district and Moradabad and Gorakhpur, which are also less developed, seem to have done better than Meerut. The loss in Garhwal, the poorest region of the state is however, considerable. This is to be expected since the only irrigation schemes are by the government through state tubewells and tanks.

3.5 The model for household

The economic loss for household as specified in the model was the difference between the minimum expenditure to reach a utility level u when demands are rationed and when they are not. To recall, Loss L was

$$L = \bar{c}(p_e^*, \tilde{p}, \overline{u}) \; - \; c^*(\tilde{p}, \tilde{x}_e, \overline{u})$$

We then defined $\psi(\tilde{p}, \tilde{x}_e, \overline{u}) \;=\; p_e^*$ as the solution to the Hicksian demand function $\tilde{x}_e$ when the consumer was induced by some 'virtual prices' to demand exactly the level of the good that was rationed. The virtual prices are p_e^*. Then the economic loss could be rewritten as :

$$L \;=\; (p_e^* - p_e)\tilde{x}_e$$

Given p_e and $\tilde{x}_e$, what is needed is only a specification for p_e^*. Recall that the unrationed cost function when the consumer is not subject to any rationing is :

$$\bar{c}(\tilde{p}, p_e, \overline{u}) = \text{Min}_{x_e,x} \quad (p_e x_e + \tilde{p}\tilde{x})$$

The rationed cost function when x_e is restricted to $\tilde{x}_e$ is then:

$$c^*(\tilde{p}, x_e, \overline{u}) = \text{Min}_x \quad (p_e\tilde{x}_e + \tilde{p}\tilde{x})$$

Since only x_e is restricted the relation between the two is :

$$\bar{c}(\tilde{p}, p_e, \overline{u}) = \text{Min}_{\tilde{x}_e} \quad c^*(\tilde{p}, \tilde{x}_e, \overline{u})$$

where $c^*(\tilde{p}, \tilde{x}_e, \overline{u}) = p_e\tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \overline{u})$. At some p_e^*, the unrationed cost function at the consumption level $\tilde{x}_e$ is :

$$\bar{c}(p_e^*, \tilde{p}, \overline{u}) = p_e^*\tilde{x}_e + \phi(\tilde{p}, \tilde{x}_e, \overline{u})$$

Minimizing with respect to $\tilde{x}_e$ will yield,

$$\frac{\partial\bar{c}(\tilde{p}, p_e^*, \overline{u})}{\partial\tilde{x}_e} = p_e^* + \frac{\partial\phi(\tilde{p}, \tilde{x}_e, \overline{u})}{\partial\tilde{x}_e}$$

or

$$p_e^* = -\frac{\partial\phi(\tilde{p}, \tilde{x}_e, \overline{u})}{\partial\tilde{x}_e}$$

by the first order conditions. In order to determine p_e^* all that is needed is the derivative of $\phi(\tilde{p}, \tilde{x}_e, \overline{u})$ with respect to $\tilde{x}_e$. To do this we first need a functional form for $\phi(\tilde{p}, \tilde{x}_e, \overline{u})$.

Since $\phi(\tilde{p}, \tilde{x}_e, \overline{u})$ is part of the cost function $\overline{c}(p_e^*, \tilde{p}, \overline{u})$ it should possess the same properties as the cost function viz, linearly homogenous in prices $\tilde{p}$, decreasing in $\tilde{x}_e$, and convex in $\tilde{x}_e$. The convexity property follows from the convexity of preferences, namely that if $\tilde{x}^1$ and $\tilde{x}^2$ were two preferred combinations of the other goods given prices $\tilde{p}$ and ration levels $\tilde{x}_e^1$ and $\tilde{x}_e^2$, then a linear combination of both will also be preferable. Formally, i.e.,

$$u(\tilde{x}^1, \tilde{x}_e^1) = u(\tilde{x}^2, \tilde{x}_e^2) = \overline{u}$$

since utility is the same and both sets are the cost minimizing bundles.
Since the utility function is assumed to be quasi-concave, for any $0 \leq \lambda \leq 1$,

$$u(\lambda\tilde{x}^1 + (1-\lambda)\tilde{x}^2, \lambda\tilde{x}_e^1 + (1-\lambda)\tilde{x}_e^2) \geq \overline{u}$$

But $\lambda\tilde{x}^1 + (1-\lambda)\tilde{x}^2$ is not neccessarily obtained at minimum cost, i.e.,

$$\phi(\tilde{p}, \lambda\tilde{x}^1 + (1-\lambda)\tilde{x}^2), \overline{u}) \leq \lambda\phi(\tilde{p}, x_e^1, \overline{u}) + (1-\lambda)\phi(\tilde{p}, x_e^2, \overline{u})$$

which shows the convexity of the function $\phi(\tilde{p}, \tilde{x}_e, \overline{u})$.

Deaton and Muellbauer [1980] provided a flexible functional form for an unrestricted cost function which led to the Almost Ideal Demand System (AIDS). Deaton [1981] used an analogous model allowing for a single rationed quantity. We tried using the same approach. This consists of specifying a flexible functional form for a cost function restricted in only one of its quantities, as follows:

$$\begin{aligned} \log\phi(\tilde{p}, \tilde{x}_e, \overline{u}) = \alpha_0 &+ \sum_{k=1}^{n}(\alpha_k + \eta_k\tilde{x}_e)\log p_k \\ &+ \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n}\gamma_{kj}\log p_k \log p_j \\ &+ \beta_0\Pi p_k^{\beta_k}[\overline{u} + \theta_0 x_e + \frac{1}{2}\theta_1\tilde{x}_e{}^2 + \frac{1}{2}\theta_2\overline{u}\tilde{x}_e] \quad (3.5.19) \end{aligned}$$

The demand functions can be obtained from minimizing with respect to the prices:

$$w_i = \frac{\partial \log\phi(.)}{\partial \log p_i}$$

$$w_i = \alpha_i + \eta_i \tilde{x}_e + \sum_{j=1}^{n} \gamma_{ij} \log p_j + \beta_i \log[\frac{M - p_e \tilde{x}_e}{P}] \quad (3.5.20)$$

where M is the total expenditure of the consumer, and

$$\log P = \alpha_0 + \sum_{k=1}^{n} [\alpha_k + \eta_k \tilde{x}_e] \log p_k + \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} \gamma_{kj} \log p_k \log p_j \quad (3.5.21)$$

with the following restrictions imposed: $\gamma_{ij} = \gamma_{ji}$, $\sum_i \alpha_i = 1$,
$\sum_i \eta_i = 0$, $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$.
and $\sum_i \beta_i = 0$.
which are the symmetry, adding-up and homogeneity conditions.

p_e^* is then derived from the following condition:

$$-\frac{\partial \phi(\tilde{p}, \tilde{x}_e, \overline{u})}{\partial \tilde{x}_e} = p_e^* \quad (3.5.22)$$

Although a flexible functional form might be empirically appealing, the limited price variation in crossection data often causes the form to violate the regularity conditions of utility theory [22]. While we found that the estimated budget share equations satisfied monotonicity, unfortunately the concavity conditions were violated. Since the virtual price is meaningfully defined only for cost functions that are concave in prices, this functional approach would lead to serious problems and misrepresent the true cost function.[23]

The above method had then to be abandoned in favour of the Linear Expenditure System (LES), formulated by Stone [1954] which is more restrictive than the AIDS form in terms of the conditions on the parameters, but which violates concavity on fewer observations. The LES is derived from the following cost function:

$$c(p, U) = \sum_{i=1}^{n} p_i \gamma_i + \prod_{k=1}^{n} p_k^{\beta_k} U \quad (3.5.23)$$

[22]The regularity conditions of utility theory are : positive Hicksian demands, symmetry & negative semidefiniteness of the substitution matrix and negatively sloping Hicksian demand functions.

[23]See Ranjan Ray [1989] for a similar discussion.

with $\sum_k \beta_k = 1$.
Using Shepherd's lemma to obtain the derived demand functions, we have :

$$\frac{\partial c}{\partial p_i} = \gamma_i + \beta_i p_i^{\beta_i - 1} \prod p_{k-1}^{\beta_k - 1} U = x_i \tag{3.5.24}$$

Substituting for U from (3.5.23), and simplifying by letting c(p,U) stand for 'M' the total expenditure, yields the following LES demand equations.

$$p_i x_i = p_i \gamma_i + \beta_i (M - \sum p_j \gamma_j) \quad i = 1, \cdots n-1. \tag{3.5.25}$$

$$p_e x_e = p_e \gamma_0 + \beta_0 (M - \sum p_j \gamma_j - p_e \gamma_0) \tag{3.5.26}$$

When x_e is restricted to $\tilde{x}_e$, the constrained demand functions for the unrationed commodities $\tilde{x}$ are:[24]

$$\tilde{p}_i \tilde{x}_i = \tilde{p}_i \gamma_i + \beta_i [M + (p_e^* - p_e)\tilde{x}_e - \sum \tilde{p}_j \gamma_j - p_e^* \gamma_0] \quad i = 1, \cdots n-1. \tag{3.5.27}$$

The virtual price of the rationed good is computed from (3.5.26) and (3.5.27) as:

$$p_e^* = \frac{\beta_0}{(1-\beta_0)(\tilde{x}_e - \gamma_0)} (M - \sum \tilde{p}_j \gamma_j - p_e \tilde{x}_e) \tag{3.5.28}$$

Substituting this value yields the rationed demand for $\tilde{x}$ which depend only on the observable quantities :

$$\tilde{p}_i \tilde{x}_i = \tilde{p}_i \gamma_i + \frac{\beta_i}{1-\beta_0} (M - \sum \tilde{p}_j \gamma_j - p_e \tilde{x}_e) \quad i = 1, \cdots n-1. \tag{3.5.29}$$

3.5.1 Data and Estimation

The data on household consumption state-wise is available from the National Sample Survey(NSS) reports compiled by the Central Statistical Organisation. The NSS reports on consumer expenditure firstly construct expenditure classes, based on the per capita monthly expenditure. Then expenditure on seven broad items is displayed, based on the sample survey of households, separately for the rural and urban sectors. The seven items are: food, pan & tobacco, fuel & light,

[24] See Neary and Roberts [1980]

clothing, footwear, miscellaneous goods and durable goods. We are concerned only with the rationing of one item, i.e., electricity. Therefore by clubbing the expenditure of all the relevant items, for our analysis here we consider only four composite items namely, all food, electricity (the rationed good), other fuel and other non-food. The main reason for doing so is to reduce the number of parameters to be estimated in the absence of a long data series.

Though similar data is available for both rural and urban sectors, we confine the analysis to only the urban sector. This has been done with a view to avoid problems of aggregation which might arise in the main rationing model. In any case, the share of rural consumption of electricity is quite low for the period that we are considering, (only 2.02 % of the households surveyed used electricity for heating, cooking or lighting, according to a 1983 survey by the National Sample Survey Organisation) therefore excluding the rural sector will produce no drastic change in the results of the model.

NSS data however, do not give any breakup of fuel components. According to the 38^{th} round of NSS, which compiled 'Tables with notes on consumption of fuel and light on the basis of the results of the first three Quinquennial rounds' the proportion of electricity expenditure in fuel expenditure was 14.8 % in the 28^{th}(1973-74) and 32^{nd}(1977-78) rounds and 15.2 % in the 38^{th}(1983). Using these percentages, we have accordingly calculated the expenditure on electricity from the total expenditure on fuel for the 32^{nd} and 38^{th} round. Consumer expenditure series is also available for the 42^{nd} round. Though there is no such available proportion for this round we assume that the percentage of electricity in total fuel consumption remains the same 15.2 % for the 42^{nd} round too. The level of $\bar{x}_e$ which is the ration level is then constructed as : The expenditure on electricity divided by the price per unit of electricity, which is available from the Bulletin on Average Tariffs and Duties published by the Central Electricity Authority. The price per unit of electricity is actually charged according to the load used by consumers. The revenue collected for electricity consumption is actually based on a kind of two part tariff. The consumer first indicates to the substation the approximate units of load he is likely to draw for a month and the fixed monthly payment is calculated on the basis of this. The variable part of the tariff rates are in different categories according to the load used by the consumer. This is described in the following table.

Table 3.5.21

Average Electricity Rates to Consumer Categories at paise per kwhr for 1983

Consumer Category	Price per Unit
Domestic Lights and Fans	
(a) 10 kwh per month	122
(b) 30 kwh per month	57
Domestic Heat and Small Power	
(a) 50 kwh per month	57
(b) 100 kwh per month	57
Combined Domestic Load	
(a) 60 kwh per month	57
(b) 130 kwh per month	57
Commercial Lights and Fans	
(a) 50 kwh per month	142
(b) 200 kwh per month	87
Commercial Heat and Small Power	
(a) 100 kwh per month	87
(b) 400 kwh per month	87
Combined Commercial Load	
(a) 150 kwh per month	87
(b) 60 kwh per month	87

But we have no means of distinguishing the different consumer types according to the load they draw. For our analysis we shall just take the price per unit as an average over all the domestic consumer categories, and treat this as the price of electricity. Note that the level of the price is not important. What is really needed is that the price per unit is fixed. $\tilde{x}_e$ will therefore be looked upon as units of electricity.

We have used the price indices constructed by Minhas, Jain, Kansal and Saluja [1989], for different goods for the whole urban sector for each state. Price indices for food and other non-food are available straightaway. From the price index for fuel and light the weight of electricity has been removed to get a price index for other fuel. The price index for electricity (used only for estimating the LES demand equations) is taken from WPI[25](Chandhok 1990). $p_e\tilde{x}_e$ (used for estimating the equations of the RLES) is just the expenditure on electricity that we have calculated as a percentage of total fuel expenditure.

The data matrix therfore consists of observations for only the urban sector. The data consists of 10 per capita monthly expenditure classes, for three years, 1977-78, 1983, 1986-87. To make the classes of different years compatible with each other, we have accordingly clubbed a few classes at both ends. The expenditure classes start from 0-30 and go on to 150 & above.

Estimation was done for both the unrationed (LES) and the rationed (RLES) demand models. The concavity conditions were checked at each observation and were found to hold. The method of estimation was the Zellner's Iterative SURE method for the system of the budget share equations, with one equation dropped to avoid a singular variance-covariance matrix. The two equations estimated were the shares for 'otherfuel' and 'food'. Since we are dealing essentially with crosssection data the Lagrange multiplier test was conducted to detect any heteroscedascity. However, the test rejected the hypothesis of unequal variances across the crosssection units. Since the data has been collected for three time periods with a gap of four to five years between

[25]This is ofcourse the All India weighted average price index, but is still a better estimate than constructing one for U.P. where the weights are not known.

each period, there remains the question of whether one can assume a common slope and intercept for all the periods. To circumvent this problem, we introduced dummy variables for both the slope and intercept terms[26]. The slope dummy was not significant and had to be dropped. The intercept dummies were however significant.

3.5.2 Results

The estimates of the LES and the RLES along with their T-statistics are presented in Table 3.5.22. The $\overline{R}^2$ for 'all food' and 'other non-food' equations in the LES are 0.953770 and 0.959843 respectively. The $\overline{R}^2$ for the corresponding equations in the RLES are 0.954939 and 0.959204 respectively. Though the explanatory power of the 'other nonfood' equation has reduced marginally from LES, that of the 'food' equation has improved to a greater extent. The F-statistic stands at : 140.2599 and 162.3384 in the LES and 127.96555 and 191.7302 in the RLES. The overall gain in the RLES system is higher. On the basis of these, it is possible to accept the hypothesis of rationing, i.e., that the rationed model is better explained than the unrationed one. For RLES, the β_i actually refer to $(\beta_{of}/1 - \beta_0)$ and $(\beta_f/1 - \beta_0)$. This simplification had to be introduced in lieu of the complication presented by the non-linearity.
δ_1 and δ_2 are the time dummies for the intercept and δ_3, δ_4 are the time dummies for the slope, both used in the equation for 'food'. The subscripts denote the following: of - other fuel; fo - food; onf - other nonfood ;

[26]The dummy variables are used only in one equation. Using them in all the equations would lead to a simultaneity bias.

Table 3.5.22

Estimates of LES and RLES

Coefficient	LES	RLES
γ_{of}	0.0079498*	-0.0002258
	(2.4544265)	(-0.0278540)
γ_{fo}	0.0199753	-0.0743513
	(0.3987555)	(-0.6907032)
γ_{onf}	−0.1401093*	-0.2635677
	(-2.2087943)	(-1.9943351)
γ_e	-0.0016399	-
	(-0.5648996)	
β_{of}	0.0350107**	-
	(14.192536)	
β_{fo}	0.4288320**	0.4253735**
	(28.739789)	(25.959210)
β_{onf}	0.5264871**	0.5350846**
	(30.693751)	(28.899637)
δ_1	-	0.00051930**
		(3.1347992)
δ_2	-	0.0009154
		(0.5510760)

Degrees of freedom: LES - 23 ; RLES - 23 .

Figures in parenthesis refer to T-statistics.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

Estimation was done using the Time Series Package (TSP) version 6.53.

Table 3.5.23

Results for 'other nonfood' budget share equation

R-squared	0.966759	Sum of squared residuals	2227.948
Adjusted R-squared	0.959204	Standard error of regression	10.06332
Durbin-Watson statistic	1.483911	F-statistic	127.9655

Table 3.5.24

Results for 'food' budget share equation

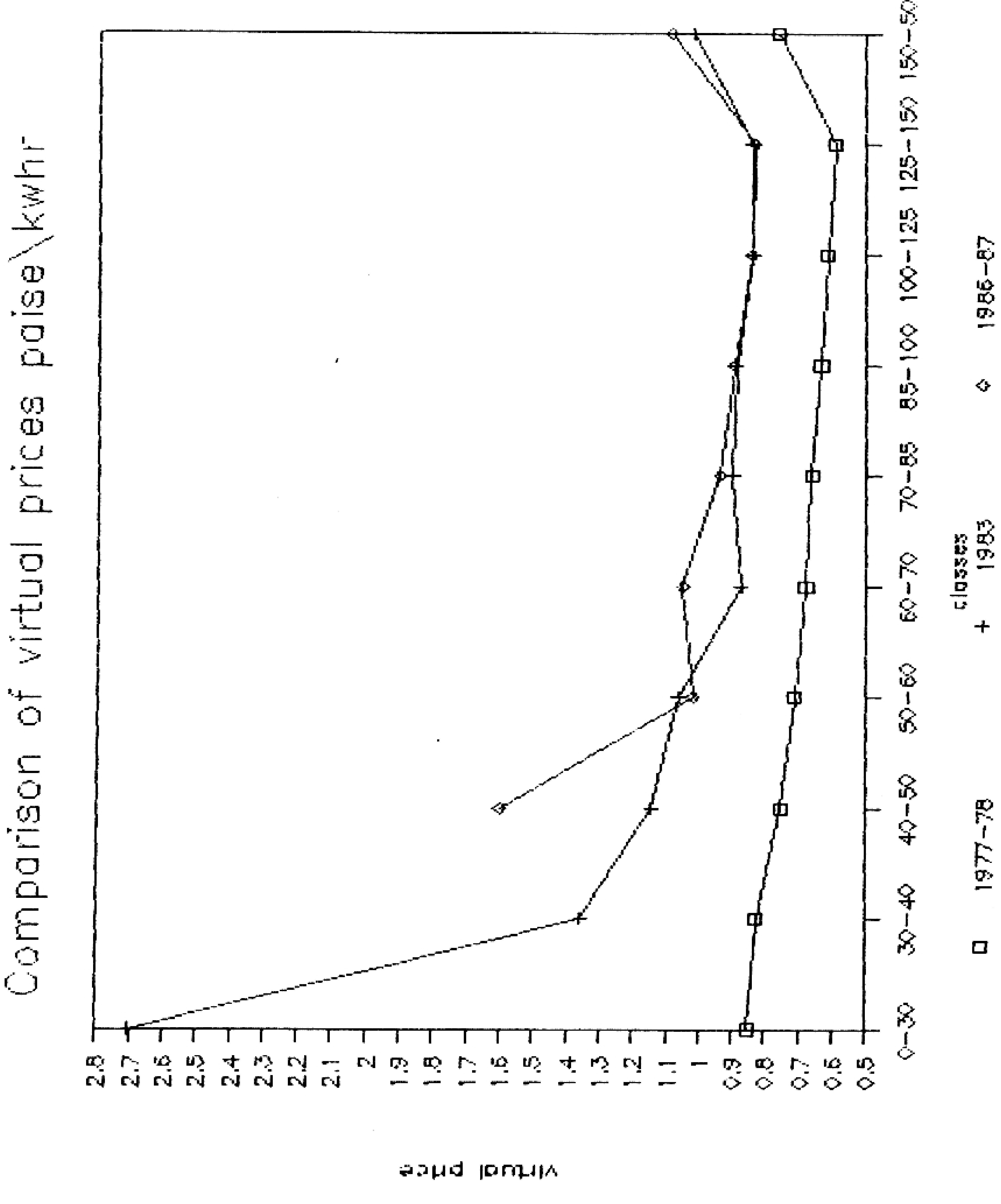
R-squared	0.959946	Sum of squared residuals	1747.968
Adjusted R-squared	0.954939	Standard error of regression	8.534167
Durbin-Watson statistic	1.539338	F-statistic	191.7302

Table 3.5.25

Determined virtual prices

	1977-78		1983		1986-87	
classes	p_e^*	x_e	p_e^*	x_e	p_e^*	x_e
0 - 30	0.854103	0.928	2.708683	0.405	-	-
30 - 40	0.828054	1.127	1.358662	0.927	-	-
40 - 50	0.757834	1.353	1.148706	1.602	1.602198	1.002
50 - 60	0.715225	1.567	1.070441	1.346	1.024535	1.675
60 - 70	0.683859	1.777	0.880038	1.747	1.058623	1.704
70 - 85	0.668970	1.963	0.909846	1.812	0.945864	2.019
85 - 100	0.638564	2.274	0.896277	2.012	0.903336	2.291
100 - 125	0.616935	2.839	0.847244	2.453	0.851027	2.792
125 - 150	0.597782	3.756	0.853047	2.998	0.842532	3.379
150-above	0.770915	4.755	1.028768	4.112	1.098673	4.210

1977-78, $p_e = 0.43$; 1983-84, $p_e = 0.6783$; 1986-87, $p_e = 0.6983$


Comparison of virtual prices paise\kwhr
virtual price
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0-30
30-40
40-50
50-60
60-70
70-85
85-100
100-125
125-150
150-500
classes
1977-78
1983
1986-87

3.5.3 Evaluation and Analysis

Given the estimates of the coefficients, p_e^* is determined by :

$$p_e^* = \frac{\beta_e}{(1-\beta_e)(\tilde{x}_e - \gamma_e)}(M - \sum \tilde{p}_j \gamma_j - p_e \tilde{x}_e)$$

(Note that β_e refers to β_0, the coefficient of the rationed good). From Table 3.5.25 it is clear that at all points, the determined p_e^* is higher than the actual p_e, thereby confirming the presence of rationing for these observations. Notice that, p_e^* levels are higher in each successive round, which can be explained both by the higher $\bar{p}$ and the higher p_e, as also the fact that demand has risen in greater proportion than the supply over the rounds. We also note that p_e^* falls across almost all the classes in the first and third rounds of the data set, and suddenly rises in only the last class of percapita monthly expenditure of Rs. 150 & above. The reason for the fall in p_e^* is not clear, but we can only conjecture that lower per capita expenditure classes live in urban parts that are not properly serviced by the Electricity Board in the matter of supply. It is also true that priority in supply is given to those urban areas which have a higher per capita income/expenditure. The figure for the last expenditure class is surprising and seems inordinately high but it must be kept in mind that this class includes all those families whose per capita expenditure is more than Rs. 150 and therefore this figure is not a precise one, but only an average, and due to this problem in measurement, is bound to show some peculiarity. For the year 1983, the virtual price falls till the middle of the sample, rises marginally, and falls again only to rise again to a high figure for the last class.

On immediate observation from the table, it seems that if the difference between the virtual price and the actual price is very high for certain classes, then x_e must be much lower than the desired level. But this we shall only know when we work out the desired level of electricity consumption which equates the actual and the virtual price.

As explained before, we shall only be considering the results of the 38^{th} round for our rationing model as the year 1983-84 is the most recent one compatible with the estimates of the models of industry, agriculture and household.

However, while the estimates for industry and agriculture refer to the financial years 1983-84 i.e., April 1, 1983 – March 31, 1984, the data for household consumption was collected only from January 1983 to December 1984. Since we could not obtain better data which was exactly compatible, we shall use January 1983 – December 1983 as a proxy for the calender year 1983-84. This discrepancy could not be avoided unfortunately.

So, for the year 1983 we find that all the household percapita expenditure classes have shown presence of rationing of electricity demand. It is apparent that the electricity supplier has to be concerned with all these classes for the purposes of electricity rationing, when the supply as well as price is fixed.

3.6 Summary

The chapter concludes with the first round of results for the main rationing model. In this chapter, we have first presented the theoretical derivation of the rationing model and then shown how the welfare loss can be measured for each of the consumer types, by assuming appropriate utility functions for each type subject to some restrictions on the parameters. The welfare loss to industry and agriculture was defined as the loss in the value of output for each of the sectors when each was rationed, and the loss to household was defined as the difference between the virtual price and the actual price when electriciy was rationed. The findings so far have been that, given the assumptions of the model, all types of consumers, that is, industry, agriculture and household have suffered substantial losses due to the rationing of electricity. Welfare or economic loss is therefore positive, and convex in the level of the restriction. We have thus determined the first part of the objective function. Armed with this information, the electricity supplier (Board) will now proceed to the second stage to perform a minimization of this welfare loss in order to determine the efficient rationing mechanism. So the next step is to incorporate the constraints of the supplier and fit these equations into the programming model. This will be taken up in the next chapter.

Appendix A.3

(1) Existence of a translog variable cost function

Theorem : Given an arbitrary variable cost function vc^* which satisfies the conditions of monotonicity, linearly homogeneous in prices, concavity and, is in addition twice continuously differentiable at $p^* \gg 0_N$ (0_N being the N vector), where $vc_i^* = \frac{\partial vc^*(p^*)}{\partial p_i}$, for all i and $vc_{ij}^* = \frac{\partial^2 vc^*(p^*)}{\partial p_i \partial p_j}$ for all i, j, then there exists a translog variable cost function $vc(p)$ defined by equation (3.3.1) which provides a second order approximation to vc^* at the point $p^* = (p_1^*, p_2^*, \cdots, p_N^*)$.

Proof: The proof is analogous to Diewert [1974].
Since vc^* is positive homogeneous of degree one in p, by Euler's theorem on homogeneous functions (which states that if $y = g(x_1, \cdots, x_n)$ then $\frac{\partial g}{\partial x_1} x_1 + \cdots + \frac{\partial g}{\partial x_n} x_n = 1 \times y$), we have,

$$vc^*(p^*) = \sum_{i=1}^{N} p_i^* \frac{\partial vc^*}{\partial p_i}$$

. Since vc^* is assumed to be twice continuously differentiable at p^*, Young's theorem implies $vc_{ij}^* = vc_{ji}^*$.
Now, $\frac{\partial vc^*}{\partial p_i}$ is homogeneous of degree 0 in p (again by Euler's theorem). So we have,

$$p_1 \frac{\partial vc^*}{\partial p_i \partial p_j} + \cdots + p_N \frac{\partial vc^*}{\partial p_i \partial p_N} = 0$$

or

$$\sum_{j=1}^{N} p_j vc_{ij}^* = 0$$

for

$$i = 1, 2, \cdots, N$$

. Thus $vc^*(p^*)$, the vc_{ji}^* $\; for \;$ $1 \le i \le j \le N$ are all determined by the N first order partial derivatives $\frac{\partial vc(p^*)}{\partial p_i} = vc_i^*$, $\quad i = 1, 2, \cdots, N$ and the $N(N-1)/2$ second order partial derivatives vc_{ij}^* $\; 1 \le i \le j \le N$.

Now consider vc defined by (3.3.1). Partially differentiating $vc(p)$ with respect to p_i at the pont p^* and setting it equal to vc_i^*, $i = 1, 2, \cdots, N$, we obtain the following system of equations :

$$\begin{aligned} vc_i^* = \frac{\alpha_i}{p_i^*} \quad &+ \quad \frac{1}{2}\sum_{j=1}^{N} \alpha_{ij}\frac{\log(p_j)}{p_i^*} + \beta_{Qi}\frac{\log(Q)}{p_i^*} \\ &+ \quad \gamma_{Ki}\frac{\log(K)}{p_i^*} + \delta_{Ti}\frac{T}{p_i^*} \end{aligned}$$

$$\text{for } i = 1, 2, \cdots, N \qquad (3.6.30)$$

Now differentiating $\frac{\partial vc(p^*)}{\partial p_i}$ with respect to p_j for $j > i$, and setting the resulting partial derivative equal to vc_{ij}^*, we obtain the following system of equations.

$$\frac{1}{2}\frac{\alpha_{ij}}{p_i^* p_j^*} = vc_{ij}^* \ \text{ for } \ 1 \leq i < j \leq N \qquad (3.6.31)$$

Parameters α_{ij} for $1 \leq i < j \leq N$ can be determined from (49) and α_{ii} can be determined from the i^{th} equation of (50) for $i = 1, 2, \cdots, N$. Thus at $p^* \gg 0_N, vc(p^* = vc^*(p^*)$ and the first and second order derivatives of vc and vc^* will coincide.

(2) Shephard's [1953] lemma

If the cost function is concave, continuous, linearly homogeneous in input prices, and differentiable with repect to input prices at $p^* \gg 0$, then

$$y\frac{\partial c(p^*)}{\partial p_i} = x_i(y; p^*) \quad \text{for all} \quad i$$

where $x_i(y; p)$ is the cost minimizing quantity of input i needed to produce y units of output given input prices p^*, where the underlying production function is defined by

$$f^*(\overline{x}) = \max_y \ \{y | c(p, y) \leq p^T \overline{x} \ \text{ for every } \ p > 0\} \ \text{ for } \ \overline{x} \gg 0$$

(3) The concavity condition

Let $Q(x) = xAx, A = [a_{ij}], a_{ij} \in \mathcal{R}, x \in \mathcal{R}^n$ be a quadratic function. Then

$Q(x)$ is negative semidefinite, if and only if all determinants $\tilde{D}_1 \leq 0, \tilde{D}_2 \geq 0, \cdots, (-1)^n \tilde{D}_n \geq 0$. For our concavity condition, this means that the sufficient condition is that the principal minors of the following matrix alternate in sign.

$$\begin{bmatrix} \alpha_{LL} & \alpha_{LF} & \alpha_{LM} \\ \alpha_{FL} & \alpha_{FF} & \alpha_{FM} \\ \alpha_{ML} & \alpha_{MF} & \alpha_{MM} \end{bmatrix}$$

(4) The iterative method for determining the potential output.

The programme written in Fortran language was run on the mainframe Super Micro 32 operated on Cromix Operating system. The files suffixed '.dat' refer to the data files stored in the mainframe.

```
              implicit real(l), real(k), real(m)
              double precision v,s,k,q
              open(1,file='ind1.dat',status='old')
              open(2,file='ind2.dat',status='old')
              open(3,file='ind3.dat',status='old')
              open(4,file='ind4.dat',status='old')
              open(5,file='ind5.dat',status='old')
              open(6,file='ind6.dat',status='old')
              do 90, i=1,2
              read(1,50)
              read(2,51)
              read(3,52)
              read(4,53)
              read(5,54)
              read(6,55)
90            continue
50            format(72x )
51            format(72x )
52            format(72x )
53            format(72x )
```

```
54      format(72x )
55      format(72x )
        do 30 i=1,1
        read(1,10) lpl,lpf,lpm,lq,lk
        read(2,11) lpllpl,lpllpf,lpllpm,lpflpf,lpflpm
        read(3,12) lpmlpm,lqlq,lqlpl,lqlpf,lklpm,lklq
        read(4,13) lklk,lklpl,lklpf,lklpm,lklq
        read(5,14) t,tt,tlpl,tlpf,tlpm
        read(6,15) tlq,tlk,pk
        write(*,10) lpl,lpf,lpm,lq,lk
        write(*,11) lpllpl,lpllpf,lpllpm,lpflpf,lpflpm
        write(*,12) lpmlpm,lqlq,lqlpl,lqlpf,lklpm,lklq
        write(*,13) lklk,lklpl,lklpf,lklpm,lklq
        write(*,14) t,tt,tlpl,tlpf,tlpm
        write(*,15) tlq,tlk,pk
10      format(8x,f8.6,3x,f8.6,3x,f8.6,3x,f8.5,3x,f8.5)
11      format(8x,f8.5,3x,f8.5,3x,f8.5,3x,f8.5,3x,f8.5)
12      format(8x,f8.5,3x,f8.4,3x,f8.4,3x,f8.5,3x,f8.5)
13      format(8x,f8.4,3x,f8.4,2x,f8.5,3x,f8.5,3x,f8.4)
14      format(7x,f9.6,1x,f10.6,1x,f10.6,4x,f9.5,1x,f10.6)
15      format(8x,f8.4,3x,f8.4,3x,f12.1)
        q1 = 4.17E+07
        q2 = 5.97E+07
100     q = (q1+q2)/2.0
        write(*,*) q
        lq = log(q)
        s = 245.05538+1.76904*lpl-0.114066*lpf-(1-.1.76904+
1       .114066)*lpm+0.5*-.0147*lpllpl-0.034284*2*lpflpl-
2       (-.0147-.034284)*2*lpmlpl)+0.5*(-.066347*lpflpf-
3       (.03428-.066347)*2*lpflpm)+0.5*(-.034284*2-.066347*
4       -.0147041)lpmlpm-24.88116*lq+1.16641*lqlq-.054678*
```

```
5        lqlpl+.031702*lqlpf-(-.054678+.031702)*lqlpm+
6        4.5541*lk+0.5*(-.28103)*lklk-.02118*lklpl-.02559*
7        lklpf-(-.02118-.025594)*lklpm+.89814*t+0.5*+
8        .00119*tt+.00634*tlpl+.005596*tlpf-(.00634+.005596)
9        *tlpm-.0918*tlq+.06558*tlk
        v=exp(s)
        g=-24.8811+1.1664*lq-.054678*lpl+.0317*lpf-(.054678+
1        .0317)*lpm-.0918*t
        write(*,*)g
        r=h(v,g,q,pk)
        write(*,*)r
        if (r.gt.0) q1=q
        if (r.lt.0) q2=q
        eps=1.0E-10
        if (r.lt.eps) go to 25
        go to 100
25      write(*,*)q
30      continue
        end
        real function h(v,g,q,pk)
        h=(v*g)/(q*q) - v/(q*q) - pk/(q*q)
        return
        end
```

(5) The Lagrange Multiplier Test

The log likelihood function and its derivatives for the sample without the retriction of equal variances for n units and T time periods are :

$$\ln L = -\frac{nT}{2}\ln(2\Pi) - T/2\sum_i \ln\sigma_i^2 - 1/2\sum_i \frac{\epsilon_i'\epsilon_i}{\sigma_i^2}$$

$$\frac{\partial \ln L}{\partial \beta} = \sum_i \frac{1}{\sigma_i^2} X_i'(y_i - X_i\beta) = \sum_i \frac{1}{\sigma_i^2} X_i'\epsilon_i$$

$$\frac{\partial \ln L}{\partial \sigma_i^2} = -\frac{T}{2\sigma_i^2} + \frac{1}{2\sigma_i^4}\epsilon_i'\epsilon_i \quad 1 = 1, \cdots, n$$

$$\frac{\partial^2 \ln L}{\partial \beta \partial \beta'} = -\sum_i \frac{1}{\sigma_i^2} X_i'X_i$$

$$\frac{\partial^2 \ln L}{\partial (\sigma_i^2)} = \frac{T}{2\sigma_i^4} - \frac{\epsilon_i'\epsilon_i}{\sigma_i^6} \quad i = 1, \cdots, n$$

$$\frac{\partial^2 \ln L}{\partial \beta \partial \sigma_i^2} = -\sum_i \frac{1}{\sigma_i^4} X_i'\epsilon_i \quad i = 1, \cdots, n$$

Under the null hypothesis of equal variances, the first derivatives are

$$y = \begin{bmatrix} \frac{\partial \ln L}{\partial \beta} \\ \frac{\partial \ln L}{\partial \sigma_i^2} \end{bmatrix} = \begin{bmatrix} (\frac{1}{\sigma^2}) \sum_i X_i'\epsilon_i \\ -\frac{T}{2\sigma^2} + \frac{\epsilon_i'\epsilon_i}{2\sigma^4} \end{bmatrix}$$

and the negative of the expected second derivatives matrix is

$$H(\beta, \sigma^2) = \begin{bmatrix} (\frac{1}{\sigma^2})X'X & 0 \\ 0 & (\frac{T}{2\sigma^4})I \end{bmatrix}$$

It is convenient to write

$$\frac{\partial \ln L}{\partial \sigma_i^2} = \frac{T}{2\sigma^2}[\frac{\hat{\sigma}_i^2}{\sigma^2} - 1]$$

where σ_i^2 is the i^{th} unit specific estimate of σ^2. The restricted maximum likelihood estimator of β is the SURE pooled estimator. The restricted MLE of the common σ^2 is

$$s^2 = \frac{e'e}{nT} = \sum_i (\frac{e'e}{nT}) = \frac{1}{n}\sum_i s_i^2$$

It is a simple average of the n consistent estimators. With this, the LM statistic (computed at the pooled SURE estimates) reduces to

$$LM = \sum_i [\frac{T}{2s^2}(\frac{s_i^2}{s^2} - 1)]^2 \frac{2s^4}{T}$$

$$= \frac{T}{2}\sum_i [\frac{s_i^2}{s^2} - 1]^2$$

having n degrees of freedom.

Reference : Greene, William H. - **Econometric Analysis**

Chapter 4

The Rationing Mechanism

The last chapter dealt with the estimation of the parameters for the first stage of the programming model pertaining to the three consumer categories, namely, industry, agriculture and household. The next step is to incorporate the results of the first stage and the constraints into the main rationing model, in order to derive the optimal rationing scheme to be used in a situation of limited capacity and excess demand. This chapter deals with the setting up of the rationing model, and the derivation and analysis of the efficient rationing scheme.

Recall that the objective function of the Board is to minimise welfare loss arising from the restriction of electricity consumption. To this end we had estimated the value of potential output for industry and proceeded under the assumption that this is what the firm should have achieved in the absence of rationing. Any other constraints operating on production has been ignored. In the same manner we had estimated the value of potential output for agriculture for each of the twelve divisions. The difference between this value of potential output and the value of observed output was defined as the welfare loss for the producing sectors. For the household sector we had estimated the virtual price levels and defined the difference between the virtual price and the actual price multiplied by the level of the rationed good as a measure of economic loss to this sector.

We also noted that the observed level of output or value of output was at the rationed level. This would mean that the level of output or value of output is a function of the variable that the supplier seeks to control, namely the rationing hours. The optimal hours of ration would be that which approaches as close to the potential output as possible, subject to the given constraints. Since the data used to work with such a model also concerns the state of Uttar Pradesh, we will first need to know the necessity for imposing the hours of ration. An analysis of the data will also help us to understand why the rationing scheme now in force is non-optimal and how it has to be improved.

The following section explains in brief the features of UPSEB, the need for rationing, and the present schedule of power supply. Section 4.2 and subsections 4.2.1, 4.2.2, 4.2.4, 4.2.5 deal with the precise formulation of the objective function for industry and agriculture. This is done by replacing the published values of the restricted output of industry and agriculture, by their estimated values, and now allowing the restricted output to be a function of the ration hours. In section 4.3 we state the model to be solved and explain the practical difficulty of solving it in totality, and the need for submodels. Sections 4.3.1, 4.3.2 and 4.3.3 are concerned with the working of the submodels, with 4.3.3 providing the solution of the optimal ration hours. Section 4.4 then analyses the results of the findings. Section 4.5 presents the summary and conclusions.

4.1 UPSEB: Some Salient Features

We have discussed in the introduction to the previous chapter how an administratively fixed price fails to inform users of the availability or scarcity of a good. As a consequence, demands are governed more by needs than by cost considerations. Where the price for social reasons is fixed low, it will lead to an excess demand situation in a growing economy. This is precisely the problem with most State Electricity Boards in India, and most certainly with UPSEB. Prices for the agricultural sector, and to some extent the household sector, are fixed well below the cost of production, and the price for the other sector fails to make up for this low revenue. In a study on energy issues for the eighth plan, Arun Ghosh [1991] points out that in 1990-91, the overall average cost of operation (which is the average of pooled thermal, hydel, and other gas turbine cost) was 111.9 paise per unit, and the overall average sale price was 77.3, while sale price for agriculture and irrigation was 21.3 paise per unit and for domestic consumers, 65.3 paise per unit[1]. This has not only led to a swelling of demand from the agricultural and domestic sector, but also led the Board to make losses. The fixed prices has had a spiralling effect on the demand situation. On one hand it brought about a high growth in demand, and on the other, insufficient revenue made it difficult to allow for investment in increasing supply to meet the growing demand.

By demand we normally mean the peak demand. Generating capacity installed is always built on a forecast of the peak demand. A look at table 1 will confirm the situation of the limited capacity and the level of the peak demand. The Regional Power Survey Department of the Central Electricity Authority (CEA) carries out annual power surveys on the level of peak demand. The following table (4.1.1) gives these figures as against peak demand met in megawatts.

[1] This figure is for 1990-91, and though our analysis is for 1983-84, the assertion that average sale price is lower than average cost still holds good.

Table 4.1.1

Peak Demand(Unrestricted) Envisaged and Peak Demand Met in MW

Year	Assessed by System	Actually Met	Year	Assessed by System	Actually Met
1965-66	560	560	1977-78	2197	1795
1966-67	675	675	1978-79	2491	2256
1967-68	728	728	1979-80	2697	2324
1968-69	989	989	1980-81	2955	2485
1969-70	1138	1138	1981-82	3200	2061
1970-71	1315	1281	1982-83	3454	2754
1971-72	1397	1397	1983-84	3295	1775
1972-73	1588	1281	1984-85	3526	2293
1973-74	1735	1262	1985-86	3622	2692
1974-75	2000	1217	1986-87	4001	3660
1975-76	2157	1744	1987-88	4281	3581
1976-77	2345	1911	1988-89	4621	3831

Source: UPSEB 'Statistics at a Glance' 1990.

The table shows that from 1972-73 onwards there has been a steady increase in the level of unsatisfied peak demand. Over the years installed capacity and thus the supply position has improved, but the demand has far outstripped the supply. A distinction has to be made between the installed capacity and the available supply. While the installed capacity has grown from 539.9 MW in 1961-61 to 4956.3 MW in 1988-89, the supply position has risen from 204 MW to 3831 MW in 1988-89. This divergence between the installed capacity and the peak supply level is due to various factors like the number of plants shut down due to repairs and hence not operable, the efficiency of operation or the plant load factor, the reservoir level for hydel stations, transmission losses, theft etc. Thus while the supply position has improved, peak demand still outstrips supply for all those years. Even in 1988-89, the latest year for which we were able to obtain data, the gap between peak supply and demand remains. A similar table for 1983-84, the specific year we will be considering, as well as the most recent year when published data was available, i.e. 1988-89, will make the situation clearer and help us to understand why the rationing is necessary. In the following table, the power supply position is in million kilowatthours or units (MU) per day.

Table 4.1.2

Actual Power Supply Position (MU per day)

	1983-84		1988-89	
Month	Required	Available	Required	Available
April	43.91	35.55	70.47	60.20
May	46.32	36.91	70.58	60.28
June	47.53	36.86	66.63	57.36
July	44.36	33.41	61.04	53.19
August	43.08	34.80	59.37	51.94
September	41.80	32.92	58.28	57.23
October	41.99	33.82	64.91	57.70
November	45.06	32.92	69.55	61.44
December	44.33	35.58	71.61	62.97
January	45.30	37.25	72.91	64.47
February	46.60	36.92	77.78	68.31
March	50.83	40.71	75.57	67.10

Source: Annual Administration Report
Northern Regional Electricity Board
Central Electricity Authority

Given that prices are institutionally fixed, the above tables show that some kind of rationing scheme has to be adopted. Just like prices which are fixed in an ad-hoc fashion, often with no relation to marginal costs and for other reasons than economic, the rationing scheme is also determined in an arbitrary manner bearing no connection to the impact on the various consumers. In fact the rationing is often in force in the peak as well as off-peak demand periods, which by itself may not be inefficient. But there is no distinction made between consumers on the basis of their utilities. Rationing is viewed as a necessary outcome of the excess demand situation, but not as a means of allocating the scarce resources *cptimally* – by which we mean that the consumer whose loss would be the highest should be subject to the least rationing. The only distinction that the Board makes in deciding the hours of ration is between the energy intensive industries which are subject to less rationing. But agriculture and household sectors have fixed predetermined hours of ration which do not change much with the level of demand.

Besides, except to a few type of consumers like the heavy industrial consumers and some urban domestic consumers, the Board does not reveal its rationing scheme to the consumers. Consequently the consumers are not prepared for the rationing. In industry, this means that the output will be affected without any efforts for substitution of electricity. Also, the Board rarely keeps to any fixed schedule. Domestic consumers are often supplied at the expense of industry.

Electricity generation also has certain characteristics that make rationing schemes more difficult to derive in practice. The supply of energy is from different technologies ; the technologies most in force are the thermal and hydel type. At present the mix of the types on an All India average is close to 50:50 meaning that about half of the plants are hydel and the other half are thermal. In UPSEB the ratio is about 70 % thermal and 30 % hydel. Thermal plants have a higher marginal cost of operation, but are difficult to shut down once they are set in operation. Hydel plants have a very low marginal cost of operation but the operation is dependant on the reservoir level of water. During the summer months when the reservoir level is lower than the level required, this means that hydel plants cannot be relied upon to supply power. Supply levels for the same capacity level changes with the seasons.

When electricty is put to domestic use, this means that during certain months the demand is bound to be higher than the other months. Besides electricity is also used for agricultural production, which is, firstly seasonal, and secondly dependant on the monsoon for irrigation purposes. For all these reasons, the demand for agriculture also increases during the summer months just as supply is also limited during these months. Rationing is even more of a neccesity during such times. Given these facts, it would seem that the derivation of an optimal rationing scheme should be a major concern. But the available data do not suggest any such thing. To illustrate, we display the data for the year under consideration, i.e., 1983-84, and then explain how we have quantified the data for further analysis.

The following is the ration hours for the three consumer types for the year 1983-84.

Schedule of Power Supply for 1983-84

1 Agricultural consumers were supplied as below.

1 (a)

From	To	Hrs supply/day
1.4.83	17.4.83	7
18.4.83	15.6.83	10
16.6.83	28.7.83	12
29.7.83	4.10.83	10
5.10.83	31.10.83	20
1.11.83	12.11.83	10
13.11.83	31.3.83	7

1 (b) World Bank tubewells (tubewells constructed under funding from the World Bank) getting supply from 11 KV independant feeders were supplied power for 18 hrs per day with effect from 1.9.83.

2 Industrial consumers were supplied as under.

2 (a) Rolling and Rerolling Mills Supply :

From	To	Hours of supply
1.4.83	12.11.83	12
13.11.83	25.12.83	8
26.12.83	31.3.84	12

2 (b) Arc induction furnaces getting supply at and below 33 KV were supplied power as per details below:

From	To	Hours of supply
1.4.83	21.8.83	12
22.8.83	30.9.83	14
1.10.83	12.11.83	12
13.11.83	25.12.83	8
26.12.83	31.3.83	12

2 (c) General industrial consumers were subjected to one day per week closure and evening peak hour restriction(PHR) throughout the year except between 13.11.83 and 15.12.83 when they were subjected to three closed holidays per week and between 16.12.83 and 25.12.83 when they were subjected to two close holidays per week.

2 (d) Cold storages located in rural areas and fed from 11 KV independant feeders were supplied power as per supply programme of rural feeders upto 30.4.83 for 16-18 hrs per day between 1.5.83 and 31.12.83 again as per supply programme of rural feeders and 16-18 hrs per day thereafter.

3 The following are the restrictions for domestic category:

3 (a) Corporate Towns

From	To	Hrs of restriction per day
1.4.83	30.11.83	No cut
1.12.83	26.12.83	1.5
27.12.83	31.12.83	No cut

3 (b) Special Class Towns:

From	To	Hrs of restriction per day
1.4.83	18.4.83	2
19.4.83	30.11.83	No cut
1.12.83	26.12.83	2
27.12.83	31.12.83	No cut
31.12.83	31.3.84	3

3 (c) District Headquarters Category - I towns:

From	To	Hrs of restriction per day
1.4.83	18.4.83	3
19.4.83	30.11.83	No cut
1.12.83	26.12.83	4
27.12.83	31.12.83	No cut
31.12.83	31.3.84	4

Source: Annual Administration Report
Northern Regional Electricity Board
Central Electricity Authority

The above data refers to the number of hours of supply and ration for the consumer types. Where nothing has been specified for a month, it is taken to mean that the previous rationing will continue to be in force until the period of the next change. One important point must be made here. Though these are the published statistics, it is a widely held belief that the Board does not reveal all the figures. The figures of the hours of ration for the domestic consumers type seem abysmally low when compared to the ration hours for the other two types. However, any domestic consumer would vouch for the fact that he has been subject to greater rationing than what is borne out by the statistics of the Board. Since we have no method of verifying these facts we shall assume throughout this chapter that the facts published are the true accounts.

Note from the above schedule that the Board only specifies the number of hours of supply per day for each type of consumer and not the 'time' of supply per day. Electricity being a good for which demand varies throughout the day, rationing should be with respect to specific times of the day when demand is at its peak. Unfortunately, no data is available on the supply to each type at various points of the day, though it is possible to measure the total supply at each hour of the day. Therefore we will also have to work with a figure for the number of hours per day, and not the time of the rationing per day, as would have been more desirable.

The ration hours for each type have been quantified into the number of ration hours per month. The number of hours of restrictions per day was used to calculate the total number of hours of restrictions per month. Where the restrictions have been changing within a month, we have calculated accordingly for the relevant number of days. The evening peak hour restriction for industrial consumers was assumed to be three hours per day. For calculating the restrictions for industry as a whole when the supply hours for various types of industries was given, we have first calculated the relevant hours of restriction for each type and averaged over the aggregate. The same method was adopted for agriculture and domestic consumers too. Needless to say, this method is not foolproof, but in the absence of any other information, this seemed the best way.

The point to be noted is that by doing this we have only an *approximate* number of hours of restriction of supply for each month. Due to problems of aggregation, an exact figure is not possible. However, for the analysis we only require some average figure for the number of hours of restrictions and it is the relative numbers between various consumer types that is important, and not the absolute figure. The Regional Power Survey centre of the CEA was able to furnish information on the total supply to the consumer types on a monthly basis. This supply in million units (million kilowatt hours) is contrasted against the hours of ration in Table 4.1.3.

Table 4.1.3

Supply (in Mill. Kwhrs) and Restrictions for 1983-84

Month	Ind.	Ration hrs.	Agri.	Ration hrs	Household	Ration hrs.
April	327.936	286.5	335.709	471	82.593	90
May	319.840	286.5	326.600	434	99.137	0
June	362.518	286.5	336.109	390	86.957	0
July	333.704	286.5	124.991	372	97.592	0
Aug.	347.533	281.5	128.242	434	107.479	0
Sept.	377.688	271.5	127.784	420	129.291	0
Oct.	336.014	286.5	346.257	217	114.804	0
Nov.	348.039	253.0	353.865	480	123.614	0
Dec.	254.406	322.2	344.280	527	116.719	77.5
Jan.	321.643	270.0	353.088	527	117.601	93.0
Feb.	338.782	270.0	353.445	476	107.838	84.0
March	383.957	270.0	360.977	527	133.0136	93.0

Source: Regional Power Survey Centre
Central Elctricity Authority

For the ration hours to affect welfare in our model, we have to consider rationing in only those periods where supply and and hence welfare is affected. Therefore we should expect a negative relationship between the supply and the hours of ration. But the available data do not give us the time of restriction, and so it is difficult to separate those ration hours which actually affect welfare. This may not provide the clear relationship that we want to establish, which is exactly what resulted. But since welfare loss for each type of consumer is

positive, we know that *there has* been some rationing during the periods of demand for each of the types. The only problem is that this may include hours of ration for a consumer type in those periods when the consumer type did not actually demand. This limitation could not be avoided unfortunately.
Notice from the above table that except for industry which shows a healthy negative relationship between supply and hours of ration, the supply to the other two types shows no such pattern. Indeed the supply has sometimes increased with an increase in the hours of ration. This can because of two reasons. One, while the number of hours of ration for agriculture has increased, simultaneously the supply during the supply hours increased. This could be because of new comnnections which were given out during the month, which increased the demand and hence the supply. Two, the quoted figures may be wrong entries. Whatever the reasons, we will have to take the figures as they are. The ration hours for the domestic sector are very erratic – for seven months of the year they show no rationing and then a steep rise. This fact will doubtless cause some problems in estimating supply as a function of the ration hours. Also notice from the table that industry's supply is still the maximum, indicating that they are the largest consumers.

In order to use this data in the rationing model we will first establish a relation between the supply and the ration hours of each type. We have to choose the proper functional form to establish this relation. As has just been pointed out, this is not easy as the supply and ration hours do not show any natural relationship. Various linear as well as non-linear forms were tried and we have chosen that form which yielded the most significant results for each type. The linear functional forms used have been deliberately chosen to keep the computation of the rationing model as simple as possible. Even slightly more complicated expressions, we found, made the non-linear model extremely difficult to solve. Given the fact that the supply for each type depends on the ration hours of all the types, a simultaneous model would be the most obvious model to estimate. But it turns out that this is not easy. For one, with so few independant variables, the equations would not be identified. This problem can be mitigated to some extent by including those exogenous variables that we might have inadvertantly left out, but this would lead to extra parameterisation, which, given our small sample range, would not be estimable. We found that by using a simultaneous equation model, this was indeed the case. For this reason the functional relationship between supply and ration hours for each type had to be chosen and estimated differently. All estimations have been done only for one year only, the relevant year that we are considering 1983-84, with twelve data points for the estimation.

For industry, the following specification yielded the best results.

$$si = \alpha_0 + \alpha_1 ri + \alpha_2 rh + \alpha_3 \text{peakavailability} \tag{4.1.1}$$

where si is the supply schedule of industry. ri is the ration hours that industry is subjected to, rh is the ration hours applicable to household. Peakavailability figures are the same figures that appear in Table 4.1.2. We have chosen that range of explanatory variables that gave the highest $\overline{R}^2$. We have not incorporated the ration hours of agriculture as the coefficient was not significant and it reduced the $\overline{R}^2$. Even though the estimates of rh and 'peakavailability' are not significant, we have included them as the presence of these two series improved the $\bar{R}^2$. The resulting estimates when the equation was estimated by ordinary least squares are given below.

Table 4.1.4

Estimates for Industry Supply

variable	Coefficient	std. error	T-stat
α_0	502.56304*	168.17452	2.9883423
α_1	−1.2413873**	0.3454840	-3.5931827
α_2	-0.3068840	0.1884089	-1.6288136
α_3	0.1833586	0.1240232	1.4784220

R-squared	0.694072	Sum of squared residuals	3728.735
Adjusted R-squared	0.579349	F-statistic	6.049977
Std error of regression	21.58916	D-W statistic	1.978921
Log likelihood	-51.46077		

Degrees of freedom 8

* significance at 95 % confidence level.

** significance at 99 % confidence level.

Notice that the coefficient of ri is highly significant indicating the negative effect of the ration on supply. From the results note that the coefficient of rh is also significant indicating that rationing to industry and household move in the same direction. From the results it is also apparent that as the supply during peak hours increases, industry gets a higher supply.

For agriculture, the same previous specification did not yield good results. The linear form finally chosen for agriculture was the following inverse supply schedule :

$$ra = \alpha_0 + \alpha_1 sa + \alpha_2 rh + \alpha_3 \text{netpeak} \qquad (4.1.2)$$

where rh is the number of hours of ration that household was subject to. Netpeak is a term used to represent the difference between the peak requirement and the peak availability of electricity (Table 4.1.2). Again, it was not possible to use any other specification which would give better results. The results are shown below.

Table 4.1.5

Estimates for agriculture supply

variable	Coefficient	std. error	T-stat
α_0	151.56038	169.35137	0.8949463
α_1	-0.2048264	0.2330291	-0.878973
α_2	1.8233839**	0.5510999	3.3086270
α_3	0.9842071	0.5687961	1.7303338

R-squared	0.605646	Sum of squared residuals	33081.11
Adjusted R-squared	0.457764	F-statistic	4.095453
S.E of regression	64.330505	D-W statistic	2.476536
Log likelihood	-64.55813		

Degrees of freedom 8.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

Observe that both the coefficient for rh and for netpeak are positive, indicating (a) if the ration hours to household were increased, then agricultural rationing is also increased. This is not a very surprising result, since both agriculture and household are rationed in the off-peak hours. (b) As the difference between the peak requirement and peak availability of supply grows, the rationing of agricultural supply is likely to increase. This is again borne out by the empirical evidence that agriculture is normally supplied in the offpeak hours, specifically during late night.

The equation for household took the following form:

$$rh = \alpha_0 + \alpha_1 sh + \alpha_2 ra + \alpha_3 \text{netpeak} \tag{4.1.3}$$

The results are shown below:

Table 4.1.6

Estimates for household supply

variable	Coefficient	std. error	T-stat
α_0	37.643363	104.09765	0.3616159
α_1	-0.1368202	0.6306649	-0.2169459
α_2	0.3679078*	0.1150907	3.1966768
α_3	-0.5177640	0.2612353	-1.9819831

R-squared	0.627856	Sum of squared residuals	8376.872
Adjusted R-squared	0.488301	F-statistic	4.499009
Std error of regression	32.35906	D-W statistic	1.598771
Log likelihood	-56.31720		

Degrees of freedom 8.
* significance at 95 % confidence level.
** significance at 99 % confidence level.

Note here that the the coefficient of netpeak is significant which is a welcome result. The peak period problem is compounded by the fact that household consumption at this time shoots up. But then household consumers also consume the bulk of their share *only* at peak time which follows just from the nature of their preferences for goods relating to electricity. Therefore any demand increase, meaning peak requirement increase, should prefer to give higher priority to supply in the household sector. The coefficient of sh though not significant, is nevertheless in the right direction. As seen in the function for agricultural rationing, the rationing to household and agriculture moves in the same direction.

Having thus established the link between supply and the ration hours, the next step is to show exactly how this supply as a function of the ration hours and other parameters, enters the main rationing model– specifically, the utility functions of the consumer types. This will be discussed in the section below.

4.2 The Restricted Output

To recapitulate, the rationing model the Board seeks to solve is as under:

$$\text{Min}_{r_i} \;\; WL \; = \; \sum_{i=1}^{n}[U_i(Q_i) \; - \; U_i(S_{ei}(r_i^t), S_{2i}(S_{ei}) \cdots S_{ni}(S_{ei}))] \qquad (4.2.1)$$

$$\text{s.t} \quad \sum_{i=1}^{n} s_{ei}^t \; \leq \; K, \;\; t = 1, \cdots, T \qquad (4.2.2)$$

$$\bar{Y}_m \geq Y_0, \quad i = 1, 2, \cdots k \tag{4.2.3}$$

$$\text{and} \quad r_i^t \geq 0, \; S_{ei} > 0, \quad i = 1, 2 \cdots n \tag{4.2.4}$$

We have defined $\sum_{i=1}^{n}[U_i(Q_i)]$ for industry and agriculture as the value of potential output at constant(1970-71) prices. The next stage is to estimate $U_i(S_{ei}(r_i^t), S_{2i}(S_{ei}) \cdots S_{ni}(S_{ei}))]$ for both these types of users, where the 'restricted' in place of 'potential' will now be paid attention. We now proceed to estimate the restricted output as a function of the restricted consumption of electricity.

4.2.1 The Restricted Industrial Output

Studies pertaining to the Indian industry which have analysed the slowdown of industrial growth since the mid-sixties, have invarably pointed out the fact that power shortage acted as a constraint to industrial growth. Kapoor [1967] and the NCAER [1965] have way back in the sixties identified electricity shortage as a main hurdle in the path of industial development in U.P. More recently Ahluwalia [1985] has pointed out that because of the cumulative impact of underinvestment and inefficiency in the power sector and the infrastructural bottlenecks arising from it, there has been an adverse impact on the industrial sector since the mid-sixties. See also Government of India (5^{th}[1974] Plan, 6^{th}[1981] Plan & 7^{th}[1985] Plan), all of which mention the fact that electricity shortage continued uptil the mideighties.

We have already defined the restricted output to be the observed value of output. The objective of the Board is to control the choice variable r in such a way that the loss to each of the consumers is minimized. This means that the Board can actually to some extent control the level of the restricted value of output or just output. So the observed output, has to be controlled through r or analogously, through the restricted electricity consumption.(We have already explained that since there is no available data on S_t, we shall only be considering $\sum_{t=1}^{T} r_t$ for each type of user and not r_t.) In order to show the observed value of output as a function of the restricted electricity consumption, we require a functional form, which bears the characteristics of a general, second order, continuously differentiable production function. That is, we need to show that

$$Q_r = f(K, L, M, F)$$

where F now stands for fuel input which itself is restricted because electricity is restricted.

Recall that we have earlier used the translog form for the variable cost function. Though the production function Q_r can also be represented by the translog form, we found that it did not yield any significant results. Besides the translog form is unfortunately highly non-linear which leads to problems in estimation as well as in the running of the non-linear programme for the rationing model. The other form which satisfies all the properties of a general production function is the Generalized Leontief form (Diewert [1971]).
This consists of specifying the production function as :

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} X_i^{1/2} X_j^{1/2} \quad \text{where } a_{ij} = a_{ji} \tag{4.2.5}$$

Using this form, we set out the five input production function as :

$$Q_{ri} = \sum_{h=1}^{n} \sum_{j=1}^{n} a_{hj} X_h^{1/2} X_j^{1/2} \tag{4.2.6}$$

where $h,\ j\ = K, L, M, F, E$
where Q_{ri} is the value of restricted industrial output at constant prices, where F is now the fuel input without electricity, and E is the electricity input. This is to enable us to use only the electricity input as a function of the ration hours. For purposes of estimating the production function, we retain E as it appears, without substituting it by the function consisting of the ration hours.

4.2.2 Data and Estimation

The data is basically the same that we have used earlier to calculate the potential output, only, we will use it in a transformed version now. Firstly we need the physical inputs which we did not need earlier. But it is not possible to obtain the physical amount or volume of the various inputs, especially for fuel and material input. So the normal practice in such situations is to use the deflated value of the inputs in the production function. The deflated value removes the effect of price changes and therefore any change is only attributable to the physical change in the inputs.

Materials input M in value figures obtained from the Annual Survey of Industries, is deflated by the material price index at constant(1970-71 = 100) prices. For fuel input, the deflator used is the price index of fuel at constant prices. Once the deflated fuel input is obtained, it is now in the form of physical input. From this the amount of electricity input is removed to obtain a figure for fuel without electricity. An important point should be noted here. ASI does not give any breakup of fuel input into electricity and other fuel. The only data on electricity consumed by the industry is from the records of UPSEB. So we have to use this data. However, this is by no means the entire electricity that industry consumes. Industry also has self-generation (captive generation), as well as purchase from private licensees. But the method we have used is fully justified, for it is only that supply from SEB which is subject to rationing that we are interested in. Fuel input may therefore contain electricity consumption from other sources, but that is not important to us.

Electricity input is the figure as is given in the records of UPSEB. Labour input is just the number of employees. Q_{ri} is the the value of output at constant prices, the same which was used for the earlier estimation – i.e., the nominal value of output deflated by the Wholesale Price Index of manufacturing items at 1970-71 prices. Capital input is also the same figure which was used in the estimation earlier.

Estimation was done by the method of Ordinary Least Squares(OLS), and gave rise to the results of the following table. The figures in the parenthesis refer to the standard errors.

Table 4.2.2

Estimates of the Leontief production function

a_{LL}	-80830.429^{*}	a_{LF}	175171.82
	(26424.612)		(191232.97)
a_{LM}	49275.296^{**}	a_{LK}	-0.7436293
	(12316.0)		(143.67155)
a_{LE}	1032.5361	a_{FF}	-322.03537
	(1860.1588)		(176.67180)
a_{FM}	-30.444014	a_{FK}	102852.58^{**}
	(3058.1380)		(31369.499)
a_{FE}	-1493748.1^{**}	a_{MM}	315.47978
	(437773.36)		(313.60577)
a_{MK}	-23016.671^{**}	a_{ME}	-104889.52^{*}
	(5533.2679)		(45937.811)
a_{KK}	-581.59488	a_{KE}	21651883^{*}
	(691.19105)		(8471234.6)
a_{EE}	1686.8356		
	(1316.6244)		

R-squared	0.996456	Sum of squared residuals	4.08 E+18
Adjusted R-squared	0.990942	F-statistic	180.7335
Std error of regression	6.73 E+08	D-W statistic	3.283403
Log likelihood	-510.1519		

Degrees of freedom 9

Figures in parenthesis refer to standard errors.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

Some of the estimated values as can be seen, are not significant. Further forms were tried but they all gave similar results which has led us to conclude the reason is because of the very nature of the data. The data that we have used cannot be improved upon, given the constraints of limited information.

But the R^2 has turned out to be very high. In any case, the estimates are not really important as far as the model is concerned. The model would run just as well with a different value of estimates. What is important is that the sign of the estimates are in the right direction. In particular the a_{ii} $i = K, L, M, F, E$ should be negative in order that the production function is concave. Unfortunately, the coefficients for fuel and electricity are positive, but we attribute this to the close and substitutable relationship between the two. We will only be using these estimates for further running of the rationing model. In a sense, therefore, these are only intermediate results and hence not very important.

4.2.3 The Restricted Agricultural Output

Just as electricity is an important input in the production of industrial ouput, it is also a major portion of energy input in the production of agricultural output from irrigated land. There are tubewells (both Stateowned and private) that are used to transmit electricity for irrigation purposes. Any shortage of power will in the short run affect output, even though it may be substituted by diesel. Pathak [1983] in a study found that there was a positive correlation between energy input and agricultural production, and that technological advances force shifts from non-commercial energy inputs (labour, bullocks etc) to commercial inputs (electricity, diesel). He also predicted that electrical energy would be the major constraint to agricultural production followed by fertilizer and diesel oil. Using a growth rate equation, Pathak calculates that in the next fifteen years (following 1983), the requirement of electrical energy would be 252 % of the present consumption. The empirical evidence for agriculture also seems to suggest that agricultural output is a positive function of electricity output. We now try to observe this empirically.

For agricultural output, neither the translog form nor the Generalized Leontief form yielded any good results. Since agricultural output has a different behavior than industrial output, we decided to try the standard Cobb-Douglas form for production. The variables were tansformed into their logarithm values in order to make the function linear.

$$\log Q_{ra} = a_0 + a_F \log F + a_{Fu} \log Fu + a_L \log L + a_5 \log A + a_E \log E \quad (4.2.7)$$

where Q_{ra} is the restricted agricultural output where F is fertilizer input, Fu is fuel input devoid of electricity input, L is labour input, A is the area under irrigation, and E is the electricity input. The advantage with using the Cobb-Douglas form is that it best captures the behavioral relationship between the agricultural output and the inouts. The limitation with using it for a purpose such as ours is that it does not take into account the interaction or crossproduct terms, especially the effect of electricity on other inputs. Since the rationing of electricty is bound to affect the usage of other inputs, ideally we should have a functional form that captures this fact. But given our constraints, we shall argue that agriculture does not behave as industry does. The reason being that, any change in inputs leads to slower changes in other agricultural inputs, and given the short term of our model, it might well be that the other inputs are not affected significantly. Therefore, while it is certainly desirable to have interaction terms, in the absence of a better set of data the Cobb-Douglas is an appropriate formulation. Besides, for econometric applications concerning agricultural production in India, the Cobb-Douglas is the most widely used form as it fits the data better. See Haque, et.al [1983], Alshi et.al [1983], Rajagopalan and Varadarajan [1983], Bal, et.al [1983], Sampath, et.al [1984], Seetaprabhu [1984].

4.2.4 Data and Estimation

Much of the data used here is the same used earlier, which has been explained in great detail in Chapter 3. So we will only mention them briefly. Normally a production function should have the physical inputs as the independant variables, but using this gave insignificant results. Therefore we have used the deflated value of all inputs, with the explanation that this is justified for atleast fertilizer and labour, because these two are not homogeneous[2]and therefore the deflated value is the more appropriate one. Fertilizer input used here is the nominal value of fertilizer input deflated by the price index of fertilizer at 1970-71 prices (Chandhok 1990). Electricity input cost is the revenue assessed from agriculture obtained from the tables of UPSEB, deflated by the price index for electricity at 1970-71 prices. Energy cost devoid of electricity cost is just the diesel cost. Recall that total energy cost was calculated as the sum of diesel and electricity cost. Therefore fuel cost is just the nominal diesel cost deflated by the price index of diesel at constant (1970-71=100) prices. A is the area under irrigation. Labour input is the total labour cost deflated by the consumer price index for agricultural labourers (CPI agricultural labourers from Chandhok 1990) at 1961-62 prices. This is a little inconsistent with the rest of the data, but unfortunately, there is no better published data available. Q_{ra} is the same series that we have used for determining the potential output.

Estimation was done by OLS. An interesting point is that the fixed effects model which had be used for the earlier translog cost function, due to cross-sectional heteroscedastic disturbances, does not seem to work too well here, it generally gave poor results. This could be because firstly, we have the deflated value of output in place of the variable cost, and the entire data matrix is different, and secondly the fact that the functional form is different. Besides, such a formulation does not work in the rationing model. It in fact gave rise to infeasible solutions. This could be because we are considering the divisions separately in the rationing model, implying that we are not allowing for division-wise variations.

Since all these intermediate estimations have to be done with a view to choosing the one which suits the rationing model best, we will only use such estimations. For this reason, we run the Cobb-Douglas with just OLS without the fixed effects. The Cobb-Douglas function was run without any restrictions

[2]Recall that fertilizer input consists of nitrogen, phosphorus and potassium ; labour input is all kinds of labour i.e. weeder, sower, reaper, cultivator etc.

on the parameters[3]. The result of the estimations along with their standard errors are given in the Table below.

Table 4.2.4

Estimates of the Cobb-Douglas production function

a_0	−9.7870491**	a_L	-0.1431076
	(3.5142628)		(0.2204713)
a_F	0.8044667*	a_A	1.6461993**
	(0.3517007)		(0.2130136)
a_{Fu}	-0.3063065	a_E	-0.3214630
	(0.1845044)		(0.2192237)

R-squared	0.857256	Sum of squared residuals	11.39860
Adjusted R-squared	0.840263	F-statistic	50.44667
Std error of regression	0.520956	D-W statistic	1.126444
Log likelihood	-33.60401		

Degrees of freedom 42

Figures in parenthesis refer to standard errors.

* significance at 95 % confidence level.

** significance at 99 % confidence level.

We see that some of the results here are significant. However, these are only the intermediate results and we shall only require the parameter values to solve for the optimal supply.

[3]In fact we did impose the restriction of constant returns to scale, but found that fewer estimates were significant now, and the explanatory power of the equation was lower. In any case, we do not see any need to impose any such restriction given that some factor is fixed in the short run.

4.2.5 Household Loss

We have already defined the loss to the households as:

$$(p_e^* - p_e)\tilde{x}_e$$

where p_e^* is the virtual price, p_e is the actual price, and $\tilde{x}_e$ is the level of ration of electricity. For ease of understanding, we change x_e to sh – meaning the electricity sold to the household. The minimum economic loss to households is then the minimization of the above expression.

4.3 The Rationing Model

We are now ready to state the exact form of the model and solve it.

$$\text{Min}_r \quad [Q_{pi} - Q_{ri}(r)] \; + \; \sum_{j=1}^{12}(Q_{pa_j} - Q_{ra_j}(r)) \; + \; [p_e^*(r) - p_e]sh(r) \qquad (4.3.1)$$

$$\begin{aligned} \text{s.t } q_{ri}(si) &\geq \overline{q}_i \\ q_{ra_j}(sa_j) &\geq \overline{q}_{aj} \text{ for all } j \\ si + sa + sh &\leq K \end{aligned}$$

where Q_{pi} and Q_{pa} are the value of potential output for industry and agriculture and Q_{ri} and Q_{raj} are the value of the restricted output respectively. q_{ri} and q_{raj} refer to the *level* of the restricted production of industry and agricultural division respectively. We are looking at the value of potential output of agriculture for the aggregate of twelve divisions. si and saj are the corresponding levels of electricity consumed. $\overline{q}_i$ and $\overline{q}_{aj}$ are some minimum production requirements, as stipulated by some central authority. This we have taken to be some index of production.

Ideally, we should minimize the above expression with respect to the r vector in order to obtain the optimal vector r that solves this problem. It was not possible to determine directly from the above model the vector r. The software used for this purpose generally gave an infeasible solution to the problem. It became necessary then to first determine the optimal supply to each kind of consumer i.e., si, sa, sh, and then use the estimates of the inverse supply schedule to determine ri, ra, rh.

Again, ideally the model should be solved exactly as it has been formulated. But the nature of non-linearity in the problem did not allow us to use all the three sectors together - again the software gave an infeasible solution. Notice that the household's loss function when expanded is highly non-linear in sh. The rationing model had to be broken up and worked in stages. It is for this reason that submodels had to be prepared so that the entire model was simpler.

As has just been mentioned, the household sector's model could not be worked in conjunction with the other sectors. It had to be solved separately because of the nature of the equation used. But we shall substantiate our method by saying that household's consumption of electricity is behaviorally different from that of the producing sectors. The consumption of electricity directly enters the utility function for domestic consumers. It can be treated differently for this purpose. We will describe below how this sub-model was solved.

4.3.1 The optimal supply to household: Submodel 1

The values of p_e^* that were determined earlier were estimated on the assumption that x_e or sh was a given parameter. What we choose to do now is to use the same functional form, only treating the sh as *variable*. The p_e^* then is a function of this sh.

Before we proceed further, we shall repeat a remark that has already been mentioned in Chapter 3(page 32), but which is more appropriate here. The rationing model that we wish to solve is for the year 1983-84. However, data and results for the household sector are only for the period January 1983–December 1983. But this includes only nine months of 1983 in the rationing model. This is another informational shortcoming in the analysis, which cannot be improved upon due to the paucity of data.

The entire estimation for the household sector was done on a class-wise or consumer type basis. We will proceed along the same lines, to determine a sh for each consumer class. The problem then is :

$$\mathrm{Min}_{sh_k} \quad \mathrm{Loss} = [p_e^*(sh_k) - p_e]sh_k$$

for $k = 1 \cdots 10$.

For each class sh was determined by minimizimg the above function using non-linear programming techniques. Recall that the sh_k is the *per capita monthly consumption* of electricity. What we are determining in this submodel is just the optimal per capita monthly consumption of electricity for each class for which the value of the Loss function is made zero. But then this would mean that the supplier wishes to meet all the unsatisfied demand of the consumers – an objective that needs to be justified. We worked along these lines but found that this required that the optimal supply to household be raised very high which would leave very little scope for improvements to industry and agriculture. So we need to add a constraint to the model.

From the statistics of UPSEB, in 1982-83 the average percantage share of the domestic sector for the different states of India is 16 % of the total supply to all the sectors. In 1983-84, the percentage share in U.P. was 13.1 %. So we have used the 16% figure as an upper bound. From the model solution for which the Loss was zero we worked higher up for a positive welfare loss and a level of $p_e^* > p_e$ that would give the nearabout figure to the optimal sh being 16 % of the total. Using this determined p_e^* we worked on the model again to determine precisely the optimal sh, for each expenditure class.

The solution values of this submodel[4]. are as below :

[4]The nonlinear programme is displayed in Appendix A.4 (1).

Table 4.4.1

Optimal per capita monthly consumtion and virtual price

sh	Class	p_e^*
0.490	0 - 30	2.25
1.094	30 - 40	1.10
1.339	40 - 50	0.97
1.511	50 - 60	0.94
2.021	60 - 70	0.76
1.987	75 - 85	0.85
2.221	85 - 100	0.78
2.714	100 - 125	0.72
3.383	125 - 150	0.93
4.429	150 - above	0.95

Having obtained the per capita *optimal* electricity consumption, there remains the question of translating this into the total consumption for the household sector, before expressing it in ration hours.

The survey on consumer expenditure conducted by the National Sample Survey Organisation(NSSO) in 1983 also displayed the number of households included in each class category for the purpose of the survey. This has enabled us to estimate *approximately* the number of people incuded in each class. The data is displayed below.

Table 4.4.2

NSS Survey for 1983

Class	no.of sample households	total consumer units
0 - 30	8	5.62
30 - 40	23	6.65
40 - 50	87	6.68
50 - 60	195	6.75
60 - 70	265	6.76
70 - 85	482	6.39
85 - 100	438	6.11
100 - 125	691	5.69
125 - 150	442	5.36
150 - above	1559	3.31

Assuming that each household comprises of 5 consumers on an average, it is possible to calculate the total number of people in each class. Multiplying this number with the optimal level of per capita monthly consumption of electricity, we get the total monthly consumption for the entire household sector under study. Taking this monthly figure to be an average, we can determine the total consumption for the whole year for the household sector. But this cannot be in any way compared to the figures of the Board, since we are only looking at a sample of the households.

Yet, what our model has shown is that consumption has risen over the previous level. In fact on comparison, we find that it has risen by 33 %. Taking this as an analogue to the overall consumption is a perfectly reasonable assumption. That is, if in a sample we were able to arrive at the fact that the consumption has increased by 33 %, then this might well be true of the entire urban population using electricity for direct consumption.

For the year 1983-84, the total energy sold to the household sector was 1317 MU. Calculating 33 % increase over this gives us 1751.61 MU. As desired, the share of the household sector's consumption in the total consumtion of electricity has risen to 16 % .

4.3.2 The optimal supply to industry & agriculture: Submodel 2

We now come to our second submodel where we treat the optimal supply to the household sector as a parameter. That is, the capacity constraint is now modified by adjusting the supply available taking into account the optimal supply to the household sector. The production functions are now functions of the consumption levels and what we seek to do in this section is to determine the optimal level of si and the sa, taking sh as a parameter, where $sh = \sum_k sh_k$. The model is then constructed as under:

$$\begin{aligned} \text{Min}_{(si,sa)} \quad Q_{pi} - Q_{ri}(si) \quad &+ \quad \sum_{j=1}^{12}[Q_{pa_j} - Q_{pa_j}(w_{aj}sa)] \\ \text{s.t} \quad q_{ri}(si) \quad &\geq \quad \overline{q}_i \\ q_{raj}(saj) \quad &\geq \quad \overline{q}_{aj} \\ si + sa \quad &\leq \quad K - sh \end{aligned}$$

for all j.

In order to determine optimal electricity for agriculture for each division, we have used the share of each division in total electricity cost for each year as the weights w_{aj}. K here is the total supply free to be redistributed between industry and agriculture, *after* taking all other auxilliary consumption into account. These are commercial, public lighting & water works, railway traction, miscellaneous supply and supply outside the state. The $\overline{q}_i$ which is the predetermined level of output, was considered to be the average output in a period of 15 years of the sample range. For industry this means the average 'value of output at constant prices' over a period of 15 years. For determining $\overline{q}_{aj}$, since we do not have a long time series, we have taken the lowest value of output in four years of each division as the predetermined level[5]. The above model

[5] In the theoretical formulation of the rationing model we had the constraints for the pro-

was then run through non-linear programming techniques[6]. The optimal levels of si and sa are 42816.815 and 2835.575. The present supply of si and sa is 4052 and 3505 respectively. The optimal supply level of sh as we have seen is 1751.61.

4.3.3 The Ration hours: Submodel 3

We now come to the last submodel, to the variable we are interested in. As was seen earlier, it was not possible to determine the ration hours directly because the estimated values of the supply schedule were not compatible with the non-linear programming technique used and the solution often was infeasible.

We now use those very estimations, with the newly determined values of si, sa, sh, in oder to determine the optimal ration hours for each type. Recall that the estimated values were :

$$si = 502.56304 - 1.2413873ri - 0.3068840rh + 0.1833586\text{peakavailability}$$

$$ra = 151.56038 - 0.2048264sa + 1.8233839rh + 0.9842071\text{netpeak}$$

$$rh = 37.643363 - 0.1368202sh + 0.3679078ra - 0.5177640\text{netpeak}$$

We have three equations in three variables. Solving for r we can determine the ration hours. sa, si, sh will now be some average for the month, 'netpeak' is also calculated as an average figure for the month. Computing, the optimal ration hours for an average month for the three types of consumers is :

ri = 266.42
ra = 447.68
rh = 34.64

ducing sectors to be the level of restricted output. Here the value of output at constant prices is a proxy for the level of restricted output, because, when devoid of price effects, the change in the value of output over the years is just the change in the level of output.

[6]See Appendix A.4 (2) for the programme.

The present average for a month for the year 1983 is :
ri = 281.73
ra = 439.58
rh = 36.46

4.4 Analysis

The fact that *si* has increased while *sa* has fallen itself points out to the fact that the ration hours for industry should have been reduced and that of agriculture should have increased. Accordingly we find this happening. This only means that under the present system of rationing, which is inefficient, the loss to industry from rationing is higher than the corresponding gain to agriculture from the diverted consumption. It would therefore be optimal to redistribute the supply from agriculture to industry.

This is also in keeping with the empirical evidence that industry suffers substantial losses due to load-shedding or power cuts. Agriculture loses too, but the advantage with agriculture is that though production is energy dependant, it is not electricity dependant. Since the alternative diesel is easily accessible, most agricultural producers who have the means will operate a diesel pumpset. Though diesel is exceedingly costly as compared to the subsidised price of electricity, the loss in output would be greater by not resorting to diesel at all during rationing. Unfortunately, the same is not true of industry, at least in the short run when the technology is given. Technologies built for operation with electricity cannot adapt easily to other alternatives during rationing. Industry should therefore be supplied even more than the present level. It is also the opinion of some economists that due to the heavily subsidised price of elctricity, it is being wastefully spent in agriculture, and so there is no justification for denying industry its due. See Ghosh [1991].

For households, we have proceeded with the assumption that there is an initial rationing in force. As long as this rationing gave rise to a virtual price higher than the actual price, economic loss is positive, and it is optimal to supply more to this sector.

But we must point out what may be regarded as a seeming limitation in the above excercise. This method has only given us an average number of hours per month which can even be transformed to number of hours per day, but it is still only an *average*. Electricity being a product which has time varying demands, it will not be very helpful if the optimal rationing is done without regard to the time of the day. Yet, there is a way to use this analysis optimally. Recall that the rationing for industry and household should be such that the restricted output that results from the rationing should be greater than a predetermined level of output. So, the solution for the optimal supply will also throw up the solution values of the optimal level of *restricted output* that result from the rationing scheme. Therefore, the application of the rationing scheme i.e., average ration hours cannot be arbitrary, since the *restricted output* will depend on the *time* of rationing. The time of the ration hours should be adjusted in such a way that this optimal level of restricted output is produced. Therefore the model presented here is quite useful even though it does not contain any information on the time of rationing.

But, the programme being non-linear, we could not guarantee the uniqueness of such a scheme. Observe that there may be more than one such set of ration hours that minimize welfare loss subject to the constraints.

4.5 Summary

Following up on the last chapter, we have concentrated on the rationing model in this chapter and demonstrated how one can determine an efficient rationing scheme for electricity by choosing to minimize the welfare loss arising from rationing. We first estimated appropriate linear relations between the supply of electricity and the ration hours. By defining the observed level of output as the restricted output, we estimated production functions for the two producing sectors. Then using the results of the production function, we proceeded to determine the optimal supply, and consequently, the optimal ration hours. Our results show that the solution to the optimum requires that the ration hours for industry and household should be reduced, and the increased supply that will result to both these sectors, should come through a transfer from agriculture. That is, the ration hours for agriculture should be increased for minimizing overall welfare loss subject to the constraints of the model.

We must remark that our analysis could have been improved and better methods devised if more and better information were obtainable. There are several areas in the analysis which could have been made clearer with availability of better data. However given this constraint we have been able to devise a mechanism that should certainly prove useful to planners and with more information the finer points of the analysis can be brought out.

Appendix A.4

(1) The following is the programme for the optimal supply to household, written and run on General Algebraic Modelling System (GAMS) Version 2.02 for PC AT/XT.

****

Programme for Sub-Model 1

TITLE HRATN HOUSEHOLD RATIONING PROBLEM
TO DETERMINE THE OPTIMAL LEVEL OF PERCAPITA MONTHLY ELECTRICITY CONSUMPTION SUBJECT TO THE GIVEN CONSTRAINT

SET EXPENDITURE CLASSES 10 k / 1*10 / ; PARAMETER S(k) : Percapita monthly expenditure
PARAMETER R(k) : Initial percapita monthly level of electricity consumption
PARAMETER Y(k) Lower level of p_e^* for each type k, where $p^* > p_e = 0.6783$
PARAMETER S(k) / 1 20.08, 2 36.78, 3 45.697, 4 55.57, 5 65.7,
6 77.14, 7 93.06, 8 121.55, 9 170.95, 10 343.03 / ;
PARAMETER R(J) / 1 0.40560, 0.92773, 3 1.17199, 4 1.34678, 5 1.74789,
6 1.81289, 7 2.0123, 8 2.4538, 9 2.9983, 10 4.1120 / ;
PARAMETER Y(J) / 1 2.256, 2 1.12, 3 0.976, 4 0.943, 5 0.7924,
6 0.812, 7 0.788, 8 0.721, 9 0.732, 10 0.958 / ;
PARAMETERS PRICES P1 P2 P3
'OTHFUEL' P1 = 380.65
'FOOD' P2 = 261.7
'OTHNONFOOD' P3 = 279.31

VARIABLES SH

```
            PSTAR
            LOSS ;
EQUATIONS VIR
            WELOSS ;
```

$$\text{VIR.. PSTAR} = E = .0098 * (R(J) + .0002258 * P1 + .0743513 * P2 + .2635677 * P3 - .6783 * SH)/(SH + .0016399);$$

$$\text{WELOSS.. LOSS} = E = (\text{PSTAR} - 0.6783) * SH;$$

```
*INITIAL VALUE FOR VARIABLE ;
SH.L = R(J) ;
*BOUNDS FOR VARIABLES ;
LOSS.LO = 0 ;
PSTAR.LO(J) = Y(J) ;
SH.LO(J) = R(J) ;

MODEL HRATN / ALL / ;
SOLVE HRATN MINIMIZING LOSS USING NLP ;

PARAMETER REP SUMMARY REPORT ;
REP = SH.L(J) ;
DISPLAY REP ;
```

****

(2) The following is the programme for the optimal supply to industry and agriculture , written and run on General Algebraic Modelling System (GAMS) Version 2.02 for PC AT/XT.

****

Programme for Sub-Model 2

```
TITLE RATION POWER RATIONING PROBLEM
```

TO DETERMINE THE OPTIMAL SUPPLY TO INDUSTRY AND AGRICULTURE, SUBJECT TO THE OUTPUT CONSTRAINT, CONSTRAINTS FOR THE BOUNDS AND THE OVERALL CAPACITY CONSTRAINT

```
SET AGRICULTURAL DIVISIONS J / 1*12 / ;
PARAMETER N1 : The estimated value of that part of output not involving
SI
PARAMETER N2(J) : The estimated value of production not involving SA
PARAMETER INDEX1 : The predetermined level of Industry output
PARAMETER INDEX2(J) The predetermined level of Agricultural output for
each J
PARAMETER W(J) : The share of each agricultural divisiom in total electric-
ity consumption
PARAMETER SH ;
SH = 1751.61 ;
N1 = 93467000000 ;
INDEX 1 = 1.15E+10 ;
PARAMETER W(I) / 1 0.215324, 2 0.214046, 3 0.045308, 4 0.079361,
                 5 0.121364, 6 0.093302, 7 0.058368, 8 0.075838,
                 9 0.077683, 10 0.01056, 11 0.008183, 12 0.00712 / ;
PARAMETER N2(I) / 1 30.45, 2 29.808, 3 29.275, 4 29.308,
                  5 29.564, 6 27.945, 7 29.101, 8 29.432, 9 29.253,
                   10 28.574, 11 26.656, 12 24.137 / ;
PARAMETER INDEX2(I) / 1 21780107, 2 7060521, 3 4718683 4 9497624
                      5 610646, 6 665356, 7 4763178, 8 5209871,
                      9 4445046, 10 5023393, 11 1090313, 12 92313 / ;

POSITIVE VARIABLES SA, SI ;
VARIABLES SA
          SI
          LOSS ;
```

```
EQUATIONS MINO1
          MINO2(I)
          CON1
          CON2
          CON3
          CON4
          CON0
          CA
          OB ;

CON1.. SI =L= 74 ;
CON2.. SA =L= 8.03 ;
CON3.. SI =G= 60 ;
CON4.. SA =G= 7.95 ;
MINO1.. N1 - 2420400000*SI + 21651883*(SI**2) =G= 1NDEX1 ;
MINO2(I).. EXP(-9.78705 + N2(I) - 0.3121463*W(I)*SA) =G= INDEX2(I) ;
CA.. (SI**2 + EXP(SA)) =L= 8874 - 1751.61 ;
CON0.. SI - EXP(SA) =L= 10 ;
OB.. LOSS =E= N1 - 2420400000*SI + 21651883*(SI**2) +
          SUM(I, (-9.78705 + N2(I) - 0.3121463*W(I)*SA)) ;

BOUND FOR VARIABLES ;
LOSS.UP = 7.54E+10 ;

MODEL RATION / ALL / ;

SOLVE RATION MAXIMIZING LOSS USING NLP ;

PARAMETER Q,P ;
Q = EXP(SA.L) ;
```

```
P = (SI.L)**2 ;
DISPLAY SI.L, SA.L, Q,P ;
```

Chapter 5

The Pricing Option

5.1 Introduction

Optimal electricity supply for a supply constrained firm is to choose that efficient rationing scheme which puts the limited resource to the best use. The rationing scheme is thus an optimal allocative mechanism in an excess demand situation. But this is only a short term measure, and deals essentially with the redistribution of the scarce resource. In the longer run, supply has to be increased to keep pace with the demand. Optimal electricity supply will then mean the supply at which the demand is satisfied.

This level of supply has to come either from increased generation within the State, or from imports and purchases from other State Electricity Boards in the region. In the context of a developing country like India, increased generation from new generating units will mean extra investment which is not easily affordable. But there is another malady in the system which, as many economists and other specialists point out, if remedied, can go a long way in improving the supply position in the country. The malady concerns the capacity utilization of electric power plants, which in more technical terms is known as the plant load factor (PLF). The PLF is defined as the ratio of the energy generated during a given period to the energy that would have been supplied had the generator operated at maximum continuous rating throughout the period.

A good part of the inefficiency of supply operates from most generating units having a poor PLF. This is due to vintage technologies, poor maintenance procedures leading to frequent breakdowns, delays in repairs and various other reasons. All this means that the affected plants do not operate upto full capacity. Consequently, supply to consumers falls far short of the capacity, even when the demand is as high as the capacity level. Besides, poor transmission lines set up by the State Electricity Boards are not able to transmit high voltage generation and consequently electricity generated is wasted along the way before it reaches the consumers. There are also instances of large scale theft where a considerable quantity of power is lifted without the consumer accounting for it. It is estimated that the extent of transmission and distribution losses in India is to the tune of nearly 20 % of electricity generated. If the supply position has to be improved, then the PLF has to increase, and the transmission and distribution losses should be drastically reduced. But these suggestions are technical improvements to be taken up by the Board themselves. The economist has really little to offer by way of detailed suggestions for improvement in this area except for the general suggestion that the PLF has to be improved.

But there is another important area which concerns the economics of supply, and except for a few observations by the Boards themselves, not much attention has been paid to it. This concerns the very nature of power planning in the country.

5.2 The distribution of generation

Most of electricity generation in India is in the States, under State Electricity Boards – the percentage is about 70 % . But power generation has to depend on natural resources of which there is an imbalance among the regions of the country. In order to avoid any disputes that might arise out of such an imbalance and to exploit such resources fully in those states which might not have the requisite resources to undertake huge investments, as well as to help the power deficient states, the Central government decided to set up generating units which could take up this task. The National Thermal Power Corporation (NTPC) and the National Hydel Power Corporation (NHPC) came into being in 1975, set up under a large investment plan and with a capacity to generate vast output levels. It is estimated that at the end of the seventh plan, the share of the State Electricity Boards, the Central units and the private units[1] would be 70%, 25% and 5% respectively, of the amount of electricity supplied[2].

The objective of the central government in setting up the NTPC is to ensure that a Central station can take care of the needs of all states during a shortage which cannot be overcome even through interstate purchases. The Central units can however sell only to the State Electricity Boards (to be denoted SEBs hereafter in this chapter), who can then supply the consumers. The thermal stations of the NTPC units are located at the coal pit-heads giving these stations an advantage over thermal units of the SEBs, because the need for long-distance transportation of coal to the generating centre is now greatly reduced. Besides, the NTPC units are also large with huge fixed costs and thereby enjoy economies of scale ; another feature is that they were set up as super thermal power stations to avail of high thermal efficiency based on the latest technology, and can provide sustained load for base load operations at low fuel consumption levels, or low marginal cost.

In comparison, the thermal generating units of the SEBs are of vintage technology, smaller size, and high marginal cost. Commercial considerations as well as overall production efficiency would suggest that the SEBs use up the vast low cost generation of the NTPC units, that is, back down their own units during low demand levels and then bring into operation their own high

[1]Examples are : Tata Electric Companies, The Ahmedabad Electric Company, Calcutta Electricity Supply Corporation etc.

[2]Report of the sub-group on Energy Pricing, SEBs finances and related issues : Ministry of Energy, 1989.

cost plants only when the demand merits it. This is known as the 'merit order operation' and if followed will result in the production of the socially optimal level of output that is, the economic generation of power.

5.3 Points of Conflict

The production of the socially optimal level of output does not, however take place in practice. This is due to the irrational tariff stucture that exists for the purchase of the low-cost power by the SEBs from the NTPC. Until recently a flat rate or one part tariff was in force. This one part tariif is substantially higher than the cost the Boards would incur from production from their own stations. The one part tariff had been designed by the NTPC so as to recover the high fixed costs. This is a policy that the SEBs had always militated against, since buying from NTPC at the expense of their own plants especially when they they have to sell subsidised power to their agricultural consumers, would result in considerable commercial losses to the SEBs. Yet, the NTPC has always argued for a high tariff on account of its rising investment costs (due to capacity accretion), increasing operational costs, and mounting arrears/outstandings from SEBs partly due to the SEBs earning insufficient revenue when they subsidise some of their consumers.

As a consequence, the one part tariff has led to the inefficient generation of power, underutilisation of the low cost NTPC units, losses to the SEBs and a consequent shortfall in the supply of power to consumers.

It was in this context that the Ministry of Energy of the Government of India set up a Committee (Department of Power, [1990]) under the chairmanship of Mr. K.P. Rao to examine possible solutions to the above problems. The objective was that a sound pricing policy should be devised that would "generate such signals as would encourage and motivate maximization of economic generation of power and optimisation of grid operations and that any conflicts of commercial interests between the various organisations in the matter of maximisation of economic generation of power and its absorption by constituent Boards should be eliminated, *irrespective* (italics added) of whether such generation takes place in the Central generating stations or the stations of a Board"[3].

The Committee recommended replacing the present one part tariff with a two part tariff[4]. The general view was that this would be financially viable to both the NTPC and the SEBs as well as promote the efficient allocation of resources by inducing the economic generation of power, and efficient utilisation of the NTPC plants through merit order operation. The Committee set up by rhe government (under the chairmanship of Mr. K.P. Rao) recommends a two part tariff that consists of a variable part based on fuel and secondary oil, and a fixed part which covers the fixed costs of the NTPC. The method of sharing the fixed costs has however, been unspecified, to be decided by the Regional Electricity Boards (REBs) in consultation with the State Electricity Boards.

The recommendations of the K.P. Rao Committee have been accepted in principle by the SEBs and the NTPC. However, several points remain to be clarified. Since the main difference between a two part tariff and a one part tariff lies in the fixed component of the price, a great deal of importance must be attached to it if the two part tariff is to be optimal. But the Committee has only given certain suggestions on the sharing of the fixed costs and kept even those suggestions general and somewhat misleading.

The alternatives for the sharing of the fixed cost as per the recommendations of the Committee are as under:

(a) in proportion to the energy drawals during the month; or

(b) in proportion to the capacity entitlement from the central generating stations; or

(c) pooling the costs of central power purchase and price the purchase by each Board of such power at the average rate; etc.

---

[3]Report of the Committee on Fixation of Tariffs for Central Sector Power Stations, page 5, Ministry of Energy 1990.

[4]An independant report from the Bureau of Industrial Costs and Prices (BICP) regarding the same issue, also recommended a two part tariff.

The above recommendations are not really an improvement over the previous system as we shall see below. Note that (a) of the recommendations is just another way of imposing a one part tariff – the fixed cost is not really independant of the level of output. (b) depends on how the capacity entitlement is decided – it is the Committee's own view that under the present system there is no way to ensure that states receive their full quota of capacity ; since interexchange might take place before power reaches the state that is entitled to it, there is no way to ensure that merit order operation will indeed take place – this is therefore not optimal. (c) is an average cost that all the users of a particular region should pay, irrespective of how much they draw. This might mean that a particular SEB whose demand from NTPC is small might find the fixed cost too high compared to the previous tariff, and so may not purchase at all. This is again not efficient.

Unless the Regional Electricity Boards come up with an efficient solution of sharing the fixed costs the governement's objective of ensuring merit order operation with a two part tariff may not really be met, because an inefficient solution might result in some SEBs actually doing worse in terms of profits.

Yet the problem is interesting from the point of view of efficient allocation of resources. This chapter will deal with this problem and study the following issues : Suppose that under a flat tariff or one part tariff (hereafter OPT) system, it was not feasible that both NTPC and the SEBs would make nonnegative profits. Then, is it true that a two part tariff (hereafter TPT) will lead to both parties making nonnegative profits under the present conditions ? If so, then the properties of such a tariff will be studied to see if optimal electricity supply can in practice hold under an appropriate tariff structure.
Section 5.4 spells out the objectives of the two players. Section 5.5 sets out the model and its assumptions, defines the infeasibility problem and presents the main results under the above assumptions. Section 5.5 provides a different version of the infeasibility problem and the result that follows under a TPT. Section 5.6 redefines the objective of the NTPC as that of maximizing welfare (SEB's objective is unchanged), and provides the results under a two part tariff.

Section 5.7 looks at the SEB redefining its objective to profit maximization (with the NTPC maximizing first profits, and then welfare) and provides the solution under a TPT. Section 5.8 is an extension of the basic model of 5.5 where we bring in uncertainty. The last section 5.9 is the concluding section and discusses the results of the chapter and its policy implications.

5.4 The Objective

In this chapter, a game theoretic approach is adopted towards the above problem. We will assume that the SEBs have their own objectives (different from that of NTPC) and that the NTPC has to take this into account while solving its own maximization, that is, the feasible set for the NTPC is found by solving the SEBs problem. This is set up as a two player Stackleberg game with NTPC as the leader and a representative SEB as the follower. The NTPC first announces its pricing policy and the SEB then chooses its output configuration. The notion of equilibrium we will be using to solve this game is the standard subgame perfect Nash equilibrium. For simpicity, we shall consider only a single SEB. The generalization to the many follower case is then straightforward.

While the previous chapters dealt with the allocation of supply to each type of consumer demanding from the SEB, here we shall be considering overall supply. The emphasis of this chapter is on the supplier or the producer, while the thrust of the previous chapter was on the consumer. Here the role of the consumer is only through the demand that he makes on the system and we shall examine the producer's (SEB's) response to this demand.

Another point to be remembered is that while discussing the costs of the two firms, we are essentially comparing only the thermal units of the SEBs with the NTPC. There are also hydel units within the SEBs, but the share is comparatively low, and they can only be compared with the NHPC. But that is a different area of research which this chapter does not consider.

The basic objective of the SEBs we shall assume is to maximize generation from their own plants. This can be justified on the grounds of the incentive schemes prevalent in the SEBs. The present structure of incentives in production is heavily linked to the plant load factor. The Central Electricity Authority provides bonuses to the SEBs for increased plant load factors. The SEBs themselves provide bonuses and rewards to their employees for achieving satisfactory levels of PLF. The K.P. Rao Committee in its report also mentions the fact that there is 'undue' emphasis on the PLF as a measure of efficient performance of the generating stations[5]. The BICP report points out that "under the system of PLF based tariff, the most accomodating stations backing down generation during off-peak loads as per grid instructions, stand to suffer the most in terms of station performance, 'sales realisation' and profitability (if profitable)[6]. All this indicates that the SEBs are interested in showing increased levels of generation from their own plants and therefore our assumption is justified. However, we assume that SEBs are not totally indifferent to profit levels. They maximize output subject to a non-negative profit constraint, and if the constraint cannot be met, they just minimize losses.

On the other hand, we assume that the NTPC units are profit maximizers. The argument given by the representatives of the NTPC for profit maximization is that the paid up capital of NTPC is financed from equity participation and loans from international loan agencies. Interests and dividends have to be paid out, thus making the functioning on a commercial line necessary.

5.5 The Model and Assumptions

Consider the industry as consisting of two firms only, the NTPC and a representative SEB. The SEB is the final distributor of electricity. The NTPC can sell only to the SEBs. It cannot sell directly to the consumers. Production takes place in both the firms, provided the demand merits it. An important point to be stressed here is that the model deals essentially with the off-peak output

[5] pages 27-28.

[6] Pricing Policy for Electricity Generation : The BICP Approach 1990, page 3.

and the off-peak price for the consumer. The controversy over the output mix between NTPC and the SEBs is essentially for the off peak period because as explained before, efficiency requires that the NTPC units be allowed to take care of the base load and the SEBs bring into operation their own plants (in addition to the NTPC units already running), only at high demand levels. At high demand levels the NTPC can run into a capacity constraint, which will necessitate SEB production. Therefore the intersting case is really the offpeak period, and the extension to other periods is straightforward, and does not yield any new results.

Since the NTPC has to function on commercial lines, we assume it is profit-maximizing. The SEB is assumed to maximize output subject to a non-negative profit constraint. Further, the following assumptions are made:

Assumption 1 :

(a) For simplicity, the marginal cost of NTPC is assumed to be constant at a level b_n. For the present it has no capacity constraint but this can be incorporated without any difficulty.

(b) The price p_n charged by NTPC is uniform for all levels of output.

(c) The marginal cost of the SEB is positive, once continuously differentiable, and an increasing function of the SEB output Q_s. So $C(Q_s) > 0$ and $C'(Q_s) > 0$. The marginal cost curve becomes asymptotic to the capacity level $\overline{K}_s$ i.e., $\lim_{Q_s \to \overline{K}_s} C'(Q_s) = \infty$.

(d) The SEB has a higher marginal cost but a lower fixed cost compared to the NTPC i.e., $C'(0) > b_n$ and $f_s < f_n$, where f_s and f_n are the fixed costs of the SEB and the NTPC respectively.

(e) The demand function is negatively sloped and once continuously differentiable, $D(p_s) > 0$, $D'(p_s) < 0$. where p_s is the price charged to the consumers. The demand that we consider here is the total demand of all consumers in that period. The price that we consider here is the average price for all types of consumers in that period.

We assume that this is a game of complete information i.e., all the above information are common knowledge. We let Q_s and Q_n stand for the SEB output and the NTPC output respectively, and we denote π_s and π_n as the profits of the SEB and NTPC respectively.

The problem for the NTPC in the OPT case is then the following :

$$\text{Max}_{p_n} \quad \pi_n(p_n) = p_n Q_n(p_n) - b_n Q_n(p_n) - f_n$$

where $Q_n(p_n)$ solves the following problem

$$\begin{aligned} \text{Max}_{Q_s,Q_n} \quad & Q_s \\ \text{s.t.} \quad \pi_s &= p_s D(p_s) - C(Q_s) - p_n Q_n - f_s \geq 0 \\ Q_s + Q_n &= D(p_s) \\ Q_s &\leq \overline{K}_s \end{aligned}$$

However, if $\forall \; Q_s, Q_n$, we have the case that $\pi_s < 0$, then the SEB solves,

$$\begin{aligned} \text{Max}_{Q_s,Q_n} \quad & \pi_s \\ \text{s.t.} \quad Q_s + Q_n &= D(p_s) \\ Q_s &\leq \overline{K}_s \end{aligned}$$

Solving the above problem we obtain the SEB demand from NTPC as a function of the NTPC price i.e. $Q_n = Q_n(p_n)$.

Thus the problem for the NTPC in the one part tariff case is the following

$$\text{Max}_{p_n} \quad \pi_n(p_n) = p_n Q_n(p_n) - b_n Q_n(p_n) - f_n$$

It it is the case that the NTPC one part tariff was too high to enable the SEBs to make nonnegative profits, then now define the following :

Definition 1 : There is a fundamental infeasibility problem under the one part tariff for all p_n, either the NTPC profits or the SEB profits are negative, i.e., either $\pi_n < 0$ or $\pi_s < 0$. So for all p_n, both the firms cannot be making non negative profits simultaneously.

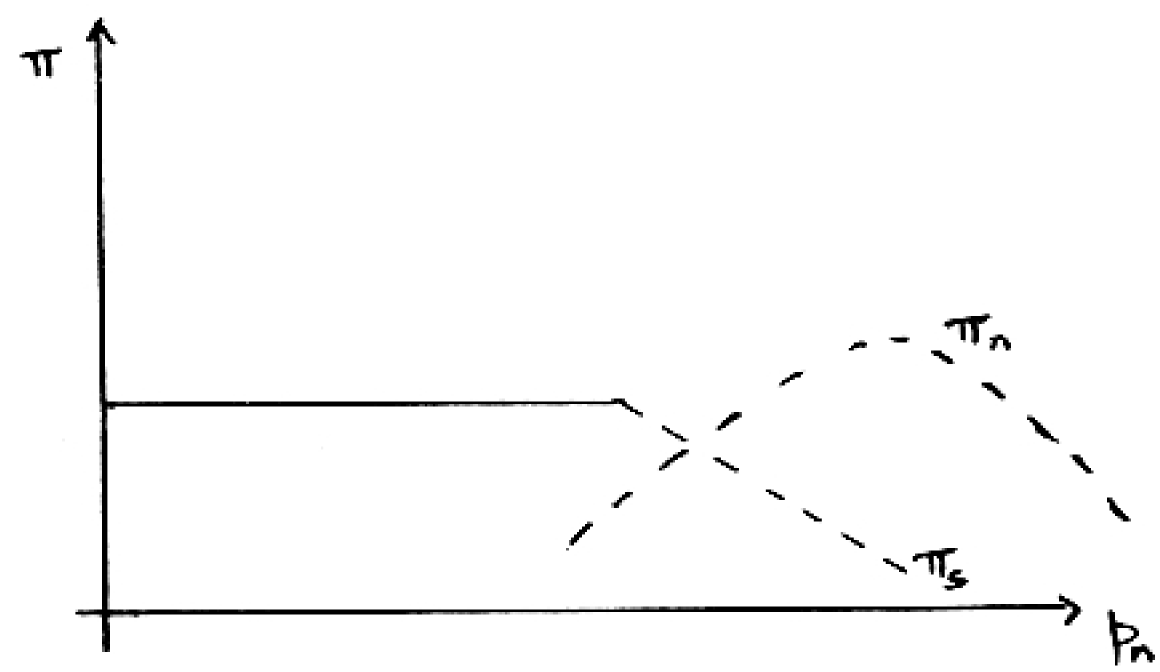


Figure 5.1: Infeasibility zone.

Define $\overline{p}_n$ as the maximum p_n for which the SEB can make non-negative or zero profits. At $\overline{p}_n$, clearly, we must be at the profit-maximizing output configuration (for otherwise, we would have a strictly positive profit at the profit maximizing configuration. Then, for a small enough increase in p_n, profits would still be non-negative at the earlier output configuration, contradicting the definition of $\overline{p}_n$.).

So at

$$p_n = \overline{p}_n,\ Q_s = \overline{Q}_s \text{ s.t. } C'(\overline{Q}_s) = \overline{p}_n$$

and

$$\overline{Q}_s + Q_n = D(\overline{p}_s) \text{ s.t } p_n = MR(D(\overline{p}_s))$$

Note that even if there existed an infeasibility under the one part tariff the principal i.e., the NTPC has to set a price p_n. Since it is not possible to devise a tariff that assures non negative profits to both, NTPC will just maximize its objective by meeting all its constraints. For the NTPC, its constraint is the subgame where the SEB maximizes its own output subject to the constraints that it makes nonnegative profits and that total demand is met. By definition, we know that for any $p_n > \overline{p}_n$, SEB makes negative profits if it wants to meet its whole demand. The feasible region where the SEB constraints can be met is $p_n \leq \overline{p}_n$. So this is the region that the NTPC has to concentrate on and it has to minimize losses (minimize negative profits, since for all $p_n \leq \overline{p}_n$ it makes negative profits). NTPC has then to choose $p_n \in [0, \overline{p}_n]$. Since π_n is increasing in p_n, it will choose $\overline{p}_n$ as the point at which its losses can be minimized after solving the SEBs problem. Under the one part tariff therefore, NTPC will set $p_n = \overline{p}_n$.

A formal proof of this step is provided in the appendix A.5 (1).

Following from our earlier chapters, we shall still consider the case where consumer prices are rigid, and then solve the problem for this case. The fact that consumer prices are fixed can be justified on the grounds that prices for domestic and agricultural sectors are really fixed by the state government on social grounds and the only possible flexibility seems to be with regards to the industrial consumers.

So we bring in the following assumption.

Assumption 2. The consumer price of electricity is kept fixed at the level $\overline{p}_s$.

The following result shows that if the price of elctricity is fixed, then there is too little flexibility in the system for even a two-part tariff to help.

Proposition 1. *Under assumption 2, an infeasibility under the one part tariff cannot be overcome by a two part tariff, if the SEB, according to its output maximizing hypothesis, seeks to produce atleast as much as it was producing under the OPT.*

Proof. Define $\overline{p}_n$ as before. Let the SEB output at the one part tariff $\overline{p}_n$ be $\overline{Q}_s$. See Figure 5.2. Clearly for $\overline{p}_n$, $\pi_s = 0$, $Q_n = D(\overline{p}_s - \overline{Q}_s)$ where $C'(\overline{Q}_s) = \overline{p}_n$. For any $p_n < \overline{p}_n$, $Q_s > \overline{Q}_s$ since as p_n declines the SEB can substitute Q_s for Q_n without violating the non-negative profit constraint. For $p_n > \overline{p}_n$ since the SEB by assumption maximize profits $Q_s \geq \overline{Q}_s$.

Now for the SEB to agree to a two part tariff we must have $Q_s \geq \overline{Q}_s$, i.e., it must produce at least the $\overline{Q}_s$ level of output from its own plant even under the

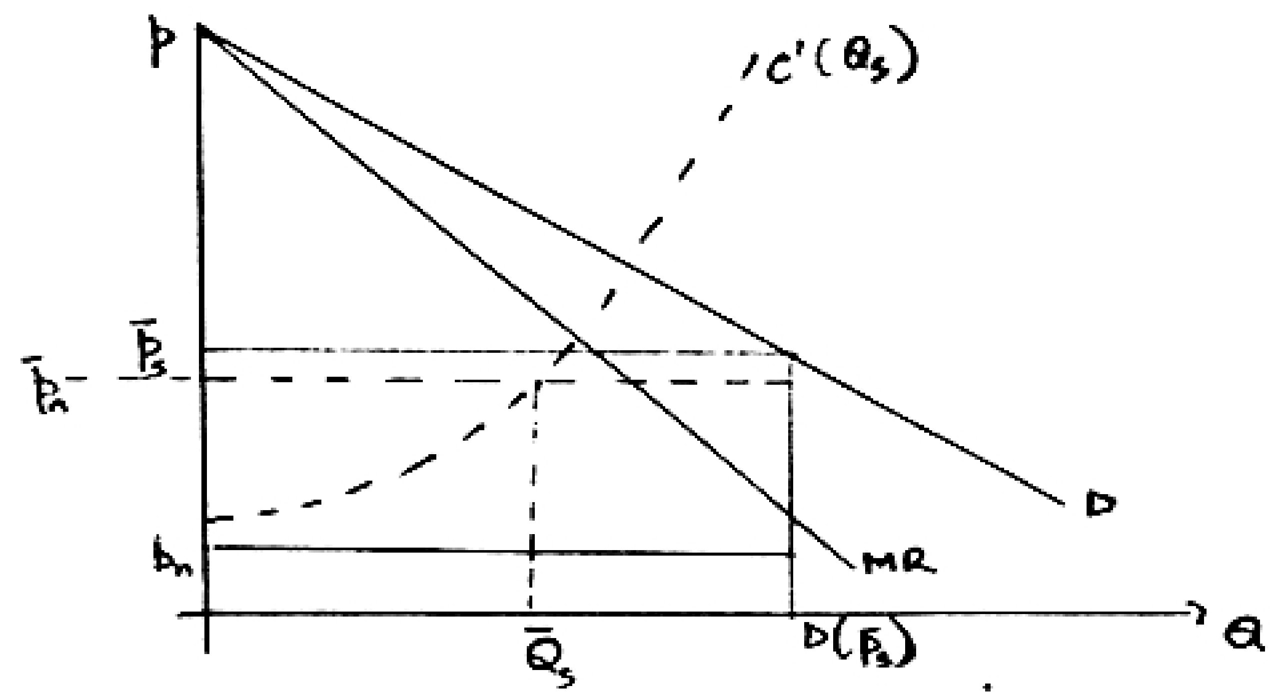


Figure 5.2: Infeasibility eith a TPT

TPT. Now under the two part tariff, when p_n falls below $\overline{p}_n$, we know that Q_s increases, and since demand is fixed, Q_n falls. This implies that the aggregate profits ($\Pi = \pi_n + \pi_s$) fall further. (Note that under infeasibility, ($\Pi = \pi_n + \pi_s$) is negative because SEB makes zero profits so $\pi_s = 0$ and NTPC makes negative profits so $\pi_n < 0$).

Under the TPT aggregate profits is still negative and of a greater magnitude, because compared to $\overline{p}_n$, revenues are still the same(consumer price is fixed), but the cost structure can only be worse, as production from the high cost plant has increased, that is, the higher cost SEB output replaces the lower cost NTPC output. Since by infeasibility $\pi_n < 0$ for any $p_n < (\overline{p}_n)$ under the one part tariff, $\pi_n < 0$ for the TPT p_n as well. ∎

The only solution in this case would be to change $\overline{p}_s$. The usual argument for lifting SEBs out of negative profits or low profits is to revise the consumers price $\overline{p}_s$ upwards. Note that aggregate profits is

$$\Pi = \pi_s + \pi_n = p_s D(p_s) - C(Q_s) - b_n(D(p_s) - Q_s) - f_s - f_n$$

. This is maximized at the point where the marginal revenue of $(Q_s + Q_n) = b_n$, or where marginal revenue is equal to the short run marginal cost. Therefore, since the aggregate profit maximizing point is at $MR(\overline{Q} = Q_s + Q_n) = b_n$, it is optimal to produce at this level $\overline{Q}$. This implies that $\overline{p}_s$ should be increased, but only if the demand $D(\overline{p}_s) > \overline{Q}$. For a demand level which is lower than $\overline{Q}$, i.e., for $D(\overline{p}_s) < \overline{Q}$, it would imply that the price fixed was too high and $\overline{p}_s$ should in fact be lowered so that output and aggregate surplus can expand to the level at $\overline{Q}$.

In peak load pricing literature it is often suggested that the off-peak price be lowered in order to induce more consumption in that period. We have just given an argument that explains under which conditions this should be done. If the consumer demand for a fixed price in the period under consideration was greater than the point at which $MR(\overline{Q}) = b_n$, then prices should be revised upwards.

So we have just seen from Proposition 1 that if consumer prices are fixed, and the SEB is output maximizing, the two part tariff is not going to solve the problem of infeasibility. It is clear that one of the above two asssumptions should be relaxed. We shall first consider the case of relaxing the assumption of fixed consumer prices, while keeping the objective of the SEBs unchanged.

In the following case we drop Assumption 2. This could be interpreted as the case where the State government does not fix the price administratively, but allows the SEB to decide on a profit maximizing price. Before we proceed to determine if the TPT can overcome the infeasibility problem now, let us characterise the behavior of the SEB in equilibrium, as p_n changes.

Proposition 2. (i) *For any $p_n > \overline{p}_n$, SEB profits are negative and the SEB chooses the profit maximizing point. For any $p_n \leq \overline{p}_n$ we have that the SEB makes exactly zero profits at the SEB optimum, and aggregate output is such that the marginal revenue is equated to the NTPC price.*
(ii) *For $p_n > \overline{p}_n$ as p_n decreases, SEBs losses decrease, SEB output decreases and purchase from NTPC increases. For $p_n \leq \overline{p}_n$ as p_n decreases, SEB output as well as the the total amount supplied to consumers increases.*

Proof.

2(i) : The first part follows trivially from the definition of $\bar{p}_n$ and our behavioural assumption.

For the second part if we have that $\pi_s > 0$ at the optimum $\overline{Q}_s$, then clearly this positive profits can be used to increase Q_s until profits are reduced to zero, thus contradicting the optimality of the solution. Now, without loss of generality, assume that $MR(Q_s+Q_n) > p_n$. Now by increasing Q_n a little bit we can increase π_s to a positive level (because the SEB can earn more from the sale of Q_n than the cost of purchase p_n). Again these positive profits can be utilised to produce a little more of Q_s, which again contradicts the optimum. Therefore at the optimum, total output is decided at the point where $MR(Q_s+Q_n) = p_n$.

2 (ii) : The first part follows from the profit-maximizing behaviour of the SEB in this zone. In the second part the result that $Q = Q_s + Q_n$ increases follows because we know that $p_n = MR(Q)$ and since the MR curve slopes downwards, this intersection can only take place at a higher Q. The fact that Q_s increases follows because with a fall in p_n even at the earlier output configuration of Q_s and Q_n, π_s is positive and hence Q_s can be increased.

We will next investigate the question whether we can have a feasible solution under a two part tariff. The fixed part of the tariff F_n is independent of the level of output and the variable part p_n is the per unit cost of purchasing the NTPC output. The problem is now as follows :

$$\text{Max}_{\{p_n, F_n\}} \quad p_n Q_n + F_n - b_n Q_n - f_n$$

where Q_n is obtained from solving the SEB problem for given p_n, F_n.

Since the SEB has accepted the TPT over the OPT, it is reasonable to impose the restriction that even in the TPT the output will be $Q_s \geq \overline{Q}_s$ where $\overline{Q}_s$ is the solution for the OPT case when the price was $p_n = \bar{p}_n$.

Claim 1 :

(a) *In any solution of the TPT case we must have* $Q_s = \overline{Q}_s$.

(b) *For any* p_n *in the TPT case,* F_n *should be such that,* $p_s(\overline{Q}_s+Q_n) - C(Q_s) -$

$p_nQ_n - F_n = 0$ and $MR(\overline{Q}_s + Q_n) = p_n$ in the optimum. That is, in the optimum F_n is always adjusted in such a way that it leaves the SEB with zero profits.

Proof :
(a) Suppose Q_s was greater than $\overline{Q}_s$, then F_n can be increased slightly such that the SEB is forced to substitute Q_n for Q_s, so that both $(p_n - b_n)Q_n$ and F_n and hence the profit of NTPC can be increased.

(b) Suppose part (b) of the claim did not hold. Then the level of F_n must be such that it gives positive profits. But since the SEB is output maximizing, Q_s can be increased out of this positive surplus thus contradicting the optimum. If the level of F_n was too high as to make the surplus negative, then this would give $Q_s < \overline{Q}_s$ for $\pi_s = 0$ at the the solution, contradicting $\overline{Q}_s$ as the optimum.

Clearly then F_n is going to push the SEB to the zero profit level. Also, for any $p_n > b_n$, the NTPC profit can always be increased by reducing p_n and increasing F_n so that Q_s is maintained at $\overline{Q_s}$.

Proposition 3 : *A sufficient condition for a solution of the two part tariff problem is that aggregate profits are non-negative if the SEB output is the at the OPT level and the NTPC output is such that price that it offers equals the marginal revenue of the SEB. i.e., $\Pi = p_s(D(p_s) - C(\overline{Q}_s) - b_nQ_n - f_n - f_s \geq 0$, where $Q_n(p_n)$ solves $MR(\overline{Q}_s + Q_n) = p_n$.*

Proof : In effect, the NTPC is maximizing the aggregate profits for $Q_s = \overline{Q}_s$, since by suitably changing F_n it can appropriate all the surplus. See Figure 5.3. The aggregate profit (sum of SEB and NTPC surplus) function is:

$$\Pi = p_sD(p_s) - C(\overline{Q}_s) - b_nQ_n - f_s - f_n$$

It is easy to check that this function is concave in p_n, and attains its maximum at $p_n = b_n$. (The formal proof is in Appendix A.5(2).) So that, provided $\Pi > 0$

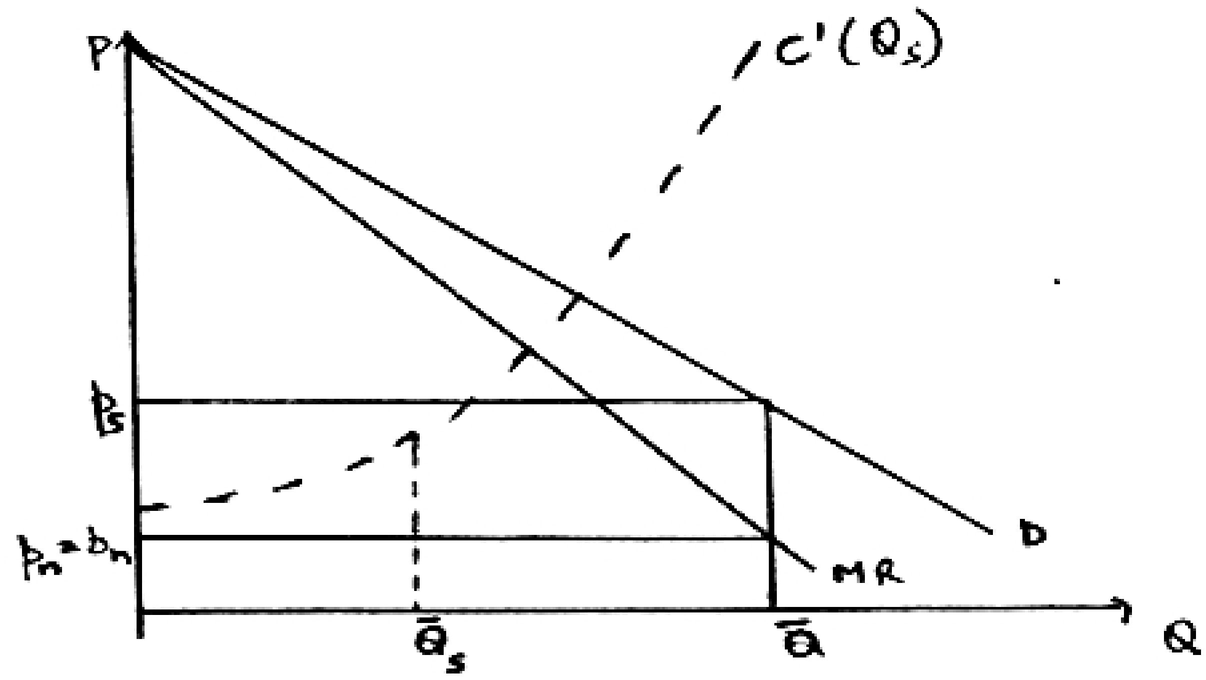


Figure 5.3: Feasibility with a TPT

at $p_n = b_n$ it is always possible to have a feasible solution for the TPT case.

However, observe that here, the feasibility is not automatically due to the reduced p_n alone, as is usually claimed by the SEB. Here, the positive F_n is exerting a disciplinary effect on the SEB output. Through the manipulation of F_n, the NTPC is preventing the SEB from expanding Q_s too much and thus from pushing up costs too much. Note that without this effect there would be no surplus to transfer to NTPC at all.

5.5.1 Infeasibility Variation

We have seen therefore, that the two part tariff can overcome the feasibility that we had defined, only if the consumer price was variable. We had defined the fundamental infeasibility in terms of there being no OPT such that both parties could make nonnegative profits, *if consumer demand had to be met.* An interesting extension is asking the question whether the infeasibility could also have risen if the constraint of output matching consumer demand at the fixed price, was violated.

That is, consider the following situation : Suppose the SEB could make nonegative profits for any OPT p_n, and consumer prices were fixed, but suppose this would mean that total demand at the given prices was not completely met, then is it possible to devise a two part tariff that can solve this problem ?

In this section we are turning back to our first case, where consumer prices are fixed (so demand is fixed), but there is an infeasibility because while both parties may make nonnegative profits, the optimum leaves us with some unmet demand. We shall define this formally below.

Definition 2 : There is a basic infeasibility problem under the one part tariff, when consumer prices are fixed, if for all p_n, either the NTPC makes nonegative profits, or there is some unmet demand in the optimum i.e., $Q_s + Q_n < D(\overline{p}_s)$.

This only means that if the demand had to be met, then this could only have been possible with a lower p_n, a point at which NTPC would make negative profits. Therefore, there exists a basic infeasibility where these two cannot hold simultaneously. We wish to examine if a two part tariff can overcome the infeasibility. Before we proceed we need to make another assumption.

Assumption 3 : The marginal cost of the SEB, $C'(Q_s)$ is not asymptotic to $\overline{K}_s$. It actually hits $\overline{K}_s$ after which it becomes vertical.

The above assumption can be rationalized as follows. The true $C'(Q_s)$ we suppose is still asymptotic to some $\overline{K}_s$. However, for any $Q_s > \overline{K}_s$, we assume that the marginal cost becomes unacceptably high, so that $\overline{K}_s$ acts as an effective cut-off point.

Proposition 4 : ***Under assumption 3, an infeasibility under the OPT can have a feasible solution in the TPT case.***

Proof: Let it be that $\overline{p}_s\overline{K}_s - C(\overline{K}_s) - f_s > 0$ where $\overline{p}_s$ (also $D(\overline{p}_s)$) is fixed, and that $p_n(OPT) > \overline{p}_s$. Now the SEB can use the excess profits out of its own units to expand output of Q_n as well (We assume that once $Q_s = \overline{K}_s$, the SEB tries to minimize unsatisfied demand). If it is the case that for the needed $Q_n = D(\overline{p}_s) - \overline{K}_s$, we have $\pi_s < 0$, then Q_n or the purchase from NTPC will

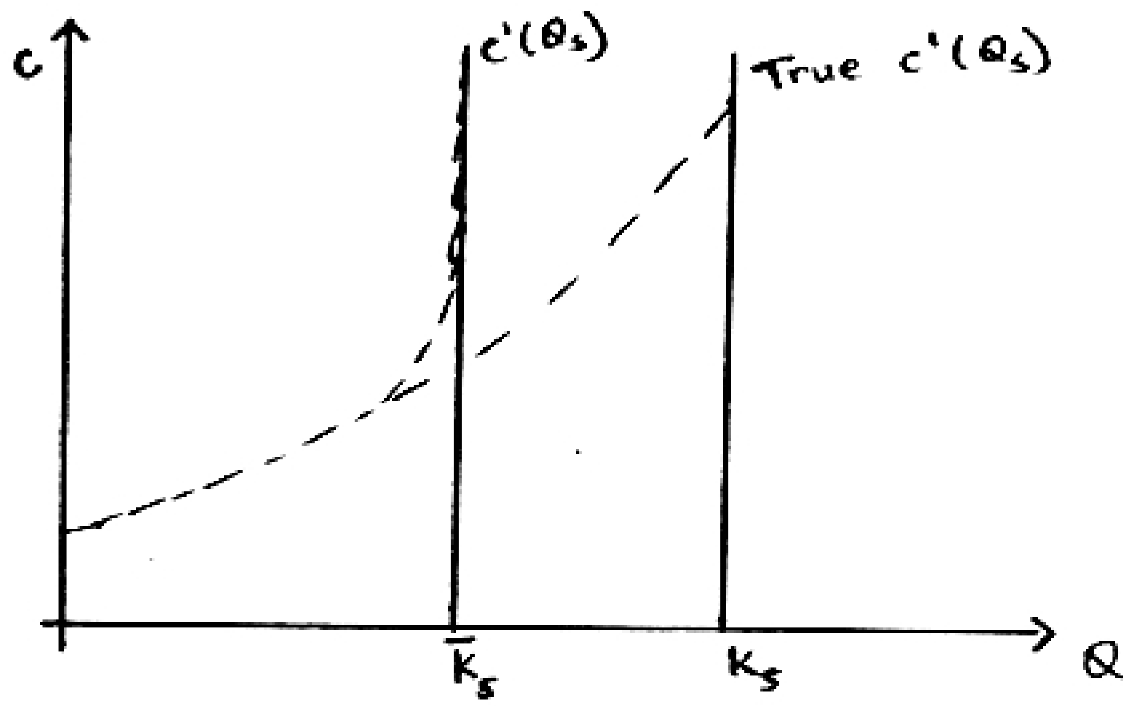


Figure 5.4: The cost curve and capacity constraint

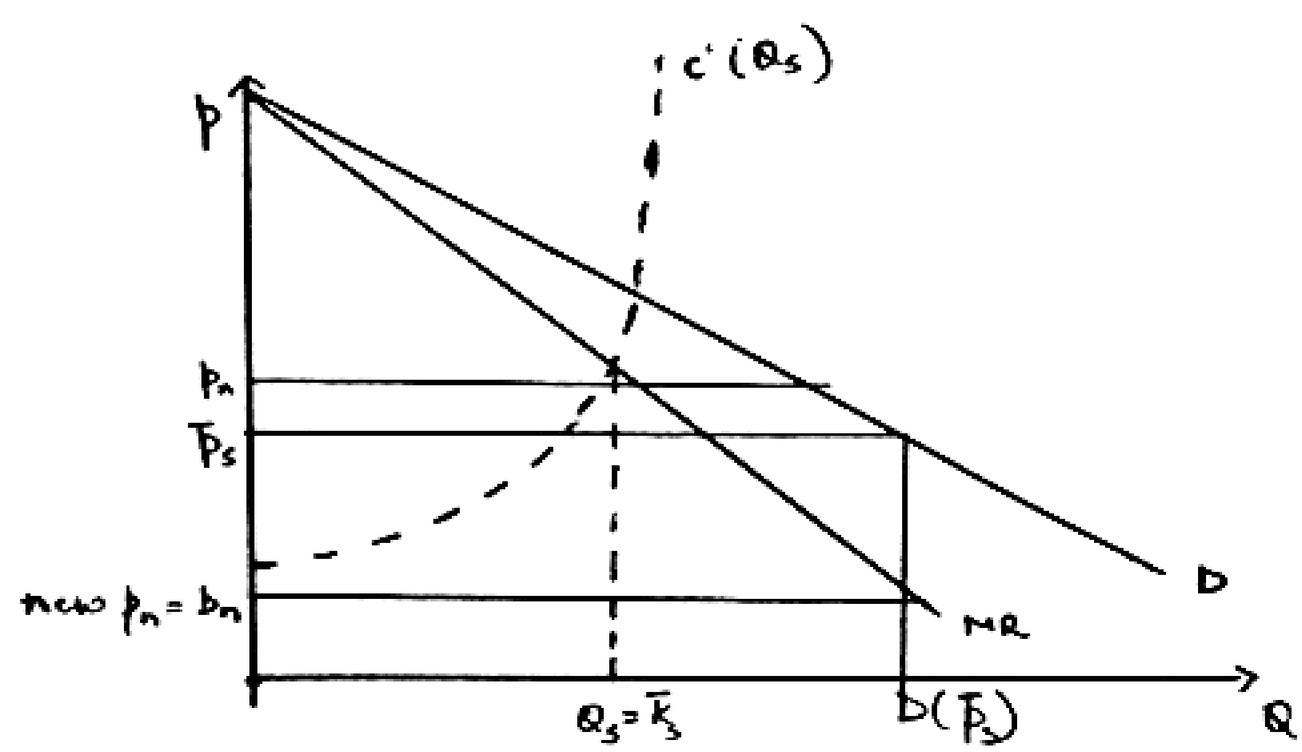


Figure 5.5: Feasibility with TPT under capacity constraint

be lower than the amount needed to satisfy the demand, and there would be unsatisfied demand at the optimum. It is clear that it is a high $p_n > \overline{p}_s$ that is causing the problem.

Note that here the infeasibility for the SEB is interpreted in terms of the unsatisfied demand. Now under a two part tariff, when p_n falls, the positive profits can be used to purchase more of Q_n than in the earlier case of a one part tariff. Since more demand can be met, more can be supplied to the consumer at the price $\overline{p}_s$, and so the revenue of the SEB will rise.

It is then possible that a TPT can be found that will induce the SEB to meet the whole demand. F_n will still be used by NTPC to take away all the surplus of SEB and leave the SEB with zero profits. Since Q_n expands, NTPC is selling more at a reduced price, but makes up for the fall in price through F_n. NTPC's profits also increase. See Figure 5.5.

So in the earlier definition of infeasibility we found that there exists no solution under the TPT also when consumer prices are fixed. But in the above alternative definition of infeasibility, we found that that even with consumer prices fixed, it may be possible to find a solution under the TPT. The difference between the two cases is the use of Assumption 3. While in the earlier case, the overproduction of Q_s hindered a feasible solution, here by imposing a capacity constraint beyond which no production of Q_s can take place, we have been able to design a feasible two part tariff.

Note here that the situation under the OPT seems to correspond very closely to reality. Here we find unsatisfied demand, and a positive amount being bought from the NTPC despite the p_n being too high. The only difference is that we have a zero profit here, while in reality the average SEB makes negative profit. However, if we relax our profit constraint to be $\Pi_s \geq B$ where $B < 0$, then even this can be incorporated.

5.6 The Welfare Maximizing Case

In the previous section we have seen how infeasibility under a single part tariff under the assumption of the NTPC maximizing profits can be overcome in certain cases by the introduction of a TPT.
We have so far assumed that NTPC has to function on commercial lines because the paid up capital of NTPC is financed from equity participation and loans from international loan agencies. Interest on the loan and dividends on shares have to be paid out, thus making the functioning on commercial lines necessary. But this fact is not true of SEBs since they are financed from the state treasury and in principle they are paid to keep the consumers price artificially low. The losses of the SEB are supposed to be subsidised by the state government. This is because state governments feel that electricity supply is a utility the benefit of which should reach all the consumers and that consumers do not like high prices. State governments can be said to be pursuing a welfare objective.

Though NTPC has to function on commercial lines, it is also basically a government undertaking. It could also have social goals to be met. In fact, if it were the government solving this problem, we would have a social welfare function as the objective. So in this section, we shall assume that the NTPC is welfare-maximizing, welfare being defined as aggregate surplus i.e., the sum of consumers surplus and aggregate producers surplus.
Consumers surplus is defined as

$$\int_0^Q p_s(y)dy - p_s Q$$

where $p_s(y)$ is the inverse demand curve, assuming that income effects are zero.

We want to work out the problem of a two part tariff under a different hypothesis of the NTPC objective. We assume that the NTPC is welfare maximizing, in contrast to its earlier profit maximizing behavior and compare the results. Note that as long as consumer surplus is high enough it is always possible to have a feasible solution under the TPT for welfare maximization.

The problem for NTPC under the two part tariff is now written as:

$$\text{Max}_{p_n, F_n} \int_0^Q p_s(y)dy - C(Q_s(p_n) - b_n Q_n(p_n) - f_s - f_n$$

$$\begin{aligned} \text{s.t.} \quad \pi_s &= p_s D(p_s) - C(Q_s(p_n)) - p_n Q_n(p_n) - F_n - f_s \geq 0 \\ \text{s.t} \quad \pi_n &= p_n Q_n(p_n) + F_n - b_n Q_n(p_n) - f_n \geq 0 \end{aligned}$$

and s.t. $[Q_s(p_n), Q_n(p_n)] \in G$
where G is the set of all feasible solution values that solve the SEBs problem of output maximization subject to the constraints of nonnegative profits, demand being met and capacity.

Proposition 5 : *Under welfare maximization, in the optimum, the following hold :*

(a) *When the consumers price p_s is fixed at $\overline{p}_s$, and the subgame is that of the SEB maximizing its output, aggregate output is $\overline{Q}(\overline{p}_s)$ and maximizing surplus is the maximization of π_n at $\overline{Q}(\overline{p}_s)$.*

(b) *When p_s is variable, aggregate surplus is maximized at the point where aggregate profits are zero, when aggregate profits are calculated for the case when the SEB output is restricted to the OPT level.*

Proofs :

5(a): Since p_s is fixed, demand is fixed. So maximizing surplus is nothing but minimizing the cost of supplying $\overline{Q} = D(\overline{p}_s)$. If the SEB generation under OPT was $\overline{Q}_s$, then clearly the least cost configuration is keeping the status quo here i.e., $Q_s = \overline{Q}_s$. (We are still assuming that the SEB may not be willing to participate in the deal if it had to worse off than before, i.e., it will not accept a $Q_s < \overline{Q}_s$). So $Q_n = \overline{Q} - \overline{Q}_s$. In order to induce the SEB to purchase that much, set p_n s.t. $p_n = MR(\overline{Q})$, and set F_n such that SEB profits become zero. (See Figure 5.6(a)).

5(b) : Aggregate surplus is clearly maximized at a point $\tilde{Q}$ such that $b_n = p_s(\tilde{Q})$.

$$\text{Max W} = \int_0^Q p_s(y)dy - C(Q_s(p_n)) - b_n Q_n(p_n) - f_s - f_n$$

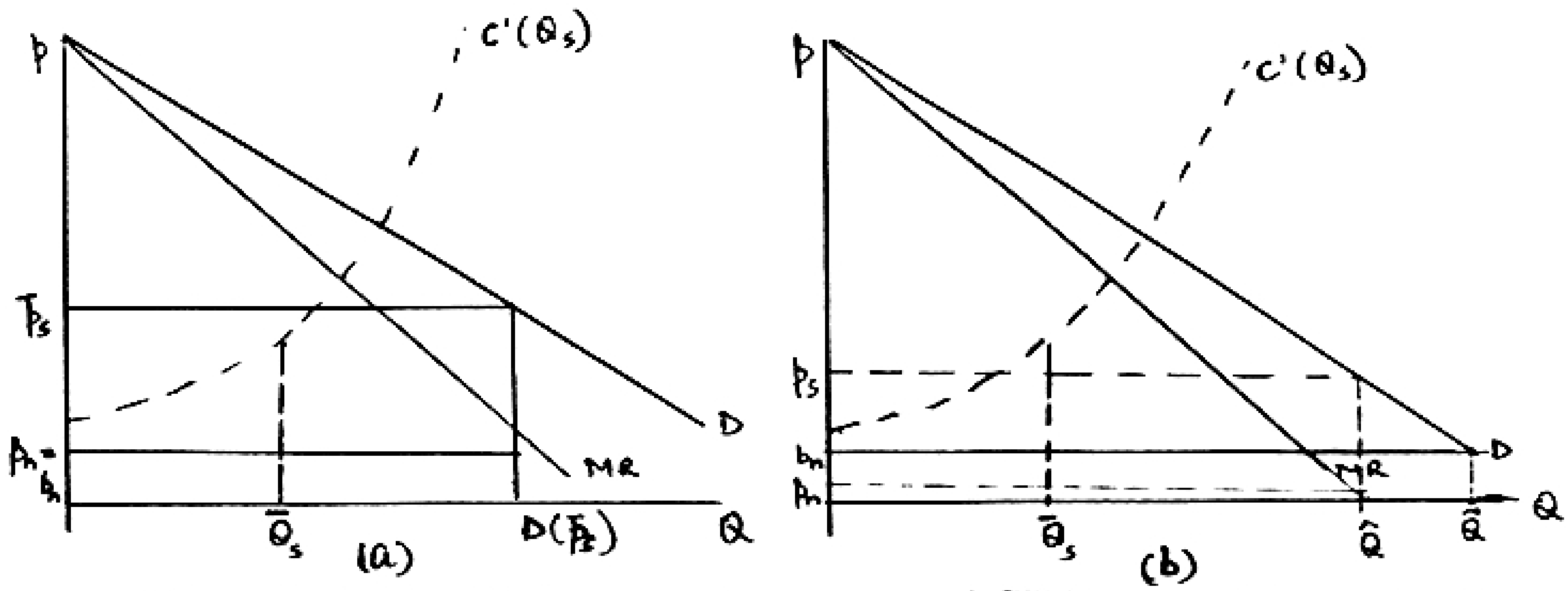


Figure 5.6: Feasibility under W-max and SEB maximizing output

The first order conditions give $p_s(\tilde{Q}) = b_n$ for some $\tilde{Q}$. However, at $\tilde{Q}$ clearly aggregate profit is negative, because with $p_s = b_n$, only the variable cost of production from the NTPC is met, but the fixed costs are not covered. Assuming that the NTPC and SEB must be self-financing, total output can be increased only till the point where $\pi(\hat{Q} = Q_s + Q_n) = 0$, where $Q_s = \overline{Q}_s$. Since Π is maximized at $p_n = b_n$ and is a concave function of p_n, clearly the solution involves $p_n < b_n$ (such that aggregate profit reduces to zero) and F_n such that SEB profits $\pi_s = 0$. See Figure 5.6(b).

It is often alleged by the SEBs that many of their problems stem from subsidising some of their consumers, charging a low $\overline{p}_s$. This price, as we have already explained, is determined exogenously (we assume from a government ministry) and bears no relation to costs. An interesting question is asking whether raising $\overline{p}_s$ will increase consumers surplus.(The direct effect is obviously to decrease consumers surplus, but indirectly it may increase consumers surplus by increasing the amount supplied.)

Proposition 6 : *For a linear demand curve,if* $p_n > \overline{p}_s$ *and* $\hat{Q} < \overline{Q}$, *where* $\pi_s(\hat{Q}) = 0$ *and* $\overline{Q} = Q(\overline{p}_s)$, *but* $\pi_s(\overline{Q}) < 0$, *then increasing* p_s *would increase consumers surplus iff* $p'_s > p_n$ *where* p'_s *is s.t.* $p'_s = p_s(\hat{Q})$. *That is, if at the*

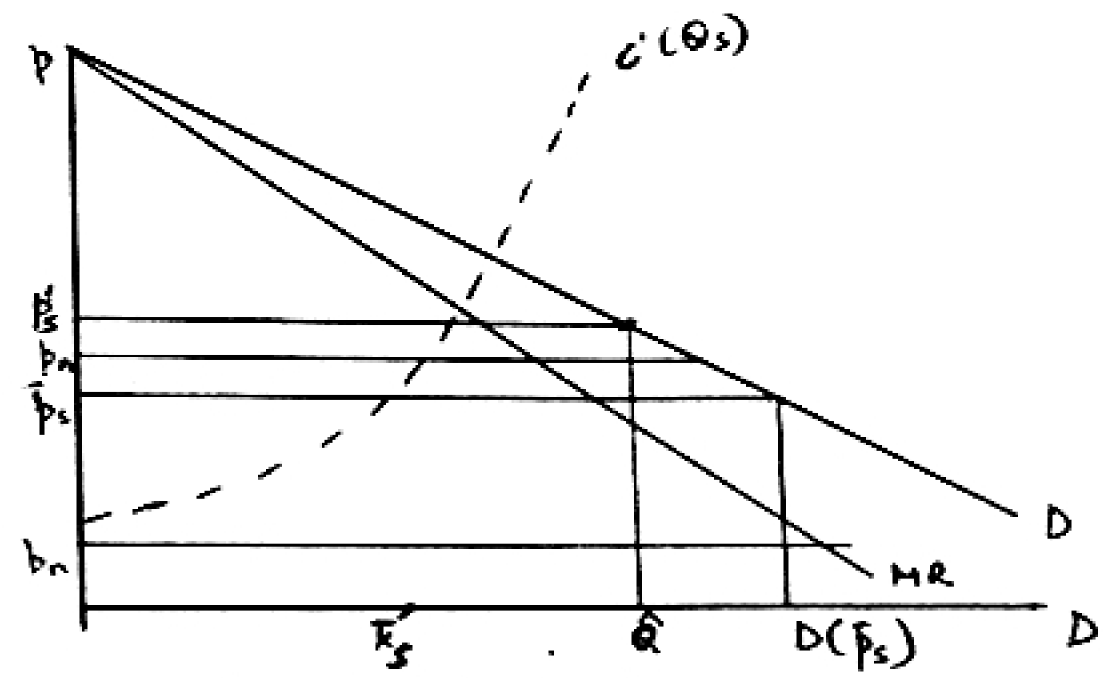


Figure 5.7: Increased prices leading to increased consumers surplus

zero profit level of the SEB there was still some unmet demand, then increasing the consumer price so that the increased revenue of SEB may help in supplying more output to the consumers, will actually increase consumers surplus only if the new price is greater than the price the NTPC is charging .

Proof : At $\hat{Q}, \pi_s = 0$, or $\hat{Q}(p_s) = [C(\overline{Q}_s) + p_n Q_n + f_s]/p_s$
Let $p_s = A - BQ$,
Then consumers surplus CS =

$$\int_0^{\hat{Q}} (A - BQ)dQ - (A - B\hat{Q})\hat{Q}$$

$$= (A - B\hat{Q}/2)\hat{Q} - p_s\hat{Q}$$

$$\frac{\partial CS}{\partial p_s} = [(A - B\hat{Q}/2)\frac{\partial \hat{Q}}{\partial p_s} + \hat{Q}\frac{\partial (A - B\hat{Q}/2)}{\partial p_s}] - p_s\frac{\partial \hat{Q}}{\partial p_s} - \hat{Q}$$

$$= (A - B\frac{\hat{Q}}{2})(-\frac{\hat{Q}}{(p_s - p_n)}) + \hat{Q}(-\frac{B}{2} \times \frac{-\hat{Q}}{(p_s - p_n)}) - (-\frac{p_s\hat{Q}}{p_s - p_n}) - \hat{Q}$$

$$= -(A - B\hat{Q}/2)(\frac{\hat{Q}}{p_s - p_n}) + \frac{B\hat{Q}^2}{2(p_s - p_n)} + \frac{p_s\hat{Q}}{p_s - p_n} - \hat{Q}$$

$$= -\frac{A\hat{Q}}{p_s - p_n} + \frac{B\hat{Q}^2}{(p_s - p_n)} + \hat{Q}(\frac{p_n}{p_s - p_n})$$
$$= \frac{1}{p_s - p_n}[B\hat{Q}^2 - (A - p_n)\hat{Q}]$$
$$= \frac{\hat{Q}}{p_n - p_s}[A - B\hat{Q} - p_n]$$

Let $A - B\hat{Q} = p'_s$. If $p'_s > p_n$ this completes the proof.

Thus consumers surplus would increase if $p'_s > p_n$. If in some sense the aggregate quantity supplied was low, or equivalently there was considerable unsatisfied demand, then price is adjusted corresponding to $\hat{Q}$ (which is level of satisfied demand), in such a way that the SEB is left with positive profits, by which it can increase supply. The proposition shows precisely how high the unsatisfied demand has to be. In such a situation there is a clear case for $\overline{p}_s$ to be raised. Not only would the producers be better off, but the consumers would gain as well. See Figure 5.7.

5.7 The Profit Maximizing SEB

The assumption that SEBs maximize output has tended to squeeze the range of solutions under the problem of infeasibility. We had argued earlier that the hypothesis of SEB maximizing output was justified on the empirical evidence of incentives based on the plant load factor. However, this will hinder merit order operation, which is the government's objective. Limiting the problem to just this objective might narrow down the interesting cases. In this section, we shall look at the problem as if the SEBs had a different objective – of profit maximization, and then compare the results. We shall work back briefly over the main results so far.

So we restate the problem as :

Maximize NTPC profits π_n

subject to SEB maximizing its profits π_s

subject to $Q_s + Q_n = D(p_s)$

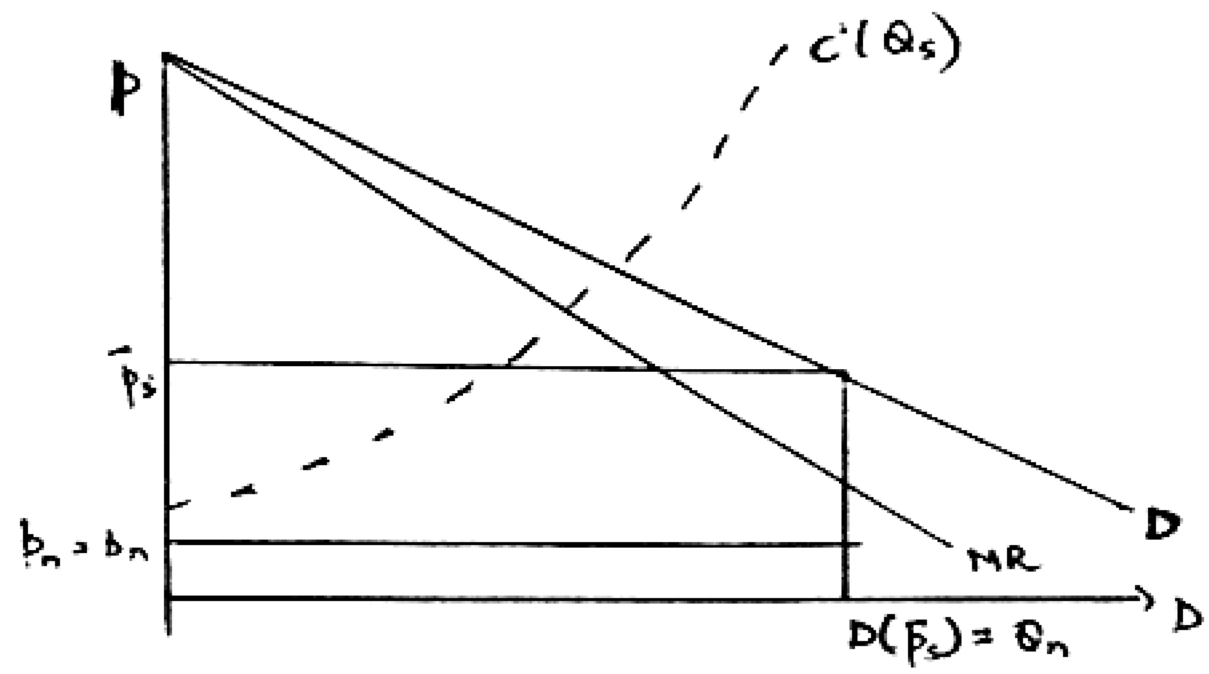


Figure 5.8: Feasibility under TPT

subject to $Q_s \leq \overline{K}_s$.

Suppose there exists a fundamental infeasibility under a OPT p_n, such that for all p_n either π_n or $\pi_s < 0$. Then the following holds :

Proposition 7 : ***Under consumer prices fixed, (demand fixed), an infeasibility of the kind defined above, can have a feasible solution under the two part tariff, when the SEB is assumed to be profit maximizing.***

Proof : Suppose the one part tariff levied was $\overline{p}_n$, at which SEB makes zero profits, Q_s is the solution to $C'(\overline{Q}_s) = \overline{p}_n$, and $Q_n = D(\overline{p}_s) - \overline{Q}_s$. Since the infeasibility holds, it must be that NTPC makes negative profits here. Now consider a two part tariff, where the variable part $p_n < \overline{p}_n$. Since the SEB is profit maximizing, the new output levels will be $C'(Q_s) = p_n$. Since p_n is lower, Q_s falls and Q_n increases, and F_n is set such that SEB makes zero profits even here. So NTPC profits increase. However, it need not stop here. Since aggregate profit is maximized at $p_n = b_n$, and since $b_n < C'(0)$ by assumption, by charging $p_n = b_n$, NTPC can supply the whole market by letting $Q_n = D(\overline{p}_s)$. NTPC profits increase to the maximum[7], where F_n keeps SEB profits at zero

[7]Since $C'(0) > b_n$, any $p_n \leq C'(0)$ will give equivalent outcomes to NTPC.

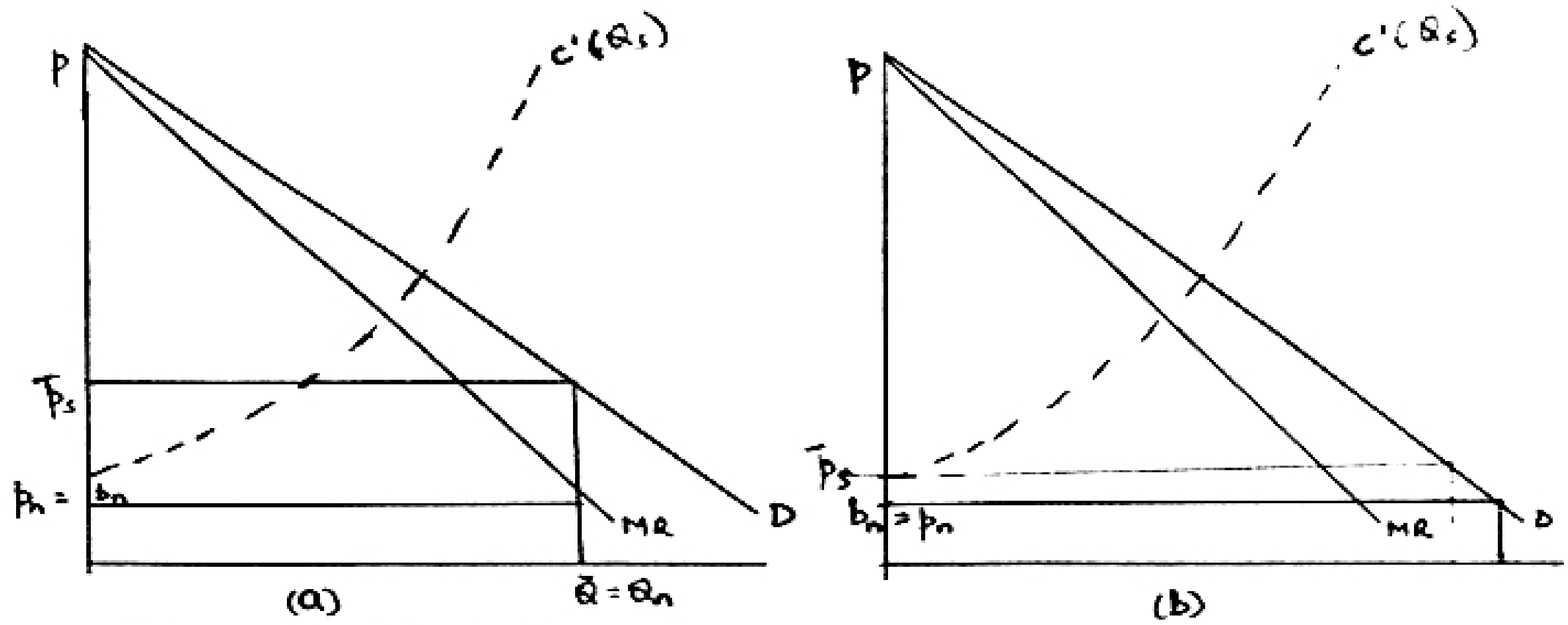


Figure 5.9: Feasibility under W-max and profit maximizing SEB

level. Therefore even under fixed consumer prices, a feasible solution can be found.(Figure 5.8).

Note that the same result would hold even in the output maximizing case, *if* we did not have a certain participation level of $\overline{Q}_s$ for the SEB under a two part tariff. But then this would defeat the very purpose of having output maximization for the SEB, so we have not considered that case here.

Under the assumption that NTPC maximizes welfare (consumers and aggregate producers surplus), we find the following results under a two part tariff.

Proposition 8 :

(a) *Under p_s fixed and aggregate output $\overline{Q}(p_s)$, the assumption of profit maximization for SEB leads to a higher surplus than output maximization does.*

(b) *Under p_s variable, both aggregate output and aggregate surplus can be increased under the assumption of profit maximization of SEB.*

For the following two proofs the problem is as under:

$$\text{Max}_{p_n} \int_0^D p_s(y)dy - C(Q_s(p_n)) - b_n Q_n(p_n) - f_s - f_n$$

s.t. $\pi_s, \pi_n \geq 0$

$[Q_s(p_n), Q_n(p_n)] \in H$
where H solves the following problem :

$$\text{Max } p_s(Q_s + Q_n) - p_nQ_n - C(Q_s) - f_s + F_n$$

s.t $D(p_s) = Q_s + Q_n$
$Q_s \leq \overline{K}_s$

Proofs

8(a) : Again as p_s is fixed, aggregate output is $\overline{Q}$. However, SEB is now profit maximizing. Therefore at $p_n = b_n$, it will not produce anything from its own plant and $\overline{Q} = Q_n$. Since F_n still takes away all its surplus, $\pi_s = 0$. Aggregate profits are higher, and since SEB makes zero profits, NTPC profits are higher than compared to an output maximizing SEB. See Figure (5.9 (a)).

8(b) : As in 6(b), the solution is where aggregate profit $\Pi(Q) = 0$. But since the SEB only wants to maximize π_s it will purchase wholly from the NTPC, and $Q = Q_n$. When p_s is free to be determined endogenously, the output level in here is higher than in 6(b), (i.e., when the SEB is assumed to maximize output and mnot profits), since a higher profit level (for the same p_n) now makes expansion of output possible. Since aggregate profits are higher, the point where $\Pi(Q) = 0$ will be to the further right, and the higher output will depress the consumer price thus making a higher consumers surplus and a higher level of welfare possible. See Figure (5.9 (b)).

5.8 Optimal two-part tariffs under uncertainty about costs : An extension

The analysis so far has assumed complete knowledge on the part of NTPC regarding the cost structure of the SEB. However in reality that is not the case. One reason why there is difficulty in imposing a merit order operation is precisely because the SEBs refuse to divulge their cost structure. According to the NTPC, there were practical difficulties in reckoning the effect of backing down as the Regional Electricity Boards cannot certify the ordering of backing or the actual extent of backing down[8]. Discussions with the officials of the Northern Regional Electricity Board (NREB) revealed that they were helpless as the SEB's of the region were not willing to reveal the cost figures because in their view 'merit order operation' would mean less usage of their own plants (atleast in the off-peak periods) which is incompatible with their incentive structure. It must be mentioned in this context that NREB has suggested that the same incentive scheme be linked to production, but only in the peak period where constraints on the NTPC's capacity will make it imperative for the Boards to operate their own plants too. However, this proposal is still to be accepted by all the Boards.

So in this section we take up the problem of devising a feasible two-part tariff so as to maximize NTPC profits where there is uncertainty regarding the cost structure of the SEB. We will keep to the assumption of SEB maximizing output, because this seems the most plausible of all hypotheses, and the behavior of a profit maximizing SEB was only of academic interest since there is nothing to suggest that SEBs actually maximize profits. So we will have to choose the most likely option – which is an output maximizing SEB.

The arguments in this section are heavily borrowed from the literature on information economics especially from the Guesnerie and Seade [1982] work on non-linear taxation.

Assume that there is some uncertainty regarding the cost structure of the SEB. We just consider a single SEB. The SEB's costs can take two values-low or high, with associated probabilities θ and $(1-\theta)$. We assume that the two types have identical capacity constraints and fixed cost levels f, however the marginal costs are different. Letting the subscripts h and l denote the high and low cost firms respectively,

[8] K.P Rao Committee Report 1990.

$$C_h(Q_{sh}) = f + \int_0^{Q_{sh}} c_h(Q_s)dQ_s$$

$$C_h(Q_{sl}) = f + \int_0^{Q_{sl}} c_l(Q_s)dQ_s$$

where C_h and C_l represent the cost curves of the high cost and low cost repectively, with $c_h(Q_s) > c_l(Q_l)$. And $c_h(Q_s) = \infty$ and $c_l(Q_s) = \infty$ for $Q_s > \overline{K}_s$, where $\overline{K}_s$ denotes the capacity level of the SEB.

So the NTPC's problem is the following:

$$\text{Max}_{\{p_{nl},\, F_{nl},\, p_{nh},\, F_{nh}\}} \quad \pi_n(p_n, F_n)$$

s.t. (i) Feasibility constraints:

$$\pi_i(p_{ni}, F_{ni}) \ \geq \ 0 \text{ for } i = h, l.$$

(ii) Incentive constraints:

$$Q_{si}(p_{ni}, F_{ni}) \ \geq \ Q_{si}(p_{nj}, F_{nj}) \,\forall\, i, j = h, l.$$

i.e., each type of SEB should be at least as well off in terms of its own production, under the two part tariff offered to it, than any other's two part tariff. This means that no SEB should have any incentive to pretend that it is of a different type and hope to do better in terms of output.

We also have the usual capacity constraints i.e. $\overline{Q}_{si} < \overline{K}_s$, the market-clearing conditions and the participation constraints that $\overline{Q}_{si} \geq \overline{Q}_s \,\forall\, i = h, l$..

We show that the single-crossing property holds in this case. The property says that the iso-output curve between p_n and F_n for an output maximizing SEB, at the output maximum, is steeper for a low cost SEB than for a high cost one. The slopes of the indifference curves measured in the $[p_n, F_n]$ space are different and intersect only once. (See Appendix A.5(3) for the proof) Having established this we make some observations. In all the observations and results that follow, the optimum is where, the NTPC solves the problem, i.e., the profit maximizing point of NTPC given the output maximizing behavior of the SEB.

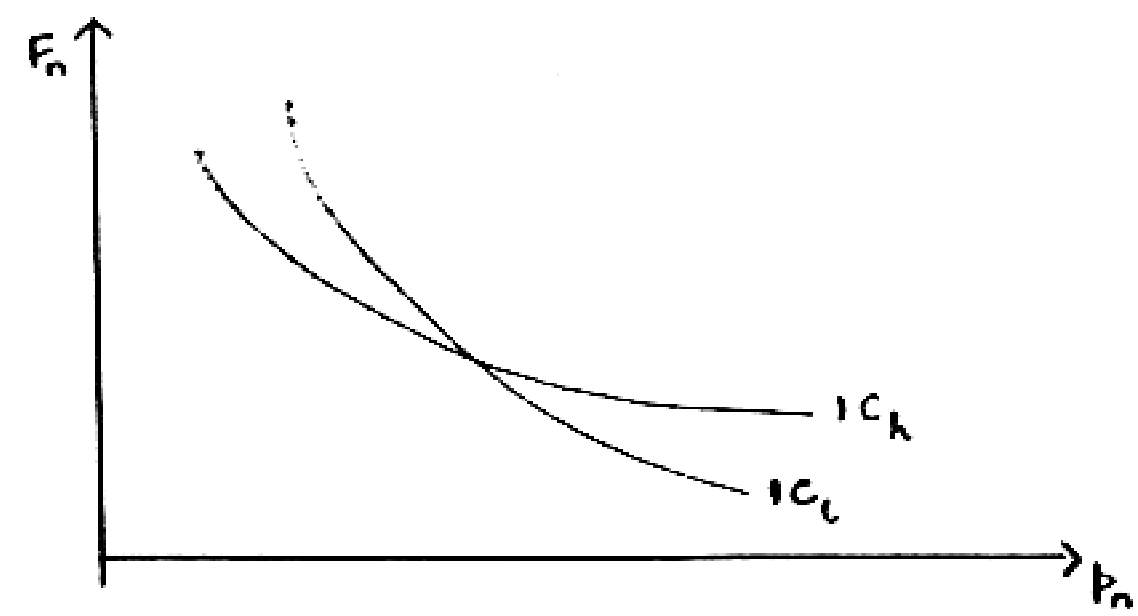


Figure 5.10: The single crossing property

Lemma 1.1: *$p_{nh} > p_{nl}$ implies $F_{nh} < F_{nl}$.*
The proof follows directly from incentive compatibility.

Lemma 1.2: *If type h weakly prefers a price vector (p_q, F_q) to (p_m, F_m) where $p_q > p_m$, then type l, strictly prefers (p_m, F_m) to (p_q, F_q) .*
Proof: (See Figure 5.11). Suppose type h is indifferent between (p_q, F_q) and (p_m, F_m). By the single crossing assumption we know that type l has a steeper slope. Therefore consider the relevant indifference curve passing through (p_q, F_q). At this point, (p_m, F_m) is to the left of l's own indifference curve. Since an indifference curve lying to the left means a higher level of output the low cost type will choose (p_m, F_m).

Lemma 1.3: *If type l weakly prefers (p_q, F_q) to (p_m, F_m), where $p_q > p_m$, then type h, strictly prefers (p_q, F_q) to (p_m, F_m).*
The proof is analogous to that of Lemma 1.2.

Lemma 1.4: *The low cost type pays a higher fixed cost than the high cost type.*
Proof: Suppose to the contrary, we had $F_{nh} > F_{nl}$. From incentive compatibility, we know that

$$Q_l(p_{nl}, F_{nl}) \geq Q_l(p_{nh}, F_{nh}) \text{ for } l$$

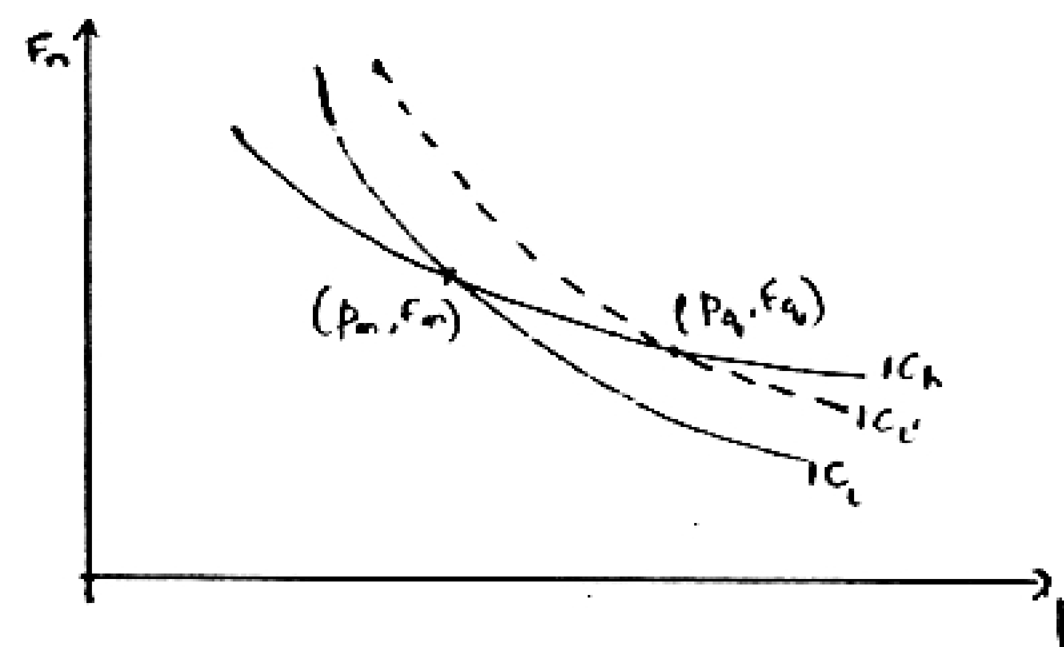


Figure 5.11: Proof of Lemma 1.2

$$Q_h(p_{nh}, F_{nh}) \geq Q_h(p_{nl}, F_{nl}) \text{ for } h$$

From Lemma 1.3,

$$Q_h(p_{nl}, F_{nl}) > Q_h(p_{nh}, F_{nh})$$

which establishes a contradiction.

Lemma 2: $Q_l(p_{nl}, F_{nl}) > Q_h(p_{nh}, F_{nh})$ *i.e., the low cost SEB type makes strictly higher output than the high cost type.*

Proof: We know from incentive compatibility that

$$Q_l(p_{nl}, F_{nl}) \geq Q_l(p_{nh}, F_{nh})$$

But at (p_{nh}, F_{nh}), the low cost SEB, being the more efficient, can make a strictly higher output. Therefore,

$$Q_l(p_{nh}, F_{nh}) > Q_h(p_{nh}, F_{nh})$$

■

Lemma 3: *In the optimum, the high cost SEB produces at exactly $\overline{Q}_s$ level of output, where $\overline{Q}_s$ is the output that it was producing under the OPT.*

Proof: Suppose the high cost SEB produces more than $\overline{Q}_s$ in the optimum. Then by Lemma 2, the low cost SEB produces more than $\overline{Q}_s$ as well. Now both F_h and F_l can be increased a little bit by identical amounts. Now all constraints are met and NTPC's profits are higher. Hence the contradiction.

Lemma 4: *In the optimum, the incentive constraint of the low-cost SEB would be binding.*

Proof: That is, in the optimum, low cost SEB should make the same output Q_s under (p_{nh}, F_{nh}) and (p_{nl}, F_{nl}). If not, then F_l can be increased without violating any constraints. This would lead to an increase in the NTPC profits which contadicts the optimum we began with.

We have seen therefore, that for any solution to the problem, the high cost SEB produces $\overline{Q}_s$ while the low cost SEB produces more than $\overline{Q}_s$. Also, the low cost SEB is indifferent between his point and the higher point, while the high cost type strictly prefers its own point. Therefore any solution in the optimum must have one participation constraint and one incentive constraint binding. The high cost SEB is indifferent between participating and not participating and where this so, we assume he chooses to participate. We are now ready to state the main result.

Proposition 9 (a) : *In the optimum, it must be that $p_l = b_n$ i.e., the low cost SEB must be producing at an efficient point.*

9 (b) : *For the high cost type $p_l \neq b_n$.*

Proof: 9 (a). Case 1: See Figure (5.12). Suppose $\pi_h(p_{nh}, F_{nh}) > \pi_h(p_{nl}, F_{nl})$. Now suppose $p_{nl} \neq b_n$. Now by moving p_{nl} a little bit towards b_n, we can increase aggregate profits and we can use F_{nl} to keep the low cost SEB on the same profit level. No constraint is violated and profits of NTPC is increased. Hence $p_{nl} \neq b_n$ is not the optimum point.

Case 2: Suppose $\pi_h(p_{nh}, F_{nh}) = \pi_h(p_{nl}, F_{nl})$. From single crossing property we know that this has to mean that $p_{nh} = p_{nl}$ and $F_{nh} = F_{nl}$. Now if $p_{nl} \neq b_n$ take (b_n, F_{nh}) as the new common point where F_{nh} is such that the high cost SEB can make exactly zero profits. Again all constraints are satisfied and the NTPC profits have increased. Therefore we could not have been in an optimum.

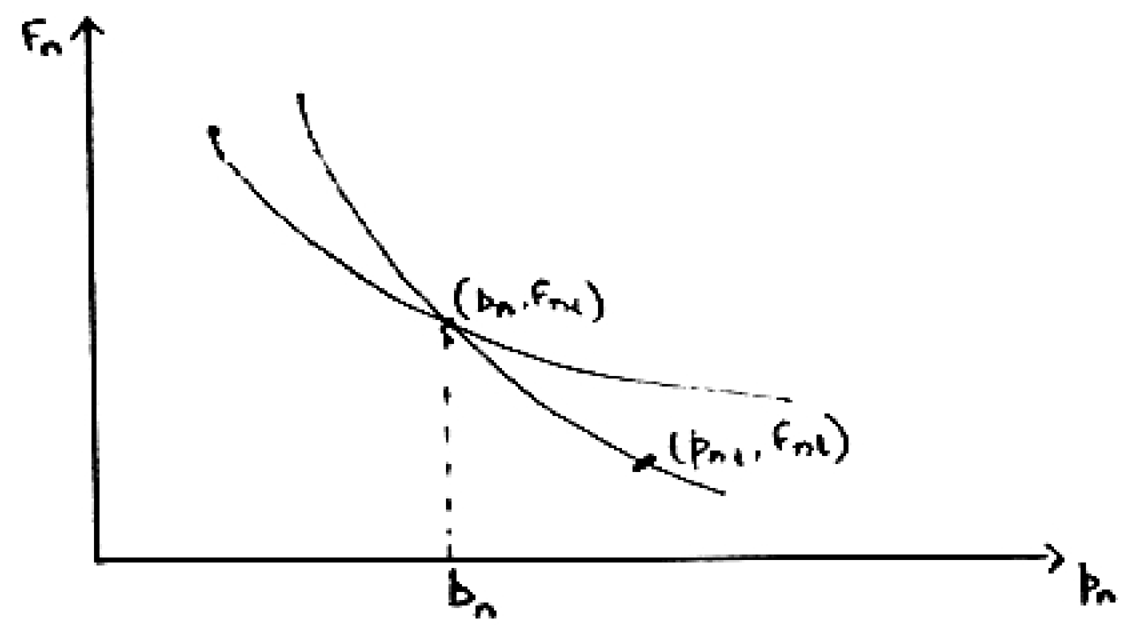


Figure 5.12: Efficiency for the low cost: Proof of 9(a)

9(b). We proceed again by contradiction, i.e., $p_{nl} = p_{nh} = b_n$. So from Lemma 1.1, $F_{nh} = F_{nl}$. Now take (p_{nh}, F_{nh}) and (b_n, F'_{nl}) as the new points. (See Figure 5.13). Clearly the NTPC loses a little bit on the high cost type as it moves away from the efficient point but the loss is of second order magnitude since it is only a movement down the curve, compared to the gain it makes on the low cost where the gain is of the first order, where the shift is to a curve downwards, implying greater profits to NTPC.

The qualitative properties that have been established at the optimum are the following :

(a) The two part tariff offered is different for different types. That is, in the event when the NTPC has to design a two part tariff when it is not sure of the costs of the SEB, choosing a schedule of two part tariffs is more efficient than offering a single two part tariff.

(b) The price schedule smoothens out the consumer types such that the low cost type chooses the same point that is first best optimal for him. By first best optimal we mean the case when the NTPC knows the cost and has no information drawback. Offering a schedule of two part tariffs in the second best situation the NTPC is able to extract the same profits out of the low cost SEB as if the NTPC knew of the low cost SEB's cost stucture. In doing so, it

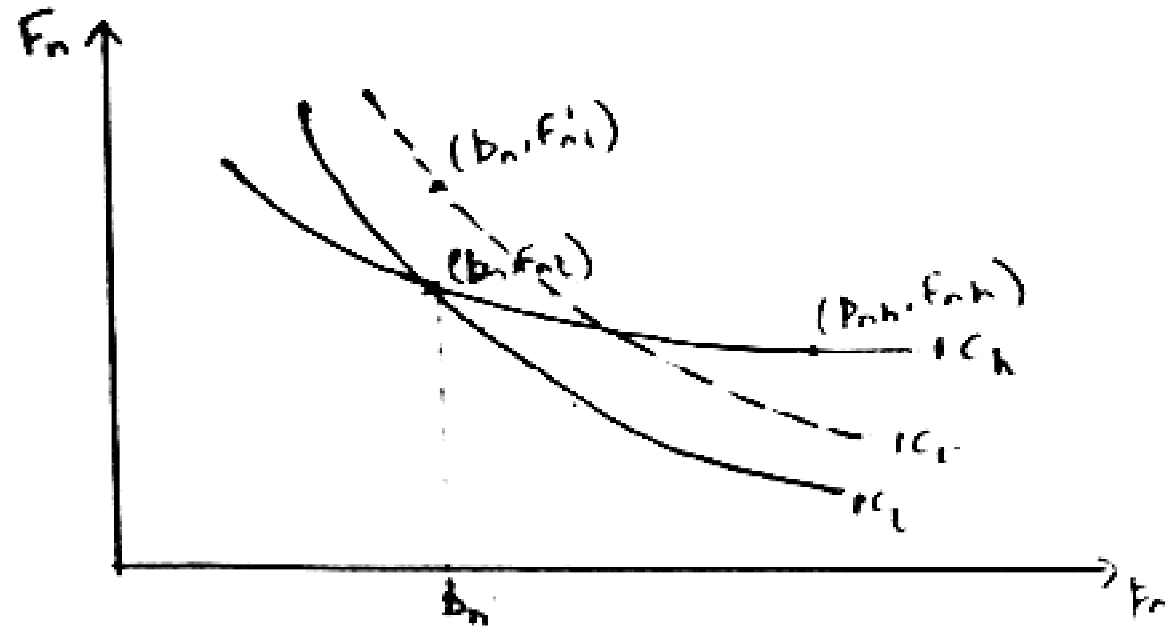


Figure 5.13: Inefficiency for the high cost: Proof of 9(b)

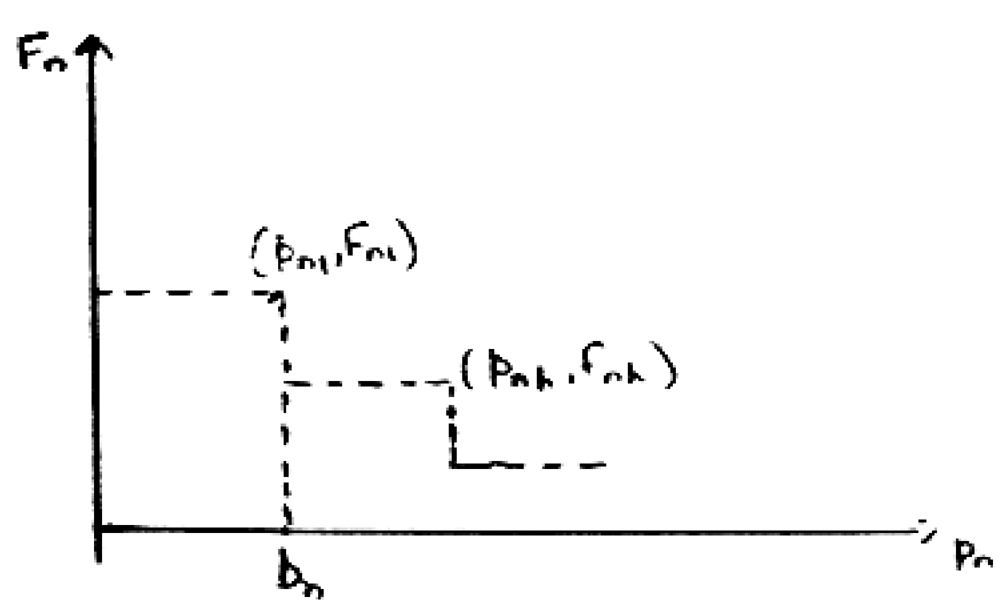


Figure 5.14: Schedule of TPTs

has to concede a higher level of Q_s for the low cost. This is the informational rent that the low cost SEB has been able to procure for itself by withholding its cost from the NTPC.

(c) The high cost type is made indifferent between participating and not participating. Since the high cost SEB makes exactly $\overline{Q}_s$ in the optimum, it may accept the two part tariff, or prefer the one part tariff, where under both cases it was making zero profits. Since it does not lose from the two part tariff, we assume that it will participate.

The price rule can now be solved explicitly using the Kuhn-Tucker theorem.

5.8.1 The Fixed Price Case

We have so far considered the case where the consumers price p_s was variable. Next we consider the case where consumer price is fixed, which, as we argued before is the more realistic case. In this case also we find that the single crossing property holds. That is, for the same vector of variable and fixed costs, the slope of the iso-output curve is steeper for the low cost SEB compared to the high cost type. The proof of this has been provided in the appendix (A.5(4)).

As before we can show that the following lemmas hold.

Lemma 1: *If* $p_{nh} > p_{nl}$ *then* $F_{nh} < F_{nl}$.

Lemma 2: $Q_l(p_{nl}, F_{nl}) > Q_h(p_{nh}, F_{nh})$.

Lemma 3: *In the optimum, the high cost SEB produces at exactly the* $\overline{Q}_s$ *level of output.*

Lemma 4: *In the optimum, the incentive constraint of the low-cost SEB would be binding.*

The proofs of the above lemmas are identical to those in the case of flexible consumer prices.

The next proposition shows that the two part tariff cannot alleviate the infeasibility problem when the consumer price of electricity is fixed, i.e., proposition 1 still goes through when there is uncertainty about the cost structure

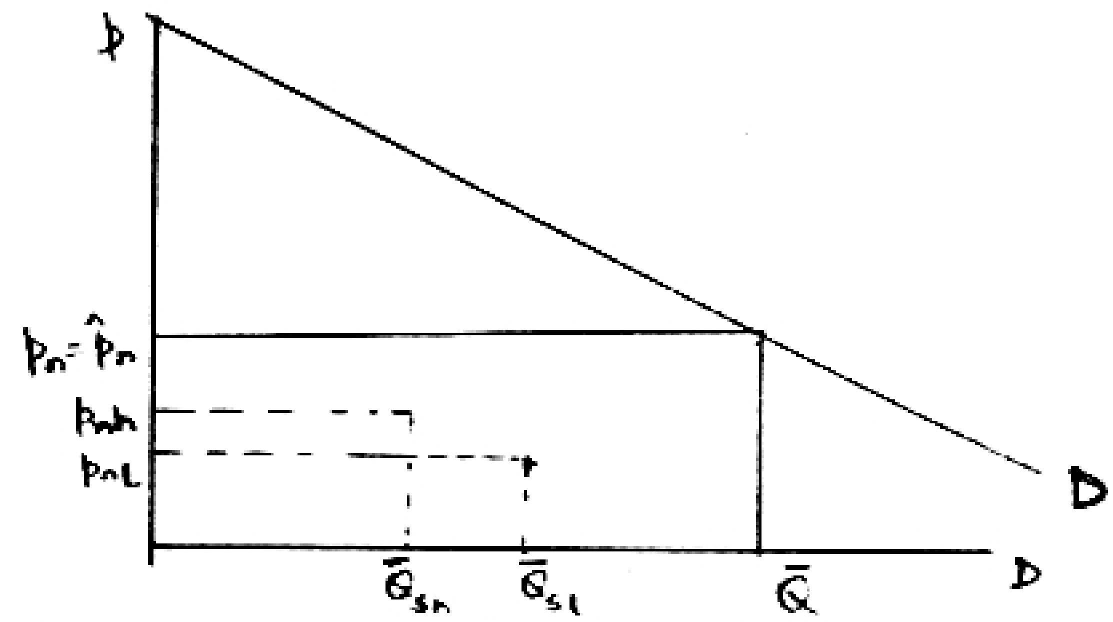


Figure 5.15: Infeasibility with TPT under uncertainty

of the SEB.

Proposition 10. *If there exists an infeasibility under the one part tariff then there is no solution under the two part tariff either.*

Proof. Under a one part tariff with uncertainty about costs, let $\overline{Q}_s$ be achieved for some $(c(\overline{Q}_s), \hat{p}_n)$. We know that at this $\hat{p}_n$, SEB is making zero profits.(assuming that this $\hat{p}_n$ is not sufficient to cover NTPC's costs, and hence the infeasibility is from the NTPC's side.)
Under uncertainty now, since both types have to make at least $\overline{Q}_s$, $p_n \leq \hat{p}_n$ for a feasible solution. But for any $p_n = \hat{p}_n$, offered to both types, the low cost makes $Q_{sl} > \overline{Q}_s$ and the high cost makes $Q_{sh} = \overline{Q}_s$, but NTPC's profits have not risen. If under the one part tariff, NTPC was making negative profits, it is still making losses. See Figure 5.15.

The next proposition characterizes the optimal solution when under the one part tariff there exists a feasible solution. As the previous proposition demonstrates, if there is no feasible solution under the one part tariff then the two part tariff case also has no feasible solution. However, the infeasibility problem is not equally severe for all the SEBs[9].

[9]States like Maharashtra, Tamilnadu, Andhra Pradesh have been showing positive surpluses

We can take the following analysis as applying to states which do not have an infeasibility problem.

Proposition 11.

(i) : *The high cost SEB produces at the previous output level and the low cost SEB produces at more than that level, i.e.,* $Q_{sh} = \overline{Q}_s$, *and* $Q_{sl} > \overline{Q}_s$.

(ii) $p_{nh} = \hat{p}$ *where* $\hat{p}$ *is such that* $\hat{p} = c_h(\overline{Q}_s)$ *and* F_{nh} *is such that the high cost SEB makes zero profits, i.e.* $\pi_h(p_{nh}, F_{nh}) = 0$.

(iii) (p_{nl}, F_{nl}) *is such that the low cost SEB is indifferent between* (p_{nl}, F_{nl}) *and* (p_{nh}, F_{nh}), *i.e.* $Q_l(p_{nl}, F_{nl}) = Q_l(p_{nh}, F_{nh})$. *Clearly there are more than one such* (p_{nl}, F_{nl}) *combination.*

(iv) *In the optimal solution both types of SEB would be making a zero profit, i.e.* $\pi_h = \pi_l = 0$.

Proofs.

(i) : This follows from the previous lemmas.

(ii) : Clearly for any given p_{nh}, the F_{nh} should be such that the production from the SEB is restricted to the lowest possible level. Since from the previous part of the proposition we know that the $Q_{sh} = \overline{Q}_s$ we choose that vector for which the marginal cost of the high cost SEB at $\overline{Q}_s$ is equal to p_{nh}, and F_{nh} such that profits are zero.

(iii) : The NTPC profits from the low cost SEB is the same as long as the SEB produces at the same output level. This is so because the aggregate output is fixed and so aggregate profits are fixed. Since the NTPC appropriates the

in their profit and loss accounts for the last few years. This may be because they are more efficient than the representative SEB that we have considered so far, or they have relatively higher consumer prices. However, our model still holds because NTPC's costs are still lower, and therefore the use of the more economical power is necessary.

whole of the surplus its profits are the same.
(iv): Since the SEB maximizes its output, this is true for any feasible solution and not just for the optimal solution.

5.9 Summary

The stated objectives of the government in recent policy formulations of electricity pricing is trying to fix a tariff rate that would induce merit order operation, thereby encouraging the production of the socially optimal level of output. In this chapter we have attempted the same objective and devised a tariff rate that meets the above conditions. We have tried to study the problem in the context of the remedy suggested by the government which is the two part tariff. We argue that the standard arguments ignore one important aspect of the problem, viz., that the SEBs in general have very different objectives from that of the NTPC, and that the suggested remedy may not always work. We then demonstrate how it might work under different hypotheses of the SEB behavior.

In our model, the NTPC decision-makers are government planners, who we assume, either maximize profits, or welfare as per the aims of the government. The planners try to replace a one part tariff that has hindered merit order operation, with an optimal two part tariff that meets the above conditons.

The results of the case where there is complete information about the costs is the following :

In the case when the NTPC maximizes profits, and the SEB maximizes its own output, given that consumer prices are fixed, a two part tariff will not solve the infeasibility problem (Proposition 1). But if we allowed the SEB to maximize profits instead of output, then under the same assumptions, a two part tariff will help, because aggregate costs are lower, due to output being supplied only from the lower cost plant (Proposition 3). Therefore, as a first step of policy, basing the SEB incentives on a certain level of profits rather than on the plant load factor, is a more rational method to employ if power generation in the country has to be at minimum cost. We also have a result that the profit maximization objective of the SEB will lead to a feasible solution even with consumer prices fixed (Proposition 7). If keeping consumer prices fixed at a low level is indeed one desired objective of the state government, then the only way this can be done is to allow the SEBs to maximize profits, which is another way of saying that incentives can be based on profits rather than output.

The second point to be noted is the following : If the SEB maximizes profits, and the NTPC maximizes welfare or total surplus, and not its profits alone, then under consumer prices fixed, not only is there a feasible solution under the two part tariff, but aggregate profits, and hence NTPC profits are higher, keeping consumer surplus unchanged (Proposition 8 (a)). So welfare maximization is a better objective for the NTPC for it leads to a higher level of profits.

Thirdly, letting the SEB maximize profits, NTPC maximize welfare and keeping consumer price variable to be fixed endogenously, we find that total output supplied to consumers is higher, consumer prices are lower, and consequently total surplus is higher (Proposition 8 (b)). Aggregate profits are of course zero at this point. So, if the government is really interested in consumer welfare, and wants the two parties i.e., NTPC and SEB which are actually public monopolies, to run only on zero profit, then this option is the most efficient one.

But it should also be observed that, the two part tariffs are not in general a Pareto improvement over the one part tariff. Under a situation when the SEB is output maximizing, and the two part tariff does bring about a feasible solution, (Proposition 3), the solution is a Pareto improvement, since SEB is atleast as well off as before in terms of output $Q_s = \overline{Q}_s$, and the NTPC makes positive profits, where it once was making negative profits.

Even for the case where the SEB is profit maximizing and the NTPC is also profit maximizing, the solution leaves SEB no worse off at zero profits, and NTPC makes strictly higher profits.

The same holds for the welfare maximizing case with consumer prices fixed, and with and without an output maximizing SEB, since consumer surplus remains unchanged, and the SEB is no worse off making the same level of profits or producing the same level of output (as under the OPT), as the case may be, and NTPC makes strictly higher profits.

But for the welfare maximizing case when the consumer price is endogenous, NTPC might actually lose compared to the case where it was maximizing profits, because the solution involves transferring the NTPC surplus to the consumers, so that agrregate profits are zero, but consumer surplus is higher. This is not a Pareto improvement. So the government has to choose a tradeoff between efficiency and equity.

We have so far discussed the findings for the case when the NTPC knows the cost of the SEB. But a more interesting case is when the planner has to devise a TPT, but under a situation of uncertainty. This is the model that almost imitates reality. For it is true that neither the Central Electricity Authority nor the NTPC is actually certain of the costs of the relevant SEBs. This is because the SEBs are reluctant to furnish this information to the NTPC as they feel it will go against their own objective of output maximization.

Since the two part tariff that solves our model depends crucially on the costs of the SEB, we also determine in this chapter, the appropriate fixed tariff that the SEBs should be charged under this situation of uncertainty. We show that the solution involves offering schedules of two part tariffs and not a single vector for all the SEBs.

The results for the uncertainty case are the following :
The outcome of the profit maximization problem which is essentially a second

best optimization, is that the SEB with the lowest cost will always choose that point (p_n, F_n) which it would have been asisgned in a first best situation (where the principal or NTPC, has full knowledge of the costs of the SEB). While, all other types will choose a higher variable cost per unit, p_n. It thus follows that the SEB with the lowest cost will pay the greatest share of the fixed cost, but will have to pay only a variable cost that equals the marginal cost of the NTPC. While the higher cost types will choose a higher variable cost per unit which comes with a lower share of the fixed cost.

The point to be noted here is the the use of *choose*. Under the single part tariff, each SEB was a price taker. But here each SEB will *choose* that point at which its output is maximized. Under the constraint of incentive compatibility, choosing someone else's point will not help it to produce a higher output.

The solution therefore shows that offering a schedule of two part tariffs is more optimal than a single two part tariff for all the SEBs in the region. This will enable the SEBs to choose the point which is optimal for them. In this sense it can be said that a schedule of two part tariffs Pareto dominates a single two part tariff because it allows SEBs to arrange themselves on suitable two part tariffs.

But even the above solution needs the assumption that consumer prices are variable. If consumer prices are fixed, then any infeasibility under uncertainty with a one part tariff cannot be overcome with a two part tariff. This result is the same as Proposition 1 and establishes that under consumer prices fixed, whether the principal has complete or incomplete information, an infeasibility cannot be overcome.

Some SEBs ofcourse might have had a feasible solution in the OPT case, even with consumer prices fixed. Even for such SEBs it is possible to devise a schedule of two part tariffs and Proposition 10 characterizes the optimal solution.
It must be mentioned in this context that according to the K.P. Rao Committee's recommendations, the REBs should be given the power to determine the

fixed portion of the TPT that the SEBs should pay the NTPC. But at least one REB, the NREB, admitted to its inadequacy in doing so, since not only was it unable to obtain the cost estimates of the various SEBs of the northern region, but also that NTPC ***would not*** itself reveal its cost figures. Unless a statutory act is passed, giving powers to the REB, the ordering of the merit order operation may be difficult to achieve.

But even given this situation, our model stands. All that the REB needs to know for the fixing of the TPT is that the marginal cost of NTPC is lower than the cost of any SEB. Knowing the fixed cost is a bit tricky, but this can be known too, if the Committee's assumption under the TPT is that the NTPC's fixed costs should be totally covered.

The current scene with regard to the tariff fixation is not clear and it is not known how far the TPT of the Committee will go in achieving the aims. Under the scheme we have suggested, no SEB stands to lose, and in fact, every SEB stands to gain by choosing such a tariff structure. Merit order operation, and hence optimal supply will be assured.

Appendix A.5

A.5(1) : Proof under Proposition 1

The problem for the NTPC in the OPT case is the following :

$$\text{Max}_{p_n} \quad \pi_n(p_n) = p_n Q_n(p_n) - b_n Q_n(p_n) - f_n$$

where $Q_n(p_n)$ solves the following problem

$$\begin{aligned} \text{Max}_{Q_s, Q_n} \quad & Q_s \\ \text{s.t.} \quad \pi_s &= \overline{p}_s D(\overline{p}_s) - C(Q_s) - p_n Q_n - f_s \geq 0 \\ Q_s + Q_n &= D(\overline{p}_s) \\ Q_s &\leq \overline{K}_s \end{aligned}$$

Since under infeasibility, the NTPC wants to meet its constraints, of which one of them is the zero profit constraint for SEB, meeting this constraint is equivalent to

$$p_n Q_s - p_n D(\overline{p}_s) - C(Q_s) \geq -\overline{p}_s D(p_s) + f_s \tag{5.9.1}$$

Let us call the above the feasibility inequality. Let us consider the following cases.

Case A : Suppose $\overline{p}_s D(\overline{p}_s) - f_s < 0$. This implies that $p_n(Q_s - D(\overline{p}_s)) - C(Q_s) \leq 0$. Therefore the feasiblity inequality can never be satisfied here.

Case B : Suppose $\overline{p}_s D(\overline{p}_s) - f_s = 0$. Then $p_n(Q_s - D(\overline{p}_s)) - C(Q_s) = 0$. The feasibility inequality is satisfied but holds only if $p_n = 0, Q_s = 0$, and this is the only feasible p_n and Q_s. Correspondingly, $Q_n = D(\overline{p}_s)$, and $p_n = 0$. So NTPC will never choose this option.

Case C : Suppose $\overline{p}_s(D(\overline{p}_s)) - C(D(\overline{p}_s)) - f_s \geq 0$.
Then $-C(D(\overline{p}_s)) \geq -\overline{p}_s D(\overline{p}_s) + f_s$. Here, $Q_s = D(\overline{p}_s)$ and $Q_n = 0$, so NTPC can charge any p_n. Of course it will not choose this option either.

Case D : The only interesting case therefore is $\overline{p}_s D(\overline{p}_s) - f_s > 0$ and $\overline{p}_s(D(\overline{p}_s)) - C(D(\overline{p}_s)) - f_s < 0$. The SEB's constraint is $p_n Q_s - p_n D(\overline{p}_s) -$

$C(Q_s) \geq -\overline{p}_s D(p_s) + f_s$.
Let the maximum Q_s that meets the above inequality be
$Q_s(p_n) = G(p_n, -\overline{p}_s D(\overline{p}_s) + f_s)$ for given p_n and parameters $\overline{p}_s, D(\overline{p}_s), f_s$. So we know that in order to satisfy the inequality we must have $p_n \in [0, \overline{p}_n]$.
Now the NTPC's profit maximization problem given this $Q_s(p_n)$ is :

$$\text{Max}_{p_n} \quad \pi_n = (p_n - b_n)(D(\overline{p}_s) - Q_s(p_n))$$

where $Q_s(p_n) = G(p_n, -\overline{p}_s D(\overline{p}_s) + f_s)$
Differentiating,

$$\frac{\partial \pi_n}{\partial p_n} = [(D(\overline{p}_s) - Q_s(p_n))] - (p_n - b_n)Q'_s(p_n)$$

$$Q'_s(p_n) = p_n \frac{dQ_s}{dp_n} + (Q_s(p_n) - D(\overline{p_s}) - C'(Q_s)\frac{dQ_s}{dp_n}$$

$$\text{or} \quad \frac{dQ_s}{dp_n} = \frac{[(D(\overline{p}_s) - Q_s(p_n))]}{p_n - C'(Q_s)}$$

$$\text{Therefore} \quad \frac{\partial \pi_n}{\partial p_n} = [(D(\overline{p}_s) - Q_s(p_n))] - (p_n - b_n)\frac{[(D(\overline{p}_s) - Q_s(p_n))]}{p_n - C'(Q_s)}$$

$$= [(D(\overline{p}_s) - Q_s(p_n))][1 - \frac{p_n - b_n}{p_n - C'(Q_s)}]$$

$$= [(D(\overline{p}_s) - Q_s(p_n))][\frac{b_n - C'(Q_s)}{p_n - C'(Q_s)}]$$

Since $b_n < C'(Q_s)$ by assumption, and for any $p_n < \overline{p_n}, p_n < C'(Q_s)$ by definition of $\overline{p}_n$, the above expression is positive.
$\frac{\partial \pi_n}{\partial p_n}$ is thus rising in p_n for $p_n \in [0, \overline{p}_n]$. Since NTPC will now want to choose that p_n for which its losses are minimized, while keeping to the feasibility constraint for SEB, it will choose $p_n = \overline{p}_n$. SEB's feasibility inequality is thus reduced to equality and it makes exactly zero profits here.

A.5(2) : Proof to show that aggregate profit Π is concave in p_n and is maximized at $p_n = b_n$.

For $\overline{Q}_s$ fixed, the aggregate profit is :

$$\begin{aligned} \Pi &= p_s D(p_s) - C(\overline{Q}_s) - b_n(D(p_s) - \overline{Q}_s) - f_s - f_n \\ &= p_s(D)D - C(\overline{Q}_s) - b_n(D - \overline{Q}_s) - f_s - f_n \end{aligned}$$

We have argued in Claim 1 that total output $Q_s + Q_n = D(p_s)$ is decided at the point where $MR(Q_s + Q_n) = p_n$.
Let revenue $R = p_s(D)D$.

$$\frac{\partial \Pi_n}{\partial p_n} = \frac{\partial R}{\partial D}\frac{\partial D}{\partial p_n} - b_n \frac{\partial D}{\partial p_n}$$

Setting the above to zero, we get

$$\frac{\partial D}{\partial p_n}[MR(D) - b_n] = 0$$

.

$$\text{where} \quad MR(D) = \frac{\partial R}{\partial D}$$

which gives $MR = b_n$. (We know that $\frac{\partial D}{\partial p_n} = \frac{\partial D}{\partial p_s}\frac{\partial p_s}{\partial p_n}$, and since $\frac{\partial D}{\partial p_s} < 0$, $\frac{\partial p_s}{\partial p_n} > 0, \Longrightarrow \frac{\partial D}{\partial p_n} < 0$).
But we know that $MR = p_n$. Therefore aggregate profit is maximized at $p_n = b_n$.

$$\frac{\partial^2 \Pi}{\partial p_n^2} = (MR')\frac{\partial D}{\partial p_n} + (MR)\frac{\partial^2 D}{\partial p_n^2} - b_n \frac{\partial^2 D}{\partial p_n^2}$$

Since $\frac{\partial MR}{\partial p_n} > 0$, and $\frac{\partial D}{\partial p_n} < 0$ we have

$$\text{Therefore,} \quad \frac{\partial^2 \Pi}{\partial p_n^2} < 0$$

which implies the concavity of the aggregate profit function.

A.5(3) : Proof of the single crossing property when consumer prices of electricity is variable

For non-linear demand and cost curves, the profit function of the SEB is:

$$\Pi = p_{si}(\overline{Q}_i)\overline{Q}_i - f_s - F_n - p_{ni}(\overline{Q}_i - \overline{Q}_{si}) - \int_0^{\overline{Q}_s} c(\overline{Q}_s) d\overline{Q}_{si}$$

Differentiating,

$$d\Pi = p_{si}[d\overline{Q}_{si} + d\overline{Q}_{ni}] + (\overline{Q}_n i + \overline{Q}_{si})dp_{si} + p_{ni}d\overline{Q}_s - dp_{ni}(\overline{Q}_i - \overline{Q}_{si}) + c_i(\overline{Q}_{si})d\overline{Q}_{si} = 0$$

$$\text{or } d\overline{Q}_{si}[p_{si} + p_{ni} - c_i(\overline{Q}_{si})] = dp_{ni}(\overline{Q}_i - \overline{Q}_{si}) - (\overline{Q}_{si} + \overline{Q}_{ni})dp_{si} - p_{si}d\overline{Q}_{ni}$$

$$\text{or } \frac{d\overline{Q}_{si}}{dp_{ni}} = \frac{(\overline{Q}_i - \overline{Q}_{si}) - (\overline{Q}_{si} + \overline{Q}_{ni})dp_{si}/dp_{ni} - p_{si}d\overline{Q}_{ni}/dp_{ni}}{p_{si} + p_{ni} - c_i(\overline{Q}_{si})}$$

$$\frac{d\overline{Q}_{si}}{dF_{ni}} = \frac{1 - (\overline{Q}_{si} + \overline{Q}_{ni})dp_{si}/dp_{ni} - p_{si}d\overline{Q}_{ni}/dp_{ni}}{(p_{si} + p_{ni} - c_i\overline{Q}_{si})}$$

$$-\frac{dF_{ni}}{dp_{ni}} = -\frac{[(\overline{Q}_i - \overline{Q}_{si}) - (\overline{Q}_{si} + \overline{Q}_{ni})dp_{si}/dp_{ni} - p_{si}d\overline{Q}_{ni}/dp_{ni}]}{1 - (\overline{Q}_{si} + \overline{Q}_{ni})dp_{si}/dp_{ni} - p_{si}d\overline{Q}_{ni}/dp_{ni}}$$

Note that aggregate output of SEB is the point where $p_n = MR$. For the same MR curve and the same p_n facing the SEB, aggregate output $\overline{Q}_i$ will be the same. And therefore $p_{si}(\overline{Q}_i)$ will also be the same for both types.

$$-\frac{dF_{ni}}{dp_{ni}} = -\frac{\{Q_{ni}\} - (\cdot)}{1 - (\cdot)}$$

Since, for the same (p_n, F_n) the low cost can produce a higher level of output, $Q_{sl} > Q_{sh} \Longrightarrow Q_{nl} < Q_{nh}$, or $-Q_{nl} > -Q_{nh}$. Therefore, the low cost type has a higher or steeper slope than the high cost one in the $[p_n, F_n]$ space.

A.5(4) : Proof of the single crossing property when consumer prices of electricity is fixed

$$\Pi = p_{si}(\overline{Q}_i)\overline{Q}_i - f_s - F_n - p_{ni}(\overline{Q}_i - \overline{Q}_{si}) - \int_0^{\overline{Q}_s} c(\overline{Q}_s)d\overline{Q}_{si}$$

$$d\Pi_i = -dp_{ni}(\overline{Q_i} - \overline{Q}_{si}) + p_{ni}d\overline{Q}_{si} - c_i(\overline{Q}_{si})d\overline{Q}_{si} = 0$$

$$\text{or } \frac{d\overline{Q}_{si}}{dp_{ni}} = \frac{\overline{Q}_i - \overline{Q}_{si}}{(p_{ni} - c_i(\overline{Q}_{si}))}$$

$$\frac{d\overline{Q}_{si}}{dF_{ni}} = \frac{1}{(p_{ni} - c_i(\overline{Q}_{si}))}$$

$$-\frac{dF_{ni}}{dp_{ni}} = -[\overline{Q_i} - \overline{Q}_{si}] = -Q_{ni}$$

Again, since $Q_{nl} < Q_{nh}$, $-Q_{nl} > -Q_{nh}$, or the low cost SEB's indifference curve between p and F is steeper.

Chapter 6

Conclusion

6.1 Introduction

A developing country like India, like all developed countries, has to depend increasingly on the intensive use of energy sources for the smooth running of the economy. One of the most important forms is electricity, which is now a basic infrastructure of the economy.

The electricity industry almost everywhere in the world is a monopoly, which means that rival firms rarely compete with one another for a share of the market. In countries like the United States of America and Canada the industry is a private monopoly, where profit maximization takes place subject to a regulatory constraint. This is because electricity is a public utility which should benefit as wide a market as possible, and a monopolist setting high prices might just push some consumers out of the market.

Where the government manages the industry, as in France, India and other developing countries, the objective is not profit maximization at all. Since it has generally been observed that consumers do not like high prices for certain essential services, the government fixes or administers the prices. About 65% – 70% of electricity generation in India is in the State sector, under various State Electricity Boards (SEBs). Since SEBs are directly under the government, their functioning is subject to the constraints set up by the government. Among one of the constraints is fixed prices for the consumers which do not depend on demand and supply changes. Therefore while aiming to curb the monopoly power of the SEBs, the government pursues its own objective of providing subsidised power.

But keeping prices artificially low can lead to many problems. Since prices are not market clearing, market distortions and inefficiencies result. When consumers are required to pay a price that is much lower than their marginal valuation of the good, this leads to an excess demand at the given price. This is most certainly true for electricity demand in India. Besides, electricity demand itself keeps varying throughout the day with significant peaks and dips, which makes the question of supply important because this would mean unutilised capacity at some points of the day, and too less capacity at all other points. When prices are not flexible, this means that at times when supply falls short of demand, suitable load management schemes have to be worked out.

6.1.1 The Questions

This thesis is concerned with optimal supply and with optimal load management schemes. It deals with two main questions :
(a) What is the optimal rationing scheme to be adopted in a situation of excess demand when capacity to supply is fixed and prices are rigid ?
(b) If the rationed demand were to be met by allowing electricity to be purchased from an outside firm, but comes with a cost which may not be viable, then what is the purchase price that will induce the SEB to purchase, while allowing the other firm as well as itself to be making nonnegative profits ? How does the situation change when consumer prices are flexible as well ?

Both these issues are important from a policy standpoint in view of the fact that electricity is an important intermediate good as well as an essential service for final consumers and any inefficiency in supply will mean a loss in overall welfare. From a research standpoint, it is the question of allocating a public good optimally and minimizing the deadweight loss to society through inefficient generation and supply.

The existing literature on disequilibrium markets in a fix price economy has been discussed in great detail in the context of socialist economies,where the solution lies in the attainment of equilibrium over time. Tobin [1951] has discussed rationing and its effect on consumer behavior. In the past few years, there have been attempts to study efficient rationing (Wilson [1989], Tschirhart and Jen [1979]). But both these studies use priority service pricing as a tool to achieve efficient allocation of resources when an excess demand occurs. All the above studies take a particular rationing mechanism as given and determine consumers response to it. What a part this thesis has attempted is to derive an optimal rationing mechanism for a supplier of electricity when consumer prices are fixed.

6.2 Models and Results

The optimal rationing mechanism should be one that causes the least loss to society. This will mean determining a mechanism that minimizes overall welfare loss. The supplier first determines the actual loss in welfare arising from the rationing, and then as a second step determines the optimal rationing mechanism by choosing to minimize this welfare loss subject to overall resource constraints. Using suitable definitions for welfare loss gives the result that the rationing mechanism will be the one that equalizes, *at the margin*, the net valuations of a unit of supply for each type of consumer. This is also the efficient rationing mechanism that will optimally allocate the available capacity.

We then proceed to provide an empirical demonstration of the rationing mechanism by choosing the state of Uttar Pradesh as an illustrative example. Welfare loss for the sectors using electricity as an intermediate input is defined as the loss in the value of output due to the restriction of electricity input. To determine the loss in the value of output, we need to show what value of output would have been achieved *in the absence* of rationing. For this we use the notion of 'potential output' defined by Hickman [1964], as that output which corresponds to the minimum point of the short run average total cost curve. Given the cost minimizing behavior of the firm, this is the optimum level of output it should have achieved. We use this definition to say that industry and agriculture would have achieved this level of output (expressed in value terms), in the absence of any restriction. The difference between the value of potential output and the actual output is then defined to be the loss in welfare for these two consumer types. Implicit is the assumption that the divergence between the potential output and the actual output is *only due to* the restriction of electricity demand. Comparing the two we find that there has been substantial loss to the producing sectors, especially the industrial sector due to the restriction.

For final consumers, we use the concept of virtual prices (first defined by Rothbarth [1940-41]) i.e., some hypothetical prices that would induce a consumer, through his utility maximizing behavior, to choose exactly the ration level available without the supplier having to enforce any rationing. The difference between the virtual price and the actual price is then defined to be a measure of loss. We conclude from the high level of determined virtual prices that there definitely arises some loss to final consumers due to electricity rationing. The optimal rationing scheme is then determined from a minimization programme. We sum up the welfare loss over all types (since all expressions are in value terms), and minimize this objective subject to resource constraints. Then the derived rationing scheme which equalizes the marginal net valuations of a unit of electricity for all types, shows that agriculture has been receiving more electricity at the expense of industrial output and therefore it is worthwhile to transfer the supply from agriculture to both industry and household. This also conforms with the opinions of many energy specialists who argue that with agricultural power being subsidised, too much of it is wasted while industry is hit in a hard way due to power cuts.

The literature on public utility pricing is vast and deals with many hypotheses regarding producers and consumers behavior. Using this vast literature as a background, we have attempted to answer the second question of optimal supply for the special case of India, where the SEB can actually supply the total demand by purchasing from an outside firm which has a comparatively lower cost of production. But it may not be prepared to do so because the outside firm charges a monopoly price that exceeds the marginal revenue of the SEB. So the pricing question is to determine the optimal purchase price that will induce the SEB to indeed supply all that is demanded so that the selling firm does not lose out in the process.

Our model to deal with this question is formulated on the notion of a principal agent problem, where the seller firm (National Thermal Power Corporation) is the principal who announces a price that maximizes profits, subject to the agent (SEB) maximizing its own output, given the purchase price. This formulation is based on the empirical evidence that the structure of incentives for workers in both firms is different. Specifically, the SEBs are given incentives to improve plant load factors, and show increased levels of generation. We also assume that the NTPC has a lower marginal cost than the SEB, but charges a price (which is single a part tariff) higher then the SEB's own costs which is the basis of the problem. So the solution is to derive an optimal price that will satisfy the SEB's objective and allow both firms to make nonnegative profits. We look upon the optimal price as a two part tariff as suggested by recent policy announcements of the Central government. Our results say that when consumer prices are fixed then even a two part tariff will not solve the problem such that both firms now make nonnegative profits. Consequently, only one firm makes nonegative profits. A two part tariff will solve the problem only if
(i) consumer prices are flexible to be determined by the SEB such that the supply is commercially viable, and
(ii) the principal i.e., NTPC uses the fixed part of the tariff to discipline the SEB into curbing the production of its own high cost output.

We then explore the same question with different hypotheses regarding the SEB's and the NTPC's objectives and determine the optimal two part tariff for each case. The other hypotheses we consider are : (i) profit maximizing behavior for SEB, (ii) welfare maximizing behavior for NTPC with output maximizing SEB, with and without fixed consumer prices, (iii) welfare maximizing behavior for NTPC with profit maximizing SEB, with and without consumer prices fixed.

Our results show that for the socially optimal level of generation and supply to take place in the economy, the welfare maximization objective for the NTPC with a profit maximizing SEB which allows consumer prices to be flexible, is the most suitable. This fits the objective admirably, because both firms (NTPC and SEB) can be pushed to the zero profit level, and more output can be supplied to the consumers, thereby lowering the price and increasing consumers surplus.

We also provide an extension where we consider a situation of uncertainty – that is, where the NTPC which sells the much needed power has to decide on a two part tariff without knowing the costs or the profit structure of the SEB. Here we show that the optimum requires setting a schedule of two part tariffs, rather than a single vector of two part tariff. The SEB with a lower cost will be charged a per unit tariff that is equal to the marginal cost of the NTPC and a fixed tariff that will leave it with zero profits after it has produced the minimum admissible level of its own output. The higher cost SEB will pay a higher per unit price and a lower fixed tariff, but where the fixed tariff wipes out its positive surplus too. We also consider the same question under fixed consumer prices and show that the results are analogous to the flexible prices case.

6.3 Suggestions for Policy Design

A developing country like India is scarce in capital resources and it has to learn to use its existing resources economically and efficiently. It is true that capacity built to generate electricity in the country is not sufficient to meet the growing demand for electricity from both the producing sectors which are getting increasingly energy intensive, and from the needs of final consumers, whose consumption of consumer goods operating on electricity has been rising. But the situation is not much to despair about if the existing capacity were to be used more efficiently.

When an excess demand occurs and in the short run no adjustment of supply is possible, then electricity should be supplied to those sources where its marginal contribution is the highest. In this context it is worthwhile reiterating that providing subsidised priority power to agricultural and certain domestic consumers distorts this optimal allocation. All consumers should pay a price that reflects the scarcity of the good and their marginal valuation of it. In sectors where there are alternatives available, the price of electricity should take this into account. It has been widely commented upon that industrial production cannot, in the short run adapt to other energy forms, and therefore any shortfall in supply can lead to a high level of loss of industrial output, thus slowing the growth rate of the economy.

In Western economies the use of 'time of use' prices has been widely advocated because they are more optimal than a single rate when the costs of supply vary depending on the load curve. This policy can be tested in India while weighing the costs of monitoring such 'time of consumption', and the elasticity of consumer demand to the time of use prices.

As regards the more economical generation of power, we have already argued in the previous chapters that the country as a whole stands to benefit if the costs of generation are minimised and the mix of output is chosen optimally such that there is more capacity utilisation of the more efficient plants. We have formulated a model such that the SEBs which are entrusted with supplying power to consumers, use up the NTPC capacity for the base load. However, a single NTPC unit may service many SEBs depending on its geographical location. We would find therefore that the NTPC would soon run into a capacity constraint. At higher levels of demand therefore the SEB has to bring its own plants into operation in addition to the NTPC plants already running. Even then, it may be the case that demand is not satisfied, but at least the resources have been used optimally. So the SEBs incentives should be based on the profit levels, *or* on the output, but only peak period output so that a reliable supply to consumers in the peak period is assured.

As our results have shown, having social objectives such as welfare nmaximization is beneficial to the consumers because it allows the surplus to be transferred from the producers to the consumers. Since electricity is an essential good, and the producers are the government firms, this is probably a more social objective.

Other suggestions include maintaining a high operating availability for plants, cutting down on transmission and distribution losses, preventing theft by strict monitoring, and getting repairs done so that plants are not left idle.

6.4 Limitations and possible research issues

This thesis is both an empirical and theoretical exercise aimed at optimal load management schedules. For the empirical part, we have taken the state of U.P. as an illustration, and determined the optimal rationing hours to be imposed. But there are some limitations. Firstly, we have worked with the actual supply and not the demand. If demand were known then more sophisticated disequilibrium models could have been used to determine the rationing mechanism in the presence of fixed prices. Not only that, if period wise demands were available, then this exercise could have been more meaningful. This is because it would allow us to determine the *periods* of rationing, and also be helpful in determining consumers response to differential prices ; elasticities could be worked out and corresponding pricing policies could be designed.

Also, such an exercise would be more helpful if it were applied to the nation as a whole, because it would then allow us a comparison between all the states in analysing the efficiency of the system. These, we accept are some of the limitations of this thesis.

We have, in this thesis examined two important issues or problems that beset electricity supply in India. One when an excess demand occurs and prices cannot be used as a tool, then it becomes necessary to choose a rationing mechanism that would optimally allocate resources. Secondly, it is necessary that the least cost output be sold to consumers. In order that this is done one needs to determine the purchase price that will induce the SEB to purchase a lower cost output, while keeping to its output maximizing behavior.

Both of these questions are essentially short term solutions to the problem of determining optimal supply. In the long run capacity has to be increased to meet the growing demand. This will mean determining the long term investment costs for addition to capacity and the method of financing to build up capacity. A related question is what should be the optimal mix of technology; viz., thermal, hydel, solar, nuclear, biogas etc. to cover different portions of the load curve. Both these questions are important for policy and research which this thesis has not attempted to answer.

There are various other issues which have potential for further research. One, it is important to examine what adequate incentives do SEBs require for cutting down on transmission and distribution losses. For, even if they agree to purchase and sell the low cost NTPC power, the objective of meeting demand may be lost if power is lost during transmission. Two, there have been some suggestions for evolving a national grid that will guide the operations of supply such that raw materials (coal) for generation need no longer be transported over long distances thus adding to costs of any plant that was far removed from the pitheads. It would be interesting to examine the following issues : (a) what should be the prices that the consumers serviced by such plant should pay ? (b) If consumers are widely dispersed geographically, then should a consumer who is far away from a plant pay a higher price than a consumer who is closer to the generating station, or should there exist a uniform price for all consumers in a single period ? (c) If so, then how should the SEB minimize the burden of subsidising such consumers ?

Three, there can be some empirical experiments using priority service pricing such that the consumers who value electricity the most will choose the more reliable schedule and consequently pay the highest price. In a power deficient state this becomes almost necessary.

There have been recent policy announcements by the government allowing for private sector participation in power generation. The private sector can then sell power to the SEBs at a tariff that will roughly depend on their plant load factors. Besides, such firms will also be allowed to earn a higher rate of return than the SEBs. Though several modalities have to be worked out, it would be an interesting exercise to determine the effects of such entry on the availability of power and the profits of the State Electricity Boards.

Bibliography

1. Ahluwalia, Isher Judge. [1985] *Industrial Growth in India: Stagnation since the mid-sixties*, 72-98, (Delhi: Oxford University Press).

2. Alshi, M. R., Kumar. P., Mathur, V. C. [1983] "Technological change and factor shares in cotton production: A case study of Akola cotton farms," *Indian Journal of Agricultural Economics*, Vol 38, 1-4, 407-415.

3. Bal, H.k., Singh, Bant., Bal, H.S. [1983] "Resource productivity and factor share in crop production in Central districts of Punjab," *Indian Journal of Agricultural Economics*, Vol. 38, 1-4, 424-428.

4. Barro, R. J. and Grossman, H. I. [1971] "A general equlibrium model of income and employment," *American Economic Review*, 61, 82-93.

5. Baumaol, W.J. and Bradford, D.F. [1970] "Optimal departures from marginal cost pricing," *American Econonomic Review*, 60, 265-283.

6. Benassy, J. P. [1982] *The Economics of Market Disequlibrium*, (New York: Academic Press).

7. Berndt, E. R. and Wood, D. O. [1975] "Technology, prices and the derived demand for energy," *Review of Economics and Statistics* Vol. 57, 259-268.

8. Boiteaux, M. [1949] "La tarification des demandes en point: application de la theorie de la vente au côut marginal, revue Generale de l'electricite' 58, 321-340 ; also translated as "Peak Load Pricing,", *Journal of Business*, 33, [April 1960], 157-179.

9. Boiteaux, M. [1956] "Sur la gestion des monopoles publics astrients a L'Equilibre budgetaire, " *Econometrica* 24, 22-40. also translated as "On the management of public monopolies subject to budgetary constraints," *Journal of Economic Theory* 3, 3[Sept 1971], 219-240.

10. Brown, G. and Johnson, M.B. [1969] "Public Utility pricing and output under risk, " *American Economic Review*, Vol. 59, No. 1, 119-128.

11. Brown, J. Stephen and Sibley, S. David [1986] *The Theory of public utility pricing*, (New York: Cambridge University Press)

12. Carlton, D. W. [1977] "Pricing with stochastic demand," *American Economic Review*, Vol 67, 1006-1010.

13. Cassel, J. M. [1937], "Excess capacity and monopolistic competition", *Quarterly Journal of Economics*, 51, 426-443.

14. Central Electricity Authority, *Average Tariffs and Duties*, various issues.

15. Central Statistical Organisation, [32^{nd}, 38^{th}, 42^{nd} round] *NSSO : Survey on Consumer Expenditure.*

16. Central Statistical Organisation, [1990] *Tables with notes on the consumption of fuel and light on the basis of the results of the first three Quinquennial rounds of NSS Surveys.*

17. Chandhok, H. L. and The Policy Group [1990], *India Database: The Economy*, Vol 1,2.

18. Chao, Hung-Po. [1983] "Peak Load pricing and capacity planning with demand and supply uncertainty," *Bell Journal of Economics*, Vol 14, 1-2, 149-170.

19. Christenson, L. R., Jorgenson, D. W. and Lau, L. J. [1971] "Conjugate duality and transcendental production frontiers," *Review of Economic Studies*, 55, 28-45.

20. Clower, R. W. [1965] " The Keynesian counterrevolution: A theoritical appraisal," in Brechling, F.P.R. and Hahn, F. H. (eds), *The Theory of Interest Rates*, (London: Macmillan).

21. Crew, A. Michael. and Kleindorfer, R. Paul. [1976] "Peak load pricing with a diverse technology," *Bell Journal of Economics*, Vol. 7, 1, 207-231.

22. Crew, A. Michael. and Kleindorfer, R. Paul. [1978] "Reliability and public utility pricing," *American Economic Review*, Vol.68, 1, 31-40.

23. Crew, A. Michael. and Kleindorfer, R. Paul. [1979] *Public Utility Economics*, (London: Macmillan Press).

24. Cuddington, John. T. Johansson, Per-Olov. Lofgren, Karl-Gustaf. [1984] *Disequlibrium macroeconomics in open economies* (Oxford: Basil-Blackwell).

25. Deaton, A. S. and Muellbauer, J [1980] "An almost ideal demand system," *American Economic Review*, 70, 312-326.

26. Deaton, A. S. and Muellbauer, J. [1980(a)] *Economics and Consumer Behavior*, (NewYork: Cambride University Press).

27. Deaton, A. S. [1981] "Theoretical and empirical approaches to consumer demand under rationing," in *The Theory and Measurement of Consumer Behavior*, ed. by Deaton, A. S. 55-72, (NewYork: Cambridge University Press).

28. Deaton, A. and Muellbauer, J. [1981] "Functional forms for labour supply and commodity demands with and without quantity constraints," *Econometrica* Vol. 49, 6, 1521-1532.

29. Diewert, W. E. [1971] "An application of the Shephard duality theorem : A Generalized Leontief production function," *Journal of Political Economy*, 79, 481-507.

30. Diewert, W. E. [1974] *Frontiers of Quantitative Economics*, Vol. 2, M. D. Intrilligator, and D. A. Kendrick (eds.) (North Holland Publishing Co.).

31. Dreze, J. H. [1964] "Some post-war contributions of French economists to theory and public policy, with special emphasis on problems of resource allocation," *American Economic Review*, Supplement, vol. 54, 1-64.

32. Dupuit, Jules. (1969) (first appeared in 1857) "On the measurement of the utility of public works," *Readings in Welfare Economics*, AEA series, 255-283, (George Allen and Unwin).

33. Fair, Ray C. and Jaffe, M. Dwight [1972] "Methods of estimation for markets in disequilibrium," *Econometrica*, Vol 40, 3, 497-514.

34. Faulhaber, Gerald. R. [1975] "Cross-Subsidization : Pricing in public enterprises," *Econometrica*, Vol 65, 5, 966-977.

35. Feldstein, Martin S. [1972] "The pricing of public intermediate goods," *Journal of Public Economics* 1, 45-72.

36. Fertilizer Association of India [1981-82, 1982-83, 1983-84, 1984-85] *Fertilizer Statistics*.

37. Friedman, M. [1963], "More on Archibald versus Chicago", *Review of Economic Studies*, 30, 65-67.

38. Gellerson, Mark W. [1979] "Marginal cost based electricity tariffs : Theory and case study of India," *Indian Economic Review*. Vol. 14, 163-176.

39. Ghosh, Arun. [1991] "Eighth Plan : Challenges and Opportunities - 6," *Economic and Political Weekly*, February 23, 405-412.

40. Goldar, B. N. [1986], *Productivity Growth in Indian Industries*, (New Delhi: Allied Publishers).

41. Government of India [1981, 1982, 1983, 1984, 1985] *Agricultural Prices in India: Index Numbers of Agricultural Production*, Ministry of Agriculture.

42. Government of India, [1981-82, 1982-83, 1983-84, 1984-85], *Agricultural Wages in India*, Directorate of Economics and Statistics, Ministry of Agriculture.

43. Government of India, [1983, 1984] *Bulletin on Commercial Crops Statistics*, Ministry of Agriculture.

44. Government of India [1984, 1985] *Comprehensive List of the Cost of Cultivation Data*, Ministry of Agriculture.

45. Government of India [1948] *The Electricity (Supply) Act*, Ministry of Law.

46. Government of India [1987] *Estimates of State Domestic Product*, Department of Statistics, Ministry of Planning.

47. Government of India [1974] *Fifth Five Year Plan*, Planning Commission, India.

48. Government of India, [June 1990], "Report of the Committee on fixation of tariffs for Central sector power stations," *Central Electricity Authority*, K. P. Rao, Department of Power, Ministry of Energy.

49. Government of India [1989] "Report of the sub-group on energy pricing, SEBs finances and related issues," Ministry of Energy.

50. Government of India [1981-82, 1982-83, 1983-84, 1984-85] *Petroleum and Natural Gas Statistics*, Ministry of Energy.

51. Government of India [1985] *Seventh Five Year Plan*, Planning Commission, India.

52. Government of India [1981] *Sixth Five Year Plan*, Planning Commission, India.

53. Government of Uttar Pradesh, [1981-82, 1982-83, 1983-84, 1984-85], *Agricultural Abstracts of Uttar Pradesh*, Directorate of Economics, Statistics and Crop Insurance, Ministry of Agriculture.

54. Government of Uttar Pradesh, [1983-84] ***Statistical Abstract of Uttar Pradesh***, Economics and Statistics Division, Lucknow, Uttar Pradesh.

55. Greene, William H. [1990] ***Econometric Analysis***, (New York: Macmillan Publishing Company).

56. Guesnerie, R. and Seade, J. [1982] "Non linear pricing in a finite economy," ***Journal of Public Economics***, 157-179.

57. Haque, T. Sharma, V. K. and Bhatia, M. S. [1983] "Temporal and spatial variation in factor shares in Indian agriculture," ***Indian Journal of Agricultural Economics***, Vol 38, 1-4, 391-406.

58. Hema, R. [1988] "An optimum rate structure for electricity pricing in Tamilnadu." Thesis submitted to the University of Madras.

59. Henderson, P. D. [1975] ***India : The Energy Sector***, (NewDelhi : Oxford University Press)

60. Hickman, B. G. [1964], 'On a new method of capacity estimation', ***Journal of the American Statistical Association***, 59, 529-549.

61. Hirshleifer, [1958] "Peak loads and efficient pricing: Comment," ***Quarterly Journal of Economics***, 72, 451-462.

62. Hotelling, H. [1938] "The general welfare in relation to problems of taxation and of railway and utility rates," ***Econometrica***, 6, 242-269.

63. Johnston, J. [1984] ***Econometric Methods***, 3rd edition, (Singapore: McGraw Hill).

64. Kapoor, T.N., [1967] "Industrial development in the states of India," (Delhi: Sterling Publications).

65. Kadekodi, G.K., [1985] "A welfare approach to energy pricing : A case study for India," ***the Energy Journal***, Vol.6, 3.

66. Kelkar, V. Gupta, K.P., Joshi, R. Roopa. [1990] - *Pricing policy for electricity generation - The BICP Approach.*

67. Leijonhufvud, A. [1968] *On Keynesian economics and the economics of Keynes* (London: Oxford University Press).

68. Lipsey, R. and Lancaster, K. [1956-57] "The general theory of the second-best," *Review of Economic Studies*, 24, 11-32.

69. Maddala, G. S. and Nelson, Forest D. [1974] "Maximum likelihood methods for models of markets in disequilibrium," *Econometrica* 6, 42, 1013-1030.

70. Meyer, R. A. [1975] "Monopoly pricing and capacity choice under uncertainty." *American Economic Review*, 65, 426-437.

71. Minhas, Jain, Kansal and Saluja, [1989], "Measurement of general cost of living for urban India – All India and Different States," Technical Report No. 8806, *Indian Statistical Institute, New Delhi.*

72. Munasinghe, Mohan and Warford, Jeremy J. [1982], *Electricity Pricing : Theory and Case Studies*, published for the World Bank, (Baltimore and London : The Johns Hopkins Univiversity Press).

73. Murty, M.N. [1986], "Interfuel substitution and the derived demand for inputs in the manufacturing sector of India", *Journal of Quantitative Economics*, 2(1), January, 119-135.

74. National Council of Applied Economic Research [1965] *Technoeconomic Survey of Utter Pradesh*, 97-130, (New Delhi: NCAER publications).

75. Neary, J. P. and Roberts, K. W. S. [1980] " The Theory of household behavior under rationing," *European Economic Review* 13, 25-42.

76. Nelson, J. R. [1964] "Marginal cost pricing in practice," (NewJersey: Prentice-Hall Inc.).

77. Nelson, Randy. A. [1989], 'On the measurement of capacity utilization', *The Journal of Industrial Economics*, March, Vol 37, 273-286.

78. Northern Regional Electricity Board, [1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990], *Annual Administration Report*, Central Electricity Authority.

79. Ng, Y. K. and Weissner, M. [1974] "Optimal pricing with a budget constraint: The case of the two-part tariff," *Review of Economic Studies* Vol 61.

80. Oi, W. Y. [1971] "A Disneyland dilemma: Two part tariffs for a Mickey Mouse monopoly," *Quarterly Journal of Economics*, Vol 85, 77-90.

81. Panzar, J. C. [1976], "A neoclassical approach to peak load pricing," *Bell Journal of Economics*, 7, 2, 521-530.

82. Pathak, B. S. [1983] "Energy constraints to agricultural production," *Indian Journal of Agricultural Economics*, Vol. 38, 1-4, 530-538.

83. Rajagopalan, V. and Varadarajan, S. [1983] "Nature of new farm technology and its implications for factor shares – A case study of Tamilnadu," *Indian Journal of Agricultural Economics*, Vol 38, 1-4, 424-438.

84. Ramsey, F. P. [1927] "A contribution to the theory of taxation," *Economic Journal*, 37, 47-61.

85. Ray, Ranjan. [1989] "The behavioral and welfare implications of housing demand under rationing - The U.K. experience," *Journal of Population Economics*, 2, 211-224.

86. Regional Power Survey Centre, [1981, 1982, 1983, 1984, 1985], *Regional Power Surveys*, Central Electricity Authority.

87. *Reserve Bank of India*, various issues.

88. Rothbarth, E. [1940-41] " The measurement of changes in real income under conditions of rationing," *Review of Economic Studies*, 8, 100-107.

89. Ruggles, N. [1949] "The Welfare basis of the marginal cost pricing principle," *Review of Economic Studies*, 17, 29-46.

90. Sampath, R.K., Singh, B.K. and Hussain, Zakir [1984] "Agricultural production functions, technical progress and relative land utilization by large farms across countries," *Indian Journal of Agricultural Economics*, Vol 39, 1-4, 53-69.

91. Sankar, U. and Hema, R. [1985] "Optimum rate structures for public enterprises : A study of electricity pricing in Tamilnadu," Department of econometrics, Madras School of economics, University of Madras.

92. Sarkar, Hiren and Kadekodi, G.K., [1988] *Energy Pricing in India : Perspective, Issues and Options*, International Labour Organisation and Asian Employment Programme (ARTEP), New Delhi.

93. Seethaprabhu, K. [1984] "The Treatment of Pesticides in the production function framework : A skeptical note," *Indian Journal of Agricultural Economics*, Vol 38, 1-4, 123-129.

94. Seth and Mehta [1987] "On the measurement of state level capital output ratios," *Journal of Industrial Relations*, Vol 22, 4, 369-390.

95. Shephard, R. W. [1953] *Cost and Production Functions*, (Princeton : Princeton University Press).

96. Shukla, Tara [1965] "Capital formation in Indian agriculture," (Bombay: Vora and Company).

97. Steiner, P. O. [1957] "Peak loads and efficient pricing," *Quarterly Journal of Economics*, 71, 585-610.

98. Stone, J. R. N. [1954] "Linear expenditure systems and demand analysis: an application to the pattern of British demand," *Economic Journal*, 64. 511-527.

99. Takayama, A. [1985] *Mathematical Economics*, 2nd edition. (NewYork: Cambridge University Press).

100. Tobin, James. [1952] "A survey of the theory of rationing,"*Econometrica*, 4, Vol. 20, 521-553.

101. Tshirhart, John and Jen, Frank. [1979] "Behavior of a monopoly offering interruptible service," *Bell Journal of Economics*, 10, 244-258.

102. Turvey, R. [1968] *Optimal pricing and investment in electricty supply* (Allen and Unwin 1968, and MIT Press 1969).

103. Turvey, Ralph. [1969] "Marginal cost," *The Economic Journal*, 281-299.

104. Turvey, R. [1970] "Peak load pricing and output under risk : Comment," *American Economic Review*, 60, 485-486.

105. Turvey, Ralph and Anderson, Dennis. [1979] *Electricity Economics*, (Batimore, Maryland : The Johns Hopkins University Press).

106. Uri, N.D., [1979] "Energy demand and interfuel substitution in India," *European Economic review*, 181-190.

107. Uttar Pradesh State Electricity Board [1985, 1990] *Statistics at a glance.*

108. Visscher, M. [1973] "Welfare maximizing price and output with stochastic demand, " *American Economic Review*, Vol. 63, No.1, 224-229.

109. Wenders, J. T. [1976] "Peak load pricing in the electricity industry," *Bell Journal of Economics*, 7, 232-241.

110. Williamson, O. E. [1966] "Peak load pricing and optimal capacity under indivisibility constraints," *American Economic Review*, 56, 810-827.

111. Willig, R. D. [1978] "Pareto-superior nonlinear outlay schedules," *Bell Journal of Economics*, 9, 56-69.

112. Wilson, Robert. [1989], "Efficient and competitive rationing," *Econometrica*, Vol. 57, No.1, 1-40.

113. Zellner, A. [1962] "An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias," *Journal of the American Statistical Association* Vol.57, 348-368.

INDIAN STATISTICAL INSTITUTE LIBRARY

Processing slip

Source..............................P/E/G date. 23.12.05 Acc. no. T 158

Author. Vishvanathan, Uma.

Title. Optimal short run electricity supply in India.

CHECKING :

Call no.

1 In library/earlier ed./later ed. [ ]

2 Earlier volumes/nos. of the series in lib. [ ]

3 New title [✓]

Suggested/Approved by

Note :

23-12.05

Signature & date

CLASSIFICATION :

Class no..............................x-ref..............................

Scrutiny report :

Signature & date

Class no..............................x-ref..............................

Note :

Signature & date

CATALOGUING ;

1 Main Card [ ]

2 Supp. Cards (Subject/Title/Series/Added entries/Shelf List) [Total no. of cards]..............................

3 Mechanical processing completed on..............................

4 Cards filed [ ]

Note :

Signature & date