SEEDS
Surrey Energy Economics
Discussion paper Series

SURREY
ENERGY
ECONOMICS
CENTRE

Efficiency Considerations in the Electricity Supply Industry; The Case of Iran

Ali Emami Meibodi

July 1998

SEEDS 95
ISBN 1852372141

Department of Economics
University of Surrey

SEEC consists of members of the Department of Economics who work on energy and environmental economics. SEEC's aims include the promotion of research and teaching in the broad area of energy economics and policy. SEEC was founded in 1983. Its creation was intended to consolidate the research on energy economics which developed at the University of Surrey after the appointment of Colin Robinson to the Chair of Economics in 1968. Colin and the colleagues he attracted to the University built up Surrey's reputation, initially with pioneering work on North Sea oil and gas, and subsequently in all the other major areas of energy economics.

- Recent research covers the following areas: Electricity, gas and coal privatisation in the UK; privatisation in the Middle East; the structure of UK energy demand; North Sea oil and gas economics and policy: international oil markets; electricity economics; the transport of energy; environmental policy in the UK; energy and environmental policy in the Third World; global environmental issues.

- SEEC research output includes **SEEDS - Surrey Energy Economic Discussion paper Series** (recent titles may be found on the backcover), as well as a range of other academic papers, books and monographs including ***SEEC Occasional Papers*** and SEEDS Technical Papers.

- Each year SEEC organises a range of energy conferences and workshops on energy themes. Specialist workshops include the meetings of the the joint SEEC/BIEE **Energy Modelling Group**, convened by David Hawdon and Paul Appleby (BP).

- Members of SEEC provide major inputs into the postgraduate energy courses run by the Economics Department - in particular, the M.Sc. courses on Energy Economics and Energy Policy, and the Diploma in the Economics of Energy and Development for Graduates.

Enquiries:

***Director of SEEC and Editor of SEEDS*:**
David Hawdon *email: d.hawdon@surrey.ac.uk*

SEEC, Economics Dept, School of Human Sciences,
University of Surrey, Guildford GU2 5XH, UK.
Telephone: +44 (0)1483 259379 Fax: +44 (0)1483 259548

Surrey Energy Economics Discussion paper Series
SEEDS 95

Efficiency Considerations in the Electricity Supply Industry; The Case of Iran

Ali Emami Meibodi
University of Surrey

ISBN: 1852372141
July 1998

British Library ...
A Catalogue re...

Discussion paper

Efficiency Considerations in the Electricity Supply Industry
The Case of Iran

July 1998

ABSTRACT

Electricity plays a vital role in modern economies. It is considered a core activity in the economic development plans of most countries. The requirement of large investments in the power sector and the rising cost of electricity provision have intensified the need for increased efficiency in the Iranian electricity supply industry. This study provides an efficiency analysis of the electricity industry in Iran. It presents efficiency scores for the Iranian electricity industry relative to the efficient frontier for electricity production, and in relation to the electricity industries of 26 developing countries. The average level of technical efficiencies in the electricity industry of these developing countries, the Iranian power plants and regional distribution organisations are estimated at 77%, 72.7% and 81% respectively. They are based on a two-year panel data of 26 developing countries, six-year unbalanced panel data of thirty Iranian power plants and one cross-section of thirty distribution organisations taken in 1995.

This study utilises two popular techniques; Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). The use of both SFA and DEA extends the capabilities of addressing issues in ways that would otherwise not be available. Econometric models using panel data are employed to investigate technical inefficiencies. The Malmquist index approach is applied to investigate technological change, technical and scale efficiency changes in the electricity industry in the sample of developing countries as well as Iranian power plants. The DEA efficiency scores are used in Tobit models to determine which factors are the main causes of inefficiency.

The crucial point of this study is to find out how technical efficiency can be improved and by how much. Is the form of ownership a determinant of the efficient operation of the electricity industry in developing countries?

1 INTRODUCTION AND BACKGROUND

Twenty years after the invention of electric power by Edison, T (21 Oct.1879) electricity was first introduced into Iran. However, the history of the electricity industry in Iran begins in 1904 when a 400 KW generator acquired by an Iranian merchant, Haaj Amin-ul-Zarb, was installed in Tehran. The major development of the electricity industry commenced in the 1960s.

The Iranian electricity supply industry has been mainly under the control of the government since 1965 when the nationalisation law was ratified by the government. The then government decided to invest directly in the electricity industry and encourage the private sector to invest in other industries. A common argument was that the electricity industry as a whole was a natural monopoly due to production economies of scale. The government argued the importance of providing ample supplies of electricity at reasonable rates was a basic necessity for economic development (UN,1965,1967). It was hoped that a publicly owned monopoly would be able to operate the electricity supply industry on a large scale and would be induce cost reduction of electricity production. However, the costs recorded were high, and electricity tariffs did not keep up with the growth in costs, which far exceeded revenue. For instance, in 1996, the average cost of electricity production based on domestic fuel prices was Rls.105 per kwh, while its average revenue was Rls.49.5, so that the subsidy paid by the Ministry of Energy per kwh was Rls. 55.5. i.e., the electricity has been sold at less than half its cost. On the other hand, the Ministry of Energy is receiving subsidies from the government in the form of:

- Low fuel prices for electricity generation
- Allocation of governmental exchange rates
- Access to state-owned banking system facilities
- Exemption from some customs and commercial rules
- Allocation of the country's income revenues (annual budget set)
- Low tax commitment (payment)

In an effort to reduce the governmental subsidy provided to the electricity industry, the government intends to increase the degree of decentralised decision making in the power sector. The first BOT (Built, Operate and Transfer) contract (1995) for building a thermal power plant (1000 MW) in the Kerman city was aimed at meeting this objective. Under the BOT model, private investors construct the power station, sell power to the electricity industry for an agreed price, then, once the debt is paid off, transfer the power station to the electricity industry at a nominal price (Sullivan, 1990). The Ministry of Energy is encouraging foreign investment in the electricity industry on a BOT basis. The Minister has declared that the country will cooperate with efficient foreign companies that are ready to transfer technical know-how to Iran and enter into long-term cooperation with the Ministry of Energy. The Ministry will also hand over some of its affiliated companies to the private sector in the future.

Given the allocation of huge subsidies to the electricity industry, it can be argued that the electricity production and pricing policies in Iran unlikely to be regarded as economically efficient. The annual subsidies may reflect managerial/scale inefficiency in electricity operations. Investigation into what went wrong, may avoid mistakes in the future.

2 AN ECONOMIC ANALYSIS OF THE IRANIAN ELECTRICITY INDUSTRY

2.1 Structure of the electricity industry

In the 1890s the appearance of large steam turbines allowed the development of the thermal power plants around the world. However, it was not until 1959 that the first steam power plant (Shahid Firozi power station) was built in Tehran.

The electricity supply industry has been based mostly upon thermal power plants in Iran. In other words, during the last 28 years the hydro-power plants contributed, on average, 21% of the Iranian electricity requirements. This contribution was only 9.1% in 1994. Considering that the country (Tehran as an indicator) had a mean annual rainfall below 250 mm during the last three decades, it is expected that thermal not hydro power generation will play an important role in the future; there is no nuclear power.

There are three categories of thermal power plants; steam turbine, gas turbine and diesel generator. During the period 1977-1994 the share of gas turbines in the country's electricity production was risen while the share of diesel generators has remained at a low level. In 1985, around 26% of the electricity produced by the Ministry of Energy came from gas turbines, about 15% came from hydro, 55% was from steam power plants and the remaining 3.8% was produced by diesel generators. Gas turbines accounted for 20% of the total electricity production in 1994.

In this period (1977-1994), the population grew so fast (e.g. at 1.95 percent annum during the period 1986-1996) that the government could hardly satisfy electrical needs, and the country suffered a large breakdown in generating capacity. Given the urgency of meeting demand, gas turbines were seen as the quick way of adding new generating capacity. In general, gas turbines tend to be used for peaking purposes because they require much quality fuel and have relatively low technical efficiency. In Iran, some existing open cycle gas turbine plants are being converted to combined cycle operation through adjusting the steam cycle equipment. As can be seen later on, the use of gas turbines in combination with steam turbines in combined cycle plants is advisable.

In the past, due to mostly political considerations, the nominal prices of domestic fuel were kept at fixed levels. Consequently, following the high inflation rates in the last two decades, fuel is supplied almost free of charge to the Ministry of Energy by the Ministry of Petroleum (World Bank, 1994a). It is expected that the economic efficiency (allocative × technical) of the electricity production is low, partly due to low fuel prices (allocative inefficiency) and partly because of the relatively high share of gas turbines (technical inefficiency) in the production process. The estimated average technical inefficiency is 27.3%, indicating that the Iranian power plants were only 72.7% technically efficient over the period 1990 to 1995. The econometric result indicates that, in order to increase the technical efficiency of the Iranian power stations, the gas turbine power plants should take decreasing share in electricity production.

2.2 Distribution organisations for electricity

During the era after the Islamic Revolution (1979) the Ministry of Energy was largely concerned with the expansion of electricity generation in order to satisfy electricity demand. Thermal power plants were badly damaged during the eight year Iran-Iraq war (1980-1988). The electricity industry had insufficient generating capacity to meet current needs, and was faced with increasing demand from a rapidly growing population. Therefore, the focus was on production aspects. This led to a neglect of distribution side of electricity which suffered from under-investment compared to production.

In 1981 there were eleven organisations responsible for the distribution and sale of electricity. During 1992, in an effort to improve the organisational structure of the electricity industry, these were reorganised into 24 distribution organisations. The public distribution organisations obtain electricity from the national system, and are obliged to supply electricity in their corresponding distribution area to all domestic, commercial and other customers. By 1995 the number of distribution organisations had been increased to 30. Supply of safe and high quality electricity to the consumers at the least possible cost are among the main objectives of the power distribution organisations. Each public distribution organisation is administered by a publicly authorised manager appointed by the Ministry of Energy.

The Ministry of Energy realized the necessity of evaluating the performance of the distribution organisations, and in October 1995 inspectors were sent to evaluate their activities. Their performances (based on some qualitative and quantitative criteria) were ranked as excellent, very good and good. The results were published as follows:

Official performance evaluation of the distribution organisations in 1994

Distribution Organisations	Ranking
Ghazveen, Mashad, Zanjan, Khorasan and Azarbaijan Gharbi	Excellent
Fars, Markazi, Khozestan, Isfahan, Tehran, Gharb Tehran, Bushehr, Hormozgan, Semnan, Azarbaijan Sharghi, Mazandaran, Ardebil, Kerman, Qum, Hamadan, Lorestan, Sistan & Balochestan, Gilan, Kordestan, Yazd, Kermanshah, Kokeeloeh & Booyer Ahmad.	Very Good
Char Mahal Bakhtiari and Ilam	Good

Source: The Ministry of Energy, PAIK- E-BARQ, Newsletter, No.25, 1995, Page10.

In the Ministry's Newsletter (1995) copying the practice of the successful distribution organisation (Fars) was recommended to less successful organisations in order to tackle inefficiency. It is interesting to note that the empirical work (Section 3) also introduces the Fars distribution organisation, as a dominant reference set.

In the absence of any frontier analysis regarding technical efficiency of the distribution organisations, the Ministry of Energy is inclined to rely on its own criteria. The existing method of performance evaluation has some drawbacks; Firstly it does not present quantitative measures of efficiency for each organisation. Secondly the procedure for selection of reference sets for inefficient units is not straightforward. The Ministry of Energy could use the frontier analysis (DEA/SFA approaches) in order to monitor the performance of the electricity distribution organisations as well as the power plants.

2.3 Ownership and institutional structure

Historically, electricity supply industries were mostly operated by publicly-owned enterprises with a high degree of integration. In the world, the most significant step in integrating the electricity industry and passing control to the government took place shortly after the Second World War in 1946, when legislation was approved by the French parliament creating Electricite de France as a state-owned integrated utility. In Iran the nationalisation law was ratified by the government in August 1965. By 1969 nearly all the electricity industry was nationalised and the regional distribution companies were set up by the government, which was a step towards improving the administration of the electricity supply industry. Private installations were purchased and work transferred to the responsibility of the Regional Companies. The institutional arrangement of the each regional company was similar to that of the Ministry, comprising engineering, commercial, financial and administrative departments. All regional companies were supervised by the then Ministry of Water and Power (UN,1969). At the same time, the Iranian power generation and transmission company was established for the purpose of generation and transmission of electricity for bulk sales to the regional companies and very large customers.

It seems that the traditional approach to electricity supply is being changed. In 1990s, the liberalisation (restructuring and privatisation) of electricity industries was well under way (World Bank, 1994b,1997). The literature on electricity sector reform is extensive (among them Pollitt, 1997). In Iran, after the Iran-Iraq war, due to the emergence of new circumstances in the country, privatisation of the public manufacturing enterprises with the aim of increasing efficiency and structural adjustment was approved by the Board of Ministers in 1991. Decentralising policies were taken into consideration for the electricity industry. In practice, based on the legislation by the Board of Ministers some duties and responsibilities of the Power Affair Deputy of the Ministry of Energy were given to the Iranian power generation and transmission company and the name of this company was also changed into the Iranian power generation and transmission organisation.

The government is considering a role for the private sector in building power stations and generating electricity. The most important policy measure, adopted in 1994, was the law passed by the Iranian parliament which obliges the Ministry of Energy to purchase electricity at guaranteed price from the private sector. These policies are intended to encourage the private sector, which was entirely absent from the Iranian electricity supply industry since 1980, to invest in the electricity generation.

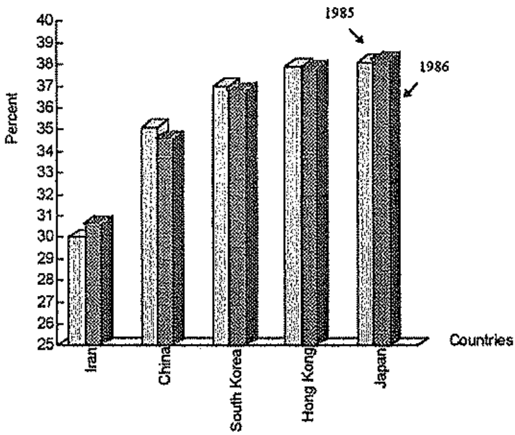
2.4 Electricity supply and operating performance

During 1967-1994 period, electricity generation increased from 1842 Million Kwh to 77,086 million kwh. Though electricity production has been increasing to satisfy the demand, it is argued that the operation of power system could not be satisfactory. Some standard criteria are used to examine the operating performance of the industry.

2.4.1 Energy utilisation

The electricity industry is an energy waster, consuming large amounts of energy unnecessarily. The critical dependence of the Iranian economy on energy exports, underlies the need for energy conservation. The issue becomes crucial, when it is noted that the energy used for generating electricity was 25.6 percent of the total used in 1993. In fact, a significant proportion of the demand for energy originates in the electricity generating sector. If domestic energy consumption decreases, this amount can be allocated for export. It is particularly meaningful for members of OPEC, that are subject to oil production quotas. Energy conservation is also desirable due to global warming and environmental problems. Comparable data highlights the extent of wasteful energy consumption pattern which needs to be rationalised (Figure 2.5).

2.5 Energy conservation of the power industry in some countries (1985-1986)



During the 1967-1994 period, energy conservation of the Iranian electricity supply industry ranged between 25.6 and 32 percent. For the energy conservation calculations, the quantities of different types of fuel used in the power stations were combined by converting them into British thermal unit (Btu) equivalents. The formula is as follows:

$$\text{Energy conservation} = \frac{\text{electricity generated (Btu)}}{\text{fuel inputs (Btu)}} \times 100$$

In electricity generation the primary mechanism to improve fuel consumption can be inter-fuel substitution. Construction of appropriate time-series data, provided an opportunity to examine the substitution possibilities among energy forms (fuel oil, gas oil and natural gas). In the era after the Islamic revolution, some significant modifications were made in the type of fuel consumed by the country's power plants.

The increasing share of natural gas in thermal power plants reflects the growing awareness of natural gas availability and its advantages for generating electricity. Iran has 20.7 trillion cubic metres of natural gas which is the second largest endowment in the world. Substituting natural gas in power generation, in addition to environmental considerations, has dual benefits. The benefits come from both import substitution for gas oil deficits and releasing fuel oil for other uses. The decrease of gas oil consumption in the country's power plants is also advisable, because gas oil causes erosion of paddles within power plants (field visit, 1997).

2.4.2 Overall electricity loss

The operational performance of the power sector can also be improved by diminishing the high system losses. The difference between electricity generated and electricity billed has been high in the Iranian electricity industry. The overall electricity loss ratio is calculated as follows:

$$\text{Overall electricity loss ratio} = \frac{\text{electricity loss (kwh)}}{\text{electricity generated (kwh)}} \times 100$$

The system loss ratio has been increased from 16.1% in 1985 to 18.5% in 1993. In comparison, one study indicates that the system loss of Japan was only 6% in 1991 (Ingco, 1996). Studies carried out by the World Bank suggest that the economic level losses on most system is in order of 10-15% (Pearson, 1991). With present technology, these losses should generally range between 7% and 10% (Schramm, 1993). It can be argued that there is major scope for loss reduction in the Iranian electricity industry. Part of these losses are due to non-technical factors such as inaccurate metering and billing, un-metered supplies, non-payments (some government departments are among the non-payees) and illegal connections. Another factor affecting high losses is the poor conditions of the Transmission and Distribution network (T&D). Efforts should be made to reduce these losses. Policy implications include some strategies to combat non-technical factors as well as improvements in Transmission and Distribution facilities.

2.4.3. Capital utilisation

In addition to the need for energy conservation in electricity production, the optimum use of capital in electricity generation is also vital for efficient electricity production. It is argued that savings can be achieved in the better utilisation of the existing installed generating capacity.

Load Factor (LF) is a measure of optimum use of capital (capacity). LF is the ratio of the actual output produced to the maximum output of electricity that a plant could produce if it were to be operated continually at maximum capacity. It is calculated as follows:

$$\text{Load factor} = \frac{\text{electricity generated (Kwh)}}{\text{peak demand (KW)} \times 8760} \times 100$$

A 100% load factor means that capacity or peak demand is used continuously for 24 hours a day. A 50% load factor means that capacity is only used for an average of 12 hours a day. In the case of the Iranian electricity supply industry the average annual load factor has ranged from 40% in 1967 to 65.7% in 1990. The highest load factor in the world which was registered is 92.9% for the state-owned electricity company in Thailand (Pollitt,1995). Substantial gains may come from the optimum use of existing capacity. Namely, with improvement in load factor, costs can be significantly reduced. In the meantime, a high load factor may indicate a near optimal amount of plants. It is worth noting that a high load factor, in most countries, may be the outcome of the peak load pricing, which can be used in policy making. Peak load pricing refers to the pricing of economically non-storable commodities whose demand varies periodically. Peak load pricing has been the subject of considerable researches (Crew, et al, 1995). In Iran, due to prevailing hot weather during summer and extensive use of air conditioning and cooling systems, maximum demand for electricity usually occurs in summer, the months of June, July, August and September. It is worth pointing out that the cooling system of buildings is mostly electric evaporating coolers and window type air conditioning. Although evaporating coolers in the dry climate of Iran is effective, the design of the present system goes back to the 1960s and does not incorporate the latest technological advances (World Bank, 1994a).

As noted the peak load demand for electricity is highly correlated with hot weather in the summer. On the other hand, in the summer due to hot weather the generation of thermal electricity is also faced with some limitations (due to increasing oil temperature in power stations, field visit, 1997). In addition, in the summer due to shortage of rainfall the level of water reserves in the dams are reduced, so that the share of the production of the hydro-power stations declines. The problem seems a dilemma for the summer. However, interestingly enough, the peak load hours of electricity consumption in Iran are not usually the same as a number of its neighbouring countries, therefore, electricity exchange among neighbouring countries may be used to optimise their use of electricity in the peak load hours (for instance, in Iran Thursdays and Fridays are weekends, however in Turkey, Saturdays and Sundays are holidays).The use of more advanced technology in cooling systems will lead to less peak load demand for electricity in the summer. Encouraging industries to take annual holidays to coincide with the summer peak period will be also met this achievement. Tariffs are powerful tools to manage electricity demand, they can be used to shift demand and reduce peak load demand to minimise capital requirements.

2.5 Some of the basic issues

As analysis revealed, the main issues of the Iranian electricity industry are low efficiencies in electricity production and pricing. It is argued that technical efficiency has not enjoyed a satisfactory status in the past. The price issue is the lack of clear policies on electricity pricing. Tariffs are set through a negotiating process between the Ministry of Energy and the Budget & Planning Organisation, which requires approval by the Iranian parliament, and hence is open to political manipulation. The average per kilowatt-hour charge for electricity in Iran was around half of what the average tariff required was to cover its costs. The Iranian government has continued to provide subsidies in order to compensate for technical and allocative inefficiencies.

To summarise, this analysis indicates that in the Iranian electricity industry, similar to most developing country utilities (Sullivan,1990, World Bank, 1990, 1992, 1994a, 1994b, Schramm, 1990,1993, Bhattacharyya,1995 and World Bank,1997), subsidised tariffs and inefficiencies are the basic issues. Research advanced to tackle the problems.

3 EMPIRICAL ANALYSIS

3.1 Introduction

This chapter deals with an investigation into technical efficiency of the Iranian electricity industry. This industry is first compared with that of other developing countries. This study naturally seeks to learn which countries in the sample are the most or least efficient. Consistent data was collected for 26 developing countries. If additional countries are introduced into the analysis, they may reduce, but cannot increase the technical efficiency of a given country. This is quite natural, since a country might be highly efficient by developing country standards, but not by international standards.

This analysis uses the data collected on thermal power plants. This selection ensures that plants in the sample constitute a homogenous technology. The previous studies (Yunos & Hawdon, 1997 and Hawdon, 1997) used the DEA approach in a cross-sectional framework to measure relative performance of developing countries in 1987 and 1988. It is useful to compare the technical efficiency of the electricity industry of developing countries under the DEA and the SFA specifications by using panel data of 1987 and 1988. Considering the effects of ownership and plant size in a

Tobit efficiency model, the intention is to shed light on the controversy over ownership and efficiency.

In the next step, the Iranian power plants and regional distribution organisations are investigated respectively. The application of the Malmquist DEA methods to panel data provides an appropriate tool to calculate indices of total factor productivity, technological, technical and scale efficiency changes in power plants of developing countries.

In determining the effective factors for efficiency improvements, the DEA efficiency scores are used as dependent variable in a Tobit regression model. Throughout this analysis, the technology is modelled in terms of input-based orientation, the objective is to provide electricity with a minimum resource level. In fact, as Coelli (1995) argues, in many studies the researchers have to select input-oriented models because Decision Making Units (DMUs) have particular orders to fill (e.g. electricity generation) and hence the input quantities appear to be the primary decision variables. Generally speaking, one should select an orientation according to which quantities (inputs or outputs) the managers have most control over.

The stochastic production frontier and technical inefficiency are estimated using the program LIMDEP 7 released by William H. Greene in October 1995. The DEA efficiency scores and the Malmquist indices are calculated using the program DEAP2 developed by Tim Coelli in 1996 which has been designed for economists. Other useful DEA software, LAMBDA4 (Hawdon and McQueen, 1996) was also used for the measurement of efficiency scores in which the equivalent scores were obtained with DEAP2.

3.2 Empirical model

The basic structure of stochastic frontier models is as follows:

$y_{it} = f(x_{it},\beta) + v_{it} - u_i$

$i = 1, 2, \ldots, N, \quad t = 1, 2, \ldots, T$

where

y_{it} = output from firm i for year t

x_{it} = input from firm i for year t

v_{it} = statistical noise

u_i = firm effect representing technical inefficiency

It is customary in panel data models to arrange the observations in vector form, taking the individuals (with all their observations) one after the other. A panel data set may alleviate the problem of multicollinearity; since the explanatory variables vary in two dimensions, they are less likely to be highly correlated.

Technical inefficiency (u_i) is assumed to be time-invariant for each firm. Technical inefficiency and its relative ranking are unlikely to change greatly over short time periods, so time-invariant assumption seems reasonable (Schmidt and Sickles,1984, Kalirajan and Shand, 1989). If N (number of firms) is large but T (period of time) is small, the time-invariant assumption fits the usual framework more closely both to usual panel data technique and stochastic frontier analysis (Schmidt and Sickles, 1984, Schmidt, 1985). In addition, the comparison between the SFA and DEA methodologies are considerably facilitated by this invariance assumption (Gong and Sickles, 1992).

The effects are treated as random, because economic effects are random and not fixed (Mundlak, 1978). As Schmidt and Sickles (1984) indicate the conventional random effects model can be used for short panels in which the assumption of independence between technical inefficiency and the explanatory variables (inputs) has empirical support (Cornwell, Schmidt and Sickles, 1990).

The stochastic error term (v_{it}) is assumed to have a normal distribution and technical inefficiency (u_i) is assumed to follow a half-normal distribution. The frontier production functions are estimated using the maximum likelihood procedure available in LIMDEP. Technical inefficiencies for individual firms were obtained through the formula suggested by Battese and Coelli (1988).

3.3 Choice of data, variables and related problems

A reliable efficiency analysis depends clearly on the quality of the data. To understand the results and policy implications, it is important to get a real feel for the data. Some of the statistics of 26 developing countries for 1987 and 1988, were taken from two surveys of developing countries electric power sectors carried out by the World Bank (Escay, 1990,1991). Other necessary data was extracted from two series of UN publications; the Energy Balances & Electricity Profiles and Electric Power in Asia and the Pacific.

For the first time in 1967 information and statistics for the Iranian electricity industry were collected and published in the form of an annual statistical report, although, the data has never been used to examine the issue of technical inefficiency. The major source of Iranian data is the statistics of the Ministry of Energy. Other sources are publications of the Central Bank and the Statistics Centre of Iran. The findings presented utilize data from these official statistical sources and the information obtained from experts in prominent positions in the Ministry of Energy as well as field visits.

The data contains information on the three common inputs (labour, capital and fuel) employed to generate electricity in thermal power plants. In measuring the efficiency performance of regional companies for electricity distribution three inputs (labour, network size and transformer capacity) and four outputs (electricity sales to residential and industrial sectors as well as the number of residential and industrial customers) are used.

The measurement of outputs and inputs followed standard practice found in the literature. The fuel input includes natural gas, gas oil and fuel oil. These fuels are used in the generation stage and are aggregated into a single input by summing over their Btu (or terajoules) equivalents. Labour is measured as the number of employees. Capital is defined as installed generating capacity, measured in MW. Network size and transformer capacity is measured in kilometre (KM) and Mega Volt Ampere (MVA) respectively. Electricity production and sales are based on million kilowatts hours (Gwh). In some cases, the variables have very different magnitudes, and so the data was scaled down to reduce the possibility of convergence problems (Greene, 1995). Recall that technical efficiency analysis required only data on the physical units of inputs and outputs.

3.4 An intercountry comparison using both DEA and SFA

The objective of this section is to evaluate the performance of the electricity sector in Iran using an intercountry comparison of efficiency and productivity growth. The panel data used in the analysis comprises information on a sample of 26 electricity utilities in developing countries for 1987 and 1988. These countries produced 17.5 % out of total thermal electricity production of developing countries in 1988.

3.4.1 Specification and estimation of the production function

In modelling electricity production function, it was assumed that electricity is produced by three inputs; capital, labour and fuel. A translog production function versus a Cobb-Douglas functional form was first applied. Most of the coefficients of the translog were found to be insignificant. Generally speaking, the Cobb-Douglas form fits the data well. In the case of Cobb-Douglas form, the initial model obtained as follows:

$$\hat{LQ}_{it} = 0.148 + 0.084\ LK_{it} + 0.053\ LL_{it} + 0.952\ LE_{it}$$

(t statistics) (1.168) (1.043) (20.222)

$R^2 = 0.998$

Where;

LQ = Log (Q), Q = electricity production (Gwh)

LK = Log (K), K = capital (MW)

LL = Log (L), L = labour (total)

LE = Log (E), E = Energy (terajoules)

The signs of the coefficients of stochastic frontier are as expected. The model did not show a highly statistically significant effect from labour. It confirms the argument that capital and fuel appear to be the most important input to the electricity production technology (Schmidt & Lovell,1979, Kopp & Smith, 1980). Therefore, the preferred model is based on capital and energy inputs. The estimated model is as follows:

$$\hat{LQ}_{it} = 0.184 + 0.146\ LK_{it} + 0.935\ LE_{it}$$

(t statistics) (2.564) (18.405)

$R^2 = 0.997$, N= 52, $\sigma_v^2 = 0.00193$, $\sigma_u^2 = 0.07032$

3.4.2 Technical inefficiency estimation

The stochastic production function estimates are only a means to an end, namely technical inefficiency estimation. To obtain the individual technical inefficiencies, the method proposed by Battese and Coelli (1988) in the context of panel data was applied. The estimation of technical inefficiencies for 26 developing countries is presented in Table 3.1.

3.1 Inefficiency estimation of 26 developing countries (1987-1988)

Country	Stochastic frontier (technical inefficiency)
Thailand	0.016
Haiti	0.030
Nepal	0.040
Guatemala	0.049
Mali	0.077
Pakistan	0.139
Costa Rica	0.153
Central African Republic	0.172
Malaysia	0.184
Nicaragua	0.197
Morocco	0.213
Egypt	0.219
Mexico	0.221
Nigeria	0.225
Sri Lanka	0.231
Niger	0.235
Indonesia	0.272
Zambia	0.274
Dominican Republic	0.292
Bangladesh	0.305
Argentina	0.343
Peru	0.343
Venezuela	0.375
Iran	0.397
Ghana	0.451
El Salvador	0.534
mean	0.230

The estimated average technical inefficiency (mean of $\hat{u}$) is 0.23, indicating 23% technical inefficiency in electricity production of developing countries. In other words, power plants in the sample of developing countries are only 77% technically efficient. Thailand by having the most efficient power plants is placed on the top, while El Salvador for its least efficient power plants is on the bottom. The Iranian power plants with an efficiency of 60.3% ranked 24-th in the sample.

3.4.3 Technical efficiency measurement

The SFA results can be compared and evaluated with the DEA efficiency scores. In the meantime, it is useful to present the reference sets for inefficient power plants as a yardstick. In this regard, the DEA approach is the best choice.

In the literature, there is no regular way to handle DEA with panel data in order to get models comparable with SFA. However, in the case of a short panel, it seems satisfactory that the data is merged and efficiency scores are calculated for only one data set (Meibodi, 1998). For comparison of the SFA and DEA results, it is necessary to calculate DEA for capital and fuel inputs, i.e., with the same variables in SFA. First, the impact of labour left out from the results obtained from DEA is compared with that of DEA including labour. This is done by the correlation method for efficiency scores that are calculated by two DEA specifications. There are two methods of measuring correlation (Harnett and Soni, 1991), namely, Pearson's product moment correlation coefficient and Spearman's rank correlation coefficient.

The computation of Pearson's Product Moment Correlation Coefficient ($r = 0.89$) indicates a good correlation between two kind of DEA calculations. In the case of Spearman's rank correlation ($R = 0.828$) a null hypothesis (no difference in ranks as evidenced by two DEA calculations) cannot be rejected at the significant level of 0.01 ($0.828 > 0.515$). Consequently, dropping the labour from the calculation does not effect the results.

The results of the DEA calculation with capital and energy inputs are presented in Table 3.2.

3.2 Efficiency measures of electricity supply industry in 26 developing countries

	Country	Overall technical efficiency	Pure technical efficiency	Scale efficiency	Scale type	Stochastic frontier efficiency
1	Argentina	0.73	0.73	1	-	0.6575
2	Bangladesh	0.664	0.665	0.999	irs	0.6952
3	Central African Republic	0.57	1	0.57	irs	0.8283
4	Costa Rica	0.702	0.784	0.895	irs	0.8472
5	Dominican Republic	0.812	0.826	0.983	irs	0.708
6	Egypt	0.824	0.833	0.99	drs	0.7813
7	El Salvador	0.449	0.464	0.966	irs	0.4661
8	Ghana	0.505	0.596	0.847	irs	0.5492
9	Guatemala	0.831	0.86	0.966	irs	0.9511
10	Haiti	0.691	0.886	0.78	irs	0.9703
11	Indonesia	0.786	0.798	0.985	drs	0.7284
12	Iran	0.747	0.773	0.967	drs	0.6032
13	Malaysia	0.787	0.788	1	-	0.8161
14	Mali	0.643	0.772	0.833	irs	0.9232
15	Mexico	0.901	1	0.901	drs	0.7792
16	Morocco	0.919	0.927	0.992	irs	0.7875
17	Nepal	0.72	1	0.72	irs	0.9604
18	Nicaragua	0.637	0.647	0.984	irs	0.8035
19	Niger	0.543	0.775	0.7	irs	0.765
20	Nigeria	0.726	0.726	0.999	irs	0.7755
21	Pakistan	0.85	0.85	1	-	0.8615
22	Peru	0.657	0.659	0.997	irs	0.6574
23	Sri Lanka	0.642	0.66	0.973	irs	0.7691
24	Thailand	1	1	1	-	0.9843
25	Venezuela	0.714	0.714	1	-	0.6252
26	Zambia	0.68	0.86	0.791	irs	0.7256
	mean	0.720	0.792	0.917		0.770

Note: Observations which score less than 1 are inefficient.
irs = increasing returns to scale, drs = decreasing returns to scale, - = constant returns to scale.

The average overall technical efficiency in developing countries power plants was found to be relatively low at 72%. This finding is in agreement with the argument that efficiency in power sectors has been a neglected goal for public policy in many developing countries (Hawdon, 1997). The relatively high average scale efficiency score (0.917) suggests that scale inefficiency is a less serious problem than managerial (pure) inefficiency (0.792) in the power plants of developing countries under investigation. Managerial inefficiency is a very serious problem for some developing countries, namely for El Salvador and Ghana. Power plants, in general, are operating at a scale less than the long-run optimum (constant returns to scale). Most of these power plants exhibit increasing returns to scale. This suggests that if they were not efficient, scale expansion should improve performance. Thailand is found to be fully efficient in this regard.

The managerial (pure) technical efficiency of the electricity sector in different countries varies widely from 46.4 percent to 100 percent. Electricity sectors in Thailand, Nepal, Mexico and the Central African Republic achieved the highest scores and form the reference frontier or reference technology.

The overall technical efficiency of Iran is 0.747. Therefore, Iran could be able to reduce the consumption of capital and energy inputs by 25.3% without reducing electricity output. The results also presents slack for energy input. It indicates the need for further reductions (6.5%) in the energy input.

The DEA results have identified the reference sets for inefficient countries (Table 3.3). Thailand appeared in the reference set of most developing countries. Thailand, Nepal, Mexico and the Central African Republic might be used as a yardstick for raising the level of efficiency of other developing countries.

3.3 Reference frontier set for efficiency improvement of the Developing countries based on variable returns to scale

Country	Objective Function θ	Central African Republic	Mexico	Nepal	Thailand	Stochastic frontier efficiency
Thailand	1					0.9843
Nepal	1					0.9604
Central African Republic	1					0.8283
Mexico	1					0.7792
Morocco	0.927	0.727			0.273	0.7875
Haiti	0.886	0.991			0.009	0.9703
Guatemala	0.86			0.9995	0.0005	0.9511
Zambia	0.86			0.991	0.009	0.7256
Pakistan	0.85			0.298	0.702	0.8615
Egypt	0.833		0.033		0.967	0.7813
Dominican Republic	0.826	0.845			0.155	0.708
Indonesia	0.798		0.035		0.965	0.7284
Malaysia	0.788			0.535	0.465	0.8161
Costa Rica	0.784			0.998	0.002	0.8472
Niger	0.775	0.995			0.005	0.765
Iran	0.773		0.132		0.868	0.6032
Mali	0.772	0.899		0.099	0.002	0.9232
Argentina	0.73			0.015	0.985	0.6575
Nigeria	0.726	0.172		0.554	0.274	0.7755
Venezuela	0.714			0.156	0.844	0.6252
Bangladesh	0.665			0.794	0.206	0.6952
Sri Lanka	0.66			0.988	0.012	0.7691
Peru	0.659			0.889	0.111	0.6574
Nicaragua	0.647	0.071		0.907	0.022	0.8035
Ghana	0.596			0.999	0.001	0.5492
El Salvador	0.464	0.483		0.506	0.011	0.4661

Thailand and Mexico are the dominant reference set for Iran. Thus if Iran wishes to move towards an efficient frontier, it might be advised to adopt the weighted combination of the technologies of these two countries.

3.4.4 Comparison of the SFA results with the DEA scores

The results of the SFA and the DEA approaches are compared using correlation methods. Calculation of Pearson's Product Moment Correlation Coefficient (r = 0.71) indicates a relatively good correlation. In the case of Spearman's rank correlation, the null hypothesis (no difference in ranks as evidenced by the DEA and SFA approaches) cannot be rejected at the significant level of 0.01 (R= 0.664 > 0.515). The DEA measure based on variable returns to scale performed the best. The differences between the two approaches are relatively small. Both techniques identified Thailand as having the most efficient electricity industry and El Salvador the least efficient one. The estimation of efficiency using two different techniques adds to the robustness of the results.

3.4.5 Productivity growth index

In studying the productivity performance of power plants in developing countries, the distinction between technological progress (innovation), changes in managerial efficiency and scale efficiency is extremely useful. In this regard, the Malmquist index is a unique tool. An attractive feature of Malmquist productivity index is that it can be decomposed into economically relevant sources of productivity changes- technological change, managerial and scale efficiency changes.

In the input-based Malmquist index calculation, a value less than one means productivity growth occurred from period t to t +1. If there is productivity retardation, then the Malmquist index exceeds one. The unity value of the Malmquist index indicates there is no change in productivity.

The Malmquist productivity index and its decomposition for power plants of 26 developing countries for 1988 relative to 1987 is presented in Table 3.4. By decomposing the Malmquist index, the sources of productivity growth/retardation were identified. The remedy for a productivity slowdown caused by a decline in efficiency could be the elimination of waste and increasing efficiency. If the problem were an adverse shift in the best-practice frontier, the relevant developing countries goals might be re-evaluated in light of the technological temptation, or more funding for research and development (R&D). The improvements in the technical-change component are considered to be evidence of innovation. Knowledge of scale economies, and changes in scale are relevant for choosing the optimal size of plants, and ultimately the structure of the industry.

The principal finding is that average managerial inefficiency (1.070) dominated average technological progress (0.88) of the developing countries in the period 1987-1988. Managerial inefficiency was the major source of productivity change for 16 out of the 26 developing countries, whereas technological inefficiency was the major source for 7 out of 26 developing countries. In the case of Iran, total factor productivity fell during the period 1987 to 1988, with the greatest reduction calculated for managerial inefficiency (1.12). Developing countries as a group experienced both productivity growth and retardation during 1987-1988. The results suggest that there were total productivity gains in twelve countries and total productivity losses in thirteen. The Malmquist index varies widely across the power plants of developing countries. The greatest productivity progress occurs in the Dominican Republic. The greatest productivity slowdown is found in Argentina's power plants.

3.4 Malmquist index summary (1988 relative to 1987)

	Country	Technical efficiency change	Technological change	Pure efficiency change	Scale efficiency change	Total factor productivity
1	Argentina	1.201	1.095	1.198	1.002	1.315
2	Bangladesh	1.083	0.893	1.076	1.007	0.967
3	Central African Rep.	1.303	0.768	1	1.303	1
4	Costa Rica	1.312	0.768	1.191	1.101	1.007
5	Dominican Republic	0.771	1.007	0.789	0.978	0.777
6	Egypt	0.892	1.019	0.891	1.001	0.909
7	El Salvador	1.201	0.772	1.032	1.163	0.927
8	Ghana	1.27	0.768	1.137	1.117	0.975
9	Guatemala	1.332	0.768	1.286	1.036	1.023
10	Haiti	1.099	0.924	0.907	1.212	1.016
11	Indonesia	1.164	0.945	1.163	1.001	1.1
12	Iran	1.115	1.004	1.12	0.995	1.119
13	Malaysia	1.146	0.922	1.145	1.001	1.056
14	Mali	1.283	0.768	1.104	1.162	0.985
15	Mexico	1	1.049	1	1	1.049
16	Morocco	1.011	1.026	1	1.011	1.037
17	Nepal	1.254	0.768	1	1.254	0.963
18	Nicaragua	1.223	0.779	1.116	1.096	0.953
19	Niger	1.146	0.881	0.99	1.158	1.01
20	Nigeria	1.061	0.94	1.058	1.003	0.997
21	Pakistan	1.21	0.885	1.21	1	1.071
22	Peru	1.223	0.769	1.197	1.022	0.94
23	Sri Lanka	1.374	0.768	1.38	0.996	1.055
24	Thailand	1	0.933	1	1	0.933
25	Venezuela	0.962	1.07	0.966	0.996	1.029
26	Zambia	1.233	0.768	1.049	1.176	0.947
	mean	**1.139**	**0.880**	**1.070**	**1.065**	**1.002**

3.4.6 Determinants of efficiency

The presentation of firm's inefficiency should allow further inquiry into the sources and causes of such differences among firms which is of great importance to improve the design of policies to deal with those sources (Cote, 1989). In this section, the effective factors in efficiency improvements are determined. In 1971, Timmer explained interstate variation in technical efficiency of US agriculture. Pitt and Lee (1981) investigated the determinants of technical inefficiency variation among the Indonesian weaving firms by regressing the inefficiencies, obtained from an estimated stochastic frontier, upon a vector of firm-specific factors, such as foreign ownership, age and size. There is, however, a serious problem with such approaches. In the first stage, the inefficiency effects were assumed to be independently and identically distributed, while in the second stage they were assumed to be a function of a number of firm-specific factors which implied that they were not identically distributed (Coelli, 1995). Due to this weakness, the DEA efficiency scores are being used as the dependent variable in recent regression models for a second stage estimation (among them, Pollitt, 1996, Majumdar, 1996). Following the argument of Favero and Papi (1995), having realized the existence of scale inefficiency in power sectors of developing countries, the concentration is on VRS measures of efficiency in investigating the determinants of efficiency. Therefore, the DEA efficiency scores from the analysis of developing countries power plants are submitted to the Tobit model in order to test the hypothesis that public ownership might have the adverse effect on technical efficiency. The Tobit model is chosen, because the dependent variable is restricted to values between zero and one. For estimation, maximum likelihood technique is preferred, since maximum likelihood estimates of the Tobit model (not OLS) provides unbiased and consistent estimates of parameters. The Tobit model is also known as a censored normal regression model because some observations (less than zero and greater than one values) are censored.

A firm's scale of operation or plant size is often considered as a factor in determining efficiency (Pitt and Lee, 1981, Mayes, Harris, & Lansbury, 1994 and Yunos & Hawdon, 1997). An attempt is made to examine the combined impact of ownership and size on performance of developing countries power plants. From examining different econometric models, the preferred model is presented as follows:

$\hat{E} = 0.903 + 0.208$ SIZE $- 0.153$ PUBOWN

(t statistics) (2.54) (- 1.16)

$R^2 = 0.22$, $N = 26$

E = pure technical efficiency ($0 \leq E \leq 1$)

SIZE = measured as installed capacity (MW)

PUBOWN = Share of public electricity production out of total electricity production

The result of the final specification is broadly in line with expectations. The model is able to explain up to 22% of the variation in efficiency by variables related to ownership and size of power plants. As can been seen, public ownership although negatively related to the efficiency scores, is not significant in the conventional sense. The result may be taken at best as weak evidence for superior performance by private ownership. On the other hand, the efficiency criteria are positively related to power plant size. The results imply that in such circumstances where public ownership coincides with big power plants, their combined effects on efficiency performance could be neutralised. In other words, developing countries may benefit from scale economies to compensate inefficiency of their power sectors due to state-owned management.

The significance of size is interpreted as an indication of greater efficiency of larger power plants. Strictly speaking, the relation between size and efficiency does not, in general, guarantee the existence of increasing returns to scale. In fact the efficiency score is a measure of the distance between the observed points and the envelope obtained by joining the most efficient points. This distance does not say anything of the shape of the envelope and therefore it cannot be interpreted as an indicator of increasing returns to scale (Favero and Papi ,1995). However, the shape of the envelope (the DEA results) indicates the evidence of increasing returns to scale in most developing countries power plants. This finding that scale effects play an important role, is consistent with the individual plant studies emphasising the importance of scale economies and their potential for stimulating productivity growth (Nerlove, 1963 and Christensen & Greene, 1976).

3.5 Iranian power plants study

In this section, the efficiency measures of the main power plants of the Iranian electricity industry are examined.

3.5.1 Specification and estimation of the production function

The data for capital, energy and labour inputs of fifteen main power plants are available in 1994 and 1995. Therefore, the model specification was first carried out in the context of panel data for one output and three inputs. The model is estimated as follows:

$$\hat{LQ}_{it} = 3.144 + 0.191\ LK_{it} + 0.095\ LL_{it} + 0.920\ Le_{it}$$

(t statistics) (2.516) (0.734) (10.993)

$R^2 = 0.968$, $N = 30$

Where;

Q =Electricity production (MWh)

K = Capital (installed capacity, MW)

L = Labour (in generating sector)

E = Energy (Btu)

The coefficient of labour is insignificant, therefore, in the final model, only capital and energy are included. The study is extended to thirty power plants and having considered the new constructed plants, the panel is based on unbalanced data during the six-year period 1990 to 1995. The functional specification is of translog form, because of its flexibility and the importance of enveloping the data, the translog form can be thought of as a generalisation of the Cobb-Douglas function which made it the preferred choice of most researchers (Griffin, 1991). The underlying translog technology is specified as follows:

$$\hat{LQ}_{it} = -14.06 + 1.013\, LK_{it} + 0.707\, LE_{it} + \frac{1}{2}(0.316)(LK_{it})^2$$

(t statistics) (2.022) (6.625) (8.007)

$$-\,0.308\,(LK_{it})(LE_{it}) + \frac{1}{2}(0.265)(LE_{it})^2$$

(-44.169) (30.915)

$R^2 = 0.986$, $N = 165$, $\sigma_v^2 = 0.01120$, $\sigma_u^2 = 0.11078$

All coefficients have acceptable signs and are statistically significant. The coefficients on the cubic terms [$(LK_{it})^2$, $(LE_{it})^2$] are positive which mean that average products demonstrate an upward trend on average product (AP) curves. For instance, since the coefficient of $(LK)^2$ is positive, then increasing K will eventually cause the average product of K to increase with K (Heathfield and Wibe, 1987).

3.5.2 Technical inefficiency estimation

Having estimated the stochastic production function, the individual technical inefficiency was obtained using the Battese and Coelli approach (1988).The estimated model implies that the five most efficient power plants are Zarand, Tabriz, Beesutoon, Isfahan and Shahid Rajaie. The least efficient power plants are Sheervan and Rey. The estimated average technical inefficiency (mean of $\hat{u}$) is 27.3%. i.e. the Iranian power plants are only 72.2% technically efficient (Table 3.5).

3.5 Inefficiency estimation by stochastic production frontier (unbalanced panel)

Power plants	Technical inefficiency
Zarand	0.035
Tabriz	0.039
Beesutoon	0.050
Isfahan (Islam Abad)	0.051
Shahid Rajaie	0.053
Ramin (Ahwaz)	0.066
Gharb (Hamadan)	0.090
Shahid Montazeri	0.094
Montazer Ghaem	0.107
Soofian	0.148
Shahid Madhaj (Zargan-Ahwaz)	0.164
Loshan (Shahid Beheshti)	0.184
Bandar Abbas	0.202
Shahid Zanbagh (Yazd)	0.211
Kermanshah(Bakhtaran)	0.217
Tous steam	0.268
Shahin Shahr (Hesa)	0.296
Besat	0.302
Gilan	0.307
Neka (Salimi)	0.309
Dorud (Bakhtar)	0.344
Bushehr	0.420
Chah Bahar (Kenarak)	0.453
Shahid Firozi (Tarasht)	0.467
Qum	0.480
Rasht	0.522
Mashad	0.534
Shariati	0.549
Rey	0.598
Sheervan	0.640
mean	0.273

3.5.3 Technical efficiency measurement

The DEA efficiency scores are calculated for power plants between the years 1990 to 1995. During the 1990s, the average overall technical efficiency of the Iranian power plants ranged between 0.691 and 0.749. The low average levels of technical efficiency indicate that inputs were over-used in the past. Power plants that are regarded as overall technically efficient are operating at constant returns to scale (e.g., Tous, Isfahan and Shahid Montazeri in 1995).

In the past, the highest average pure (managerial) technical efficiency was only 86.9% (1992). The pure technical inefficiency appeared to be the main problem across the inefficient power plants for the first six years of 1990s. For instance, in 1995 managers could be able to eliminate 21.3% of the inefficiency in the power plants without the need to change scale.

Considering the whole sample, the power plants have relatively low average scale efficiency scores in 1990s. For instance, in 1995, most power plants (68%) were operating in the increasing returns to scale region. The rest with equal share (16%) exhibited decreasing returns or constant returns to scale. The results indicate that scale expansion should improve performance. The presence of increasing returns to scale implies that large power plants are required for efficient production.

Having considered three inputs (capital, energy and labour), the DEA efficiency scores are calculated for fifteen main power plants in 1995 (Table 3.6). The mean level of overall technical efficiency for power plants was 0.85 suggesting that these power plants could, on average, reduce their operating costs by 15%. In some cases, however, substantially less efficient scores were identified (e.g. Shahid Firozi, 0.53 and Rey, 0.54).

DEA suggests that Shahid Firozi and Rey can become efficient by simply reducing their input consumption proportionately to their efficiency score level. It is worth noting that the Shahid Firozi (Tarasht) power plant is the first thermal power plant (1959) built in Iran. In the case of Rey power station, it consists of only 40 gas turbines (gas power station).

Seven power plants are scale inefficient because they operate under increasing returns to scale whereas three are scale inefficient as a result of operating under decreasing returns to scale. The former group can become scale efficient if they increase their operations until they reach the level of constant returns to scale, the latter group have over-expanded.

Although Montazer Ghaem and Ramin power plants have quite high scale efficiency scores, their managerial inefficiency make a big contribution to their overall inefficiency, i.e. given their scale of operations, these plants consume more inputs than needed to produce the given output level.

3.6 Efficiency measures of main power plants in 1995

	Power Plants	Overall technical efficiency	Pure technical efficiency	Scale efficiency	Scale type
1	Shahid Firozi (Tarasht)	0.532	1	0.532	irs
2	Montazer Ghaem	0.901	0.905	0.996	irs
3	Loshan (Shahid Beheshti)	0.813	0.877	0.927	irs
4	Neka (Salimi)	0.88	1	0.88	drs
5	Shahid Rajaie	1	1	1	-
6	Besat	0.814	0.885	0.919	irs
7	Tabriz	1	1	1	-
8	Mashad	0.685	0.763	0.897	irs
9	Tous steam	1	1	1	-
10	Isfahan (Islam Abad)	1	1	1	-
11	Ramin (Ahwaz)	0.916	0.921	0.995	drs
12	Rey	0.543	0.611	0.89	irs
13	Qum	1	1	1	-
14	Gilan	0.784	0.829	0.945	irs
15	Bandar Abbas (Hormozgan)	0.845	0.891	0.949	drs
	mean	**0.848**	**0.912**	**0.929**	-

Five power plants are identified as most efficient under constant returns to scale. Among them, Isfahan and Tabriz have a high number of appearances (six times) in the reference set of other power plants. These efficient power plants might be used as a yardstick in raising the level of efficiency of other power plants (Table 3.7).

3.7 Reference frontier for inefficient power plants based on constant returns to scale (1995)

Power plants	CRS θ	Shahid Rajaie	Tabriz	Tous	Isfahan	Qum	VRS θ
Shahid Firozi (Tarasht)	0.532				0.043		1
Montazer Ghaem	0.901	0.404	0.354		0.179		0.905
Loshan (Shahid Beheshti)	0.813		0.09		0.251		0.877
Neka (Salimi)	0.88	0.285	1.247			0.622	1
Shahid Rajaie	1						1
Besat	0.814		0.053		0.307		0.885
Tabriz	1						1
Mashad	0.685		0.031	0.324			0.763
Tous steam	1						1
Isfahan (Islam Abad)	1						1
Ramin (Ahwaz)	0.916				1.017		0.921
Rey	0.543				0.348		0.611
Qum	1						1
Gilan	0.784	0.265				0.34	0.829
Bandar Abbas (Hormozgan)	0.845	0.154	0.967			0.24	0.891

3.5.4 Productivity growth index

Panel data was available for twenty five power plants from 1990 to 1995, and a Malmquist index was constructed to identify the differences in the total factor productivity of power plants.

Table 3.8 presents the average Malmquist productivity index and its decomposition; technological change, pure technical and scale efficiency changes. Recall that the distinction between efficiency growth and technological change is important because they are essentially different phenomena, and so different policies may be required to handle them. The improvements in the technological change component are evidence of innovation while improvements in the efficiency-change component are evidence of catching-up with the frontier.

This decomposition provides an attractive way of examining convergence of productivity growth, as well as allowing identification of inefficiencies. These calculations indicate that power plants experienced both productivity growth and slow down between 1990-1995. The results suggest that there was technological progress in most power plants. However, four power plants (Shahid Firozi, Rasht, Shariati, and Hesa) displayed technological regress in this period.

The Malmquist index varies widely across power plants in the period 1990-1995. The highest total productivity progress occurs at the Rasht power plant. However, on the other hand, the Rasht power plant registered technological regress during this period, so much its total productivity progress originates from scale efficiency. The greatest productivity slow down is found at the Tous power plant due mainly to managerial inefficiency.

The principal finding is that scale inefficiency dominated technological progress and pure technical efficiency in power plants in the period 1990-1995. The moderate total productivity progress over the period is due mainly to technological progress and pure technical efficiency.

3.8 Malmquist index summary of power plant means (1990-1995)

Power Plants	Technical efficiency change	Technological change	Pure technical efficiency change	Scale efficiency change	Total factor productivity change
Shahid Firozi (Tarasht)	0.909	1.007	0.956	0.951	0.915
Montazer Ghaem	0.98	0.991	0.997	0.984	0.971
Loshan (Shahid Beheshti)	1.038	0.995	1.041	0.997	1.033
Neka (Salimi)	1.016	0.997	1	1.016	1.013
Besat	1.004	0.995	1.006	0.998	0.999
Tabriz	0.997	0.98	0.997	1	0.977
Mashad	1.036	0.975	1.034	1.002	1.01
Tous steam	1.071	0.971	1.07	1.001	1.04
Isfahan (Islam Abad)	1	0.99	1	1	0.99
Ramin (Ahwaz)	1.02	0.993	1.021	0.998	1.012
Rey	1.001	0.992	1.001	1	0.993
Bandar Abbas	0.992	0.987	0.977	1.015	0.979
Shahid Montazeri	1.027	0.982	1.027	1	1.009
Shahid Madhaj (Zargan-Ahwaz)	1.041	0.995	1.037	1.003	1.036
Soofian	1.009	0.987	0.965	1.046	0.996
Shahin Shahr (Hesa)	1.01	1.008	0.99	1.02	1.018
Dorud (Bakhtar)	0.969	0.983	0.899	1.078	0.953
Sheervan	1.01	0.999	0.994	1.016	1.009
Shariati	0.968	1.016	0.974	0.993	0.983
Chah Bahar (Kenarak)	1.028	0.988	1	1.028	1.016
Bushehr	1.003	0.99	0.926	1.083	0.993
Zarand	0.933	0.99	0.958	0.974	0.924
Rasht	0.856	1.006	1	0.856	0.861
Shahid Zanbagh (Yazd)	1.009	0.969	0.971	1.04	0.978
Kermanshah(Bakhtaran)	0.998	0.987	0.961	1.038	0.985
mean	0.996	0.991	0.991	1.005	0.987

3.5.5 Determinants of efficiency

Recall that for policy implications, it is important to search for the effective factors of efficiency improvement so that appropriate policy strategies can be arranged. In the modelling, the share of steam electricity production out of total electricity production is included and serves as an indicator of the size of power plant. It is, therefore, expected to have a positive effect on the efficiency score. The presence of research and development (R&D) activity in the power plant is probably a significant explanatory variable. In this regard, the share of R&D employees out of total employees is used in the model specification. The preferred Tobit model is as follows:

$$\hat{E}_p = 0.72 + 0.003\ S_{TM} + 0.039\ L_{RD}$$

(t statistics) (2.66) (1.62)

$R^2 = 0.43$ $N = 15$

Where

E_P = pure technical efficiency in power plants

S_{TM} = share of steam electricity production out of total electricity production

L_{RD} = share of R&D employees out of total employees in production sector

Forty three percent of efficiency variations could be explained by means of these two variables (S_{TM} and L_{RD}). The model indicates that the increasing share of steam power plant in power stations has a significant effect on efficiency improvement. The finding implies that there is immediate benefit from a combined cycle pattern, so that the gas power stations should be converted into combined cycle plants. As expected, the R&D activity in power plants has a positive effect on efficiency improvement with a significance level of between 10% and 5%. The analysis shows that those power plants which spend a great deal on R&D tend to have higher efficiency scores than those which spend little.

3.6 Electricity distribution organisations study

There are 30 public distribution organisations, each operating in one of the Iranian geographical regions. These organisations employ similar technology (homogenous set of units), thus forming a suitable sample for applying the DEA model. DEA is preferred since accommodates the multi-input, multi-output nature of the electricity distribution organisations.

Data and variables

The data used in this analysis were extracted from the publication of the Ministry of Energy. The data contains conventional input and output variables consistent with the empirical studies of electricity distributions reviewed in Meibodi (1998). Four outputs and three inputs were employed as follows:

Output 1 = electricity sales to residential customers (measured in Gwh)

Output 2 = electricity sales to industrial customers (measured in Gwh)

Output 3 = number of residential customers

Output 4 = number of industrial customers

Input 1 = network size (measured in kilometre)

Input 2 = transformer capacity (measured in MVA)

Input 3 = labour (numbers of employees in distribution sectors)

As argued by Hjalmarsson and Veiderpass (1992), both the amount of electricity supplied and the number of customers were considered. For the capital input, the physical measures of capital, namely the transformer capacity and network size were used (Weyman-Jones, 1991).

3.6.1 Technical efficiency measurement

In this section the efficiency measurement of the thirty distribution organisations of electricity in Iran is under investigation. The efficiency scores presented in Table 3.9 are carried out assuming constant returns to scale and variable returns to scale. The overall technical, pure technical and scale efficiencies are calculated for the distribution organisations in 1995. Recall that technical efficiency can be measured by two different approaches, input-based or output-based. The distribution organisations are required to supply electricity at a predetermined output level. Therefore, the input based approach is more suitable for efficiency measurement in the Iranian distribution organisations where they can become more efficient only by using fewer inputs.

Having considered the whole sample, the calculated mean pure technical efficiency and scale efficiency scores have almost the same value, suggesting that both managerial and scale inefficiency are equally the cause of overall technical inefficiency in the electricity distribution organisations of Iran. Most distribution organisations exhibit increasing returns to scale. Only Mazandaran distribution is scale inefficient as a result of operating in the decreasing returns region whereas nineteen organisations are scale inefficient due to increasing returns to scale. These organisations have the potential to increase output greater than the increase in their input to attain constant returns to scale. Ten organisations are scale efficient. These findings suggest that the structure of regional distribution monopolies for the Iranian electricity industry is appropriate. Some other previous studies also found significant increasing returns to scale in distribution sector (Meyer, 1975, Neuberg, 1977, Kumbhakar and Hjalmarsson, 1998).

Amongst the inefficient organisations, seven organisations (3, 5, 11, 15, 16, 20, 29) are pure technically efficient, indicating that their overall technical inefficiency originates from scale inefficiency. Five organisations (1, 12, 13, 28 and 30) have slack variable in labour input. This may be treated as evidence of over employment. The central feature of the results is that most organisations do not appear to show a great level of overall efficiency. The least efficient organisations are Kerman, Sistan & Baluchestan and Kokeeloeh & Booyer Ahmad.

For entire organisations, the average pure technical efficiency and scale efficiency are 90% and 90.5% respectively. The results for the whole distribution organisations indicate that DEA found 9 efficient and 21 inefficient organisations under constant returns to scale. The average overall technical efficiency score for every organisation was 81% out of 100%, with a range of 50% to 100%. The number of efficient distribution organisations increases to 16 under the variable returns to scale technology, suggesting that 7 organisations are measured as technically inefficient solely because of scale inefficiency.

3.9 Technical efficiency of regional companies for electricity distribution (1995)

	Organisations	Overall technical efficiency	Pure technical efficiency	Scale efficiency	Scale type
1	Azarbaijan Sharghi	0.694	0.702	0.989	irs
2	Azarbaijan Gharbi	0.631	0.631	0.999	-
3	Ardebil	0.693	1	0.693	irs
4	Isfahan	1	1	1	-
5	Char Mahal Bakhtiari	0.658	1	0.658	irs
6	Markazi	1	1	1	-
7	Hamadan	0.747	0.833	0.897	irs
8	Lorestan	0.637	0.748	0.851	irs
9	Tehran	1	1	1	-
10	Gharb Tehran	1	1	1	-
11	Qum	0.869	1	0.869	irs
12	Khorasan	0.717	0.718	0.998	irs
13	Mashad	0.962	0.976	0.985	irs
14	Khozestan	1	1	1	-
15	Kokeeloeh & Booyer A.	0.582	1	0.582	irs
16	Zanjan	0.822	1	0.822	irs
17	Ghazveen	1	1	1	-
18	Kermanshah	0.852	0.919	0.927	irs
19	Kordestan	0.793	0.971	0.817	irs
20	Ilam	0.629	1	0.629	irs
21	Fars	1	1	1	-
22	Bushehr	1	1	1	-
23	Shiraz	0.897	0.954	0.94	irs
24	Kerman	0.507	0.513	0.988	irs
25	Gilan	0.8	0.802	0.997	irs
26	Mazandaran	0.69	0.714	0.966	drs
27	Hormozgan	1	1	1	-
28	Yazd	0.633	0.833	0.76	irs
29	Semnan	0.909	1	0.909	irs
30	Sistan & Baloochestan	0.561	0.652	0.86	irs
	mean	**0.809**	**0.899**	**0.905**	

The DEA results indicate that the performance of the overall technically inefficient organisations can be improved by adjusting their operations to match those of the organisations making their reference set (Table 3.10). Nine organisations are technically and scale efficient. Each of the 21 overall technically inefficient distribution organisations can become efficient by adjusting its operation to the associated target point determined by the efficient distribution organisations which define its reference frontier. The reference technology is defined for constant returns to scale production structure. Fars distribution organisation appears in the reference sets for twenty one inefficient organisations. This organisation is considered as the best practice efficient electricity distributor in Iran.

The DEA results show that distribution organisations corresponding to the advanced provinces (such as Tehran, Isfahan, Fars) have high efficiencies. Low efficiencies are observed for less developed regions (such as Sistan & Bloochistan, Ilam, Kerman) with more scattered population and smaller network size. Scale inefficiency appears to be a big problem in most distribution organisations.

The efficiency score suggests that Kerman distribution is 50.7% efficient. In general, this means that Kerman distribution can reduce all its inputs by at least 50.7% without reducing its outputs. For instance, it needs to reduce its number of staff by nearly 50.7% while maintaining the same level of outputs in order to become efficient. The reference set weights (0.174, 0.498 and 0.247) show the relative importance of each reference distribution organisation in determination of the target values. For instance, Gharb Tehran distribution has the highest weight (0.498), so its share is relatively more important for the Kerman distribution than two other distribution organisations of Markazi and Fars (Table 3.10).

3.10 Reference Frontier set for inefficient organisations

Base on constant returns to scale (1995)

Organisation	Objective function θ	Isfahan	Markazi	Tehran	Gharb Tehran	Khozestan	Fars	Bushehr	Hormozgan
Isfahan	1								
Markazi	1								
Tehran	1								
Gharb Tehran	1								
Khozestan	1								
Ghazveen	1								
Fars	1								
Bushehr	1								
Hormozgan	1								
Mashad	0.962	0.025				0.02	0.689		
Semnan	0.909	0.088					0.064		
Shiraz	0.897	0.042				0.01	0.392		
Qum	0.869		0.007	0.021			0.214		
Kermanshah	0.852						0.427		
Zanjan	0.822		0.019				0.232		
Gilan	0.8	0.073					0.596		
Kordestan	0.793						0.32		
Hamadan	0.747	0.027					0.392		
Khorasan	0.717						0.957		
Azarbaijan Sharghi	0.694					0.088	0.6	0.16	0.066
Ardebil	0.693						0.23		
Mazandaran	0.69		0.006	0.042			1.001		
Char Mahal B.	0.658						0.19		
Lorestan	0.637		0.157			0.033	0.195		
Yazd	0.633		0.085		0.001	0.004	0.255		
Azarbaijan Gharbi	0.631		0.029	0.001			0.253	0.703	
Ilam	0.629						0.116		
Kokeeloeh & B.	0.582					0.007	0.083		
Sistan & B.	0.561					0.064	0.204		
Kerman	0.507		0.174		0.498		0.247		

Note: Each row contains efficiencies (θ) and reference set weights (λ)

4 RESULTS AND DISCUSSION

This study applies two popular techniques of efficiency measurement in a sample of electricity industries in developing countries. The empirical evidence suggests that public ownership of electricity production might have an adverse effect on technical efficiency. The result may confirm the favourable impact of the structural reform in developing countries. However, ownership is not the only relevant factor in explaining efficiency changes. What the current study has been able to demonstrate is that a substantial proportion of the variation in efficiency within the electricity industry in developing countries is due to a factor related to size of the plant. Most of the highly efficient power plants are found to be relatively large. The results also indicate that increasing returns to scale prevail in the electricity generation of most developing countries. These findings imply that the privatisation proposal concerning efficiency improvement of the power sectors in most developing countries is not the only solution.

The findings also indicate that a more effective check on the efficiency of individual electricity industries, power plants and distribution organisations is required to avoid the unnecessary use of resources. Frontier analysis is proposed as a useful tool for analysing the performance of the electricity industry, power plants and distribution organisations. SFA is useful because it is able to identify the best and the worst performers in the context of panel data. DEA is useful because it identifies the reference sets, which suggest ways of improving the inefficient performance. As can be seen, each inefficient electricity industry, power plant and distribution organisation has a reference set consisting of the plants or organisations with the most similar operating characteristics, and input and output combinations. This information can be used as a direction of an inefficient unit to perform at least as well as those making up its reference set. Adjustment to the constant returns to scale frontier can be thought of as a long-run target, whilst adjustment to its variable returns to scale counterpart can be regarded as a short-run goal. An inefficient unit could be advised to examine the performance of its reference set for guidance. For the Iranian electricity industry, the reference set consists of techniques used in Thailand and Mexico. Based on the implementation of their techniques, the Iranian electricity industry could raise its efficiency above the low level of 75%. This could be achieved through co-operation arrangements with Thai and Mexican power companies, and supplemented by sending employees for training to the power industries of such countries. The authorities are paying attention to the development of human capital and the creation of skilled labour forces. More effort should be spent in developing training programmes for managerial employees in the electricity industry.

It is shown that R&D activity benefits technical efficiency. Strengthening domestic R&D capacity and investment in innovation could enable the adoption of imported technology and the development of new technology in the long run.

The important conclusions which emerge from the study indicate that adopting the reference frontier for the electricity industries of developing countries, the Iranian power plants and distribution organisations could reduce costs by 23%, 27.3 % and 19% respectively. Judging from the degree of technical inefficiency observed, the opportunity costs from this particular failure of the decision-making process seem to be quite large for developing countries. Much better use of energy and policies designed to increase the utilisation of existing capacity should yield benefits in terms of improved performance and reduced opportunity costs. The optimum use of energy in power plants is crucial. In Iran, the government determines the price of energy used in power stations which are far below their economic opportunity cost (e.g. 10.4% for fuel oil and 11% for gas oil in 1992). At such low price levels, energy savings are unattractive and power plants are not under pressure to save energy. The estimates show that, in the Iranian power plants, around 27% of energy (or 180 million barrel oil equivalent) could have been saved during the period 1990 to 1995. The opportunity costs and the environmental effects of such energy consumption (Pearson, 1991, 1993) are beyond the scope of the present study, but could be a task for further research. The role of gas turbine power stations in energy wastage is extremely important, so that the combined cycle arrangement could solve this problem. It is also advisable to design generating systems where some of the rejected heat is recovered for productive use, such as process uses in industry, space-heating, water-heating etc.

Given that the analysis is restricted to the electricity supply industry in developing countries, the prevalence of increasing returns to scale is not surprising. The hypothesis that scale economies in the electricity generation process appears to be exhausted might be rejected by most developing countries. The empirical results also imply that the electricity pricing cannot be followed by equivalent marginal cost pricing, while this industry has variable returns to scale. As a consequence, the suggestion of second-best pricing (Ramsey pricing rule) can be more appropriate than marginal cost pricing for publicly-owned power industries of most developing countries. A more detailed analysis ca be found in Meibodi (1998).

The low efficiencies of the Iranian electricity industry have spurred the search for a new structured approach in the industry. A hands-off approach in the distribution organisations (and transmission) does not seem to be appropriate, due partly to the existence of increasing returns to scale. This study reveals that economies of scale in electricity generation are less persistent than in distribution organisations. Therefore, the proposed structure of the Iranian electricity industry is competition in the generation, and national transmission with regional distribution monopolies. This structure introduces competition in the generation sector, while regulation is taken into consideration the transmission and distribution sectors. A more detailed discussion of such a structure can be found in Bhattacharyya (1995) and Vaziri Sabeghi (1996). In some countries (UK, Norway and New Zealand), the selling of electricity to consumers (supply function) has been seen as an activity separate from distribution, and one in which competition is also potentially possible.

It is argued that the most important and most demanding task is the regulation of the electricity industry. The suggestion is that a national independent institution responsible for the oversight of the electricity industry should be established. The useful lesson from other countries is that regulatory reform was undertaken while the industry was still in public ownership (Newbery,1994). Regulation, in a broad sense, consists of laws, licence conditions, agreements, and other instruments that control or guide the behaviour and operation of electricity supply industry (IEA/OECD, 1994). Regulatory body should largely consider incentive issues. A theory of incentives in regulation can be found in Laffont and Tirole (1993).

The low level of efficiency monitoring in the electricity industry and lack of incentives for cost reduction provide insufficient pressure for the achievement of managerial efficiency. Special emphasis should be placed on the efficiency monitoring of the electricity supply industry. It is advisable that the salary of managers is linked to the performance of their organisations, which give them incentives to reduce costs.

To date, the electricity industry is in public ownership in Iran. Institutional arrangements and high concentration (less competitive conditions) can be criticised due to the lack of sufficient incentives for increasing technical efficiency. As Cave (1993) argues, high concentration is found to be hostile to technical efficiency. Policy priority could involve the private sector and the enhancement of competition in electricity generation. Such a practice was achieved in privatising the electricity supply industry in the UK, where the generation of electricity was first separated from the monopolistic distribution system. This policy reflects a belief that, with the national grid operating as a common carrier, the generating section may become less concentrated, leading to greater price competition and increased efficiency.

It will take time for the Iranian electricity industry to prepare for privatisation. To take an example, as Bacon (1995) argues, the implementation of selling methods is an area that clearly requires care. The investment in generation may be considered as the vehicle for private sector participation. e.g., in various states in the US, independent electricity producers sell their electricity to the existing vertically-integrated company. It is worth pointing out that involvement of the private sector in electricity generation needs sound and stable planning. The governments of developing countries need to give necessary guarantees for investment of the private sector due to the long period of investment in electricity generation. The obligation of the Ministry of Energy in Iran to purchase the electricity from the private sector using a forward price seems puts this idea into practice.

In developing countries, the existence of an independent regulatory system is crucial to a successful privatisation programme. Indeed, for the governments of developing countries, the transition from the easier task of intervening directly to the more difficult but constructive role of regulating their electricity industries is a recommended move.

REFERENCES

Bacon, R. W. (1995) Privatisation and reform in the global electricity supply industry. Annual Review of Energy Environment. Vol. 20, PP.119-143.

Battese, G. E, and T. J. Coelli (1988) Prediction of Firm-Level Technical Efficiencies with A Generalised Frontier Production Function and Panel Data. Journal of Econometrics. Vol. 38, PP. 387-399.

Bhattacharyya, S. C.(1995) Power sector privatisation in developing countries: Will it solve all problems? Energy Sources, Vol. 17. PP. 373-389.

Caves, R. E. (1993) Industrial Efficiency in Six Nations. The MIT Press, Cambridge, Massachusetts, London.

Christensen, L. R. and W. H. Greene (1976) Economies of scale in US electric power generation. Journal of Political Economy. Vol. 84, No.4, PP. 655-676.

Coelli, T. J. (1995) Recent developments in frontier modelling and efficiency measurement. Australian Journal of Agricultural Economics. Vol.39, No.3, PP.219-245.

Coelli, T. J. (1996) A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Paper 96/08. Department of Econometrics, University of New England, Armidale, Australia.

Cornwell, C, P. Schmidt and R. C. Sickles (1990) Production frontiers with cross-sectional and time-series variation in efficiency levels. Journal of Econometrics, Vol. (46), PP.185-200.

Cote, D. O. (1989) Firm efficiency and ownership structure-The case of US electric utilities using panel data. Annals of Public and Co-operative Economics. Vol. 60, No.4, PP. 431-450.

Crew, M. A., C. S. Fernando and P. R. Kleindorfer (1995) The Theory of Peak Load Pricing: A Survey. Journal of Regulatory Economics. Vol. 8, PP. 215-248.

Escay, J. R. (1990) Summary Power Sheets of 1987 Power and Commercial Energy Statistics for 100 Developing Countries. INED, Washington, The World Bank.

Escay, J. R. (1991) Summary 1988 Power Data Sheets for 100 Developing Countries. The World Bank.

Favero, C. and L. Papi (1995) Technical efficiency and scale efficiency in the Italian banking sector: A non-parametric approach. Applied Economics, Vol.27, PP. 385-395.

Gong, B. H and R. C. Sickles (1992) Finite Sample Evidence on the performance of Stochastic frontier Models using Panel Data. Journal of Econometrics. Vol. 51, PP. 259-284.

Greene, W. H. (1995) LIMDEP. Version 7.0 User's Manual. Econometric Software.

Griffin, J. M. (1991) Methodological Advances in energy Modelling: 1970-1990. The Energy Journal. Vol. 14 , No.1, PP. 111-124.

Harnett, D. and A. Soni (1991) Statistical Method for Business and Economics. Fourth Edition, Addison-Wesley publishing Company.

Hawdon, D. (1997) Improving the Performance of Electricity Industries in Developing Countries: Is World Bank Policy on Deregulation the Way Forward? Economics Departmental Research Seminar, University of Surrey, 23 September 1997.

Hawdon, D. and I. M. McQueen (1996) Using Lambda (4) for DEA. SEEDS, April, Department of Economics, University of Surrey.

Heathfield, D. F. and S. Wibe (1987) An introduction to cost and production function. Macmillan Education Ltd.

Hjalmarsson, L. and A. Veiderpass (1992) Productivity in Swedish electricity retail distribution. Scandinavian Journal of Economics, Vol. 94, Supplement, PP.193-205.

Horowitz, I,. D. Seeto and C. K. Woo (1996) Ramsey pricing of electricity under unknown bypass cost. The Energy Journal, Vol.17, No.2, PP.59-77.

IEA/OECD (1994) Electricity supply industry: Structure, ownership and regulation in OECD countries. IEA publication.

Ingco, S. P. (1996) Structural Changes in the Power Sector in Asia. Energy Policy, Vol. 24, No. 8, PP. 723-733.

Kalirjan, K. P. and R. T. Shand (1989) A Generalised Measure of Technical Efficiency. Applied Economics, Vol. 21, PP. 25-34.

Kopp, R. J. and V. K. Smith (1980) Frontier production function estimates for steam electric generation: A comparative analysis. Southern Economic Journal, Vol. 46, No.4, PP.1046-1059.

Kumbhakar, S.C and L. Hjalmarsson (1998) Relative performance of public and private ownership under yardstick competition: electricity retail distribution. European Economic Review, Vo..42, No.1, PP 97-122.

Laffont, J. and J. Tirole (1993) A theory of incentives in procurement and regulation. The MIT Press, Cambridge, Massachusetts, England.

Majumdar, S. K. (1996) Government policies and industrial performance: An institutional analysis of the Indian experience. Journal of Institutional and Theoretical Economics (JITI), Vol. 152, PP.380-411.

Mayes, D., C. Harris and M. Lansbury (1994) Inefficiency in Industry. Harvester Wheatsheaf. New York. London.

Meibodi, E, A.(1998) Efficiency considerations in the electricity supply industry: The case of Iran, Ph.D. thesis. Department of Economics, University of Surrey.

Meyer , R. A. (1975) Publicly owned versus privately owned utilities: A Policy Choice. The Review of Economics and Statistics, Vol. LVII, No.4, PP. 391-399.

Mundlak, Y. (1978) On the pooling of time series and cross section data. Econometrica, Vol.46, No.1, PP.69-85.

Nerlove, M. (1963) Returns to scale in electricity supply. In Christ C. F. et al (eds.), Measurement in Economics. PP. 167-198.

Neuberg, L.G. (1977) Two issues in the municipal ownership of electric power distribution systems. The Bell Journal of Economics, PP.303-323.

Newbery, D. M. (1994) Restructuring and privatising electric utilities in Eastern Europe. Economics of Transition, Vol. 2, No.3, PP.291-316.
PAIK-E-BARQ, Newsletter, No.25 and No.28, 1995, Ministry of Energy.

Pearson, P. J. G. ed. (1991) Environment, energy efficiency and the third world. Surrey Energy Economics Centre Discussion papers-SEEDS 60.

Pearson, P.J. G. (1993) Environmental priorities and economic development: Issues in electricity generation. IAEE 15 TH North American conference, 11-13 October.

Pitt, M. M. and L. F. Lee (1981) The measurement and sources of technical inefficiency in the Indonesian weaving industry. Journal of Development Economics. Vol. 9, PP. 43-64.

Pollitt, M. G. (1995) Ownership and performance in Electric Utilities: The International Evidence on privatisation and efficiency. Oxford University press for Oxford Institute for Energy Studies. Oxford and New York.

Pollitt, M. G. (1996) Ownership and efficiency in nuclear power production. Oxford Economic Papers. Vol. 48, PP. 342-360.

Pollitt, M. G. (1997) The impact of liberalisation on the performance of the electricity supply industry: An international survey. The seminar handout at Department of Economics, University of Surrey. 4 Nov.1997.

Schmidt, P. (1985) Frontier Production Functions. Econometric Reviews, Vol. 4, No.2, PP. 289-328.

Schmidt, P. and C. A. K. Lovell (1979) Estimating technical and allocative inefficiency relative to stochastic production and cost frontiers. Journal of Econometrics. Vol. 9, PP.343-366.

Schmidt, P., and R. C. Sickles (1984) Production frontiers and panel data. Journal of Business and Economic Statistics. Vol. 2, PP. 367-374.

Schramm, G. (1990) Electric power in developing countries: Status, problems, prospects. Annual Review of Energy, Vol. 15, PP. 307-33.

Schramm, G. (1993) Issues and problems in the power sectors of developing countries. Energy Policy. PP.735-747.

Sullivan, J. B. (1990) Private Power in Developing Countries: Early Experience and a Framework for Development. Annual Review of Energy. Vol. 15, PP. 335-63.

Timmer, C. P. (1971) using a probabilistic frontier production function to measure technical efficiency. Journal of Political Economy, Vol.79, No. 4, July/August, PP. 776-794.

UN (1994) Energy Balances and Electricity Profiles in 1992, The United Nations. New York.

UN, Electric Power in Asia and the Pacific, 1962, 1965,1967, 1969,1975-6, 1981-2, 1985-6, 1987-8 and 1991-2.

Vaziri Sabeghi, H. (1996) Electricity in Iran: Structure and opportunities. Financial Times Energy Publishing, Maple house, London.

Weyman-Jones, T. G. (1991) productive efficiency in regulated industry: The area electricity boards of England and Wales. Energy Economics 13, PP.116-122.

World Bank (1990) Review of Electricity Tariffs in Developing Countries during the 1980s. Industry and Energy Department Working Paper, Energy Series Paper, No.32.

World Bank (1992) Electricity Pricing: Conventional Views and New Concepts. Industry and Energy Department Working Paper. Energy Series Paper No.52.

World Bank (1994a) An End-Use Energy Efficiency Strategy for Iran, Technical Report. Industry and Energy Division. Maghreb and Iran Department, Middle East and North Africa Region.

World Bank (1994b) World Development Report, Infrastructure for development, Oxford.

World Bank (1997) World Development Report, The State in a Changing World, Oxford.

Yunos, J. M. and D. Hawdon (1997) The Efficiency of the National Electricity Board in Malaysia: An Intercounty comparison using DEA. Energy Economics, Vol. 19, PP.255-269.

X

LIST OF SURREY ENERGY ECONOMICS DISCUSSION PAPER SERIES (SEEDS) 71-95
SEEC OCCASIONAL PAPER and SEEDS TECHNICAL PAPER

SEEDS Number

95 Efficiency Considerations in the Electricity Supply Industry: The Case of Iran
Ali Emami Meibodi ISBN 1852372141 July 1998

94 Economic Models of OPEC Behaviour and the Role of Saudi Arabia
Nourah AbdullRahman Al-Yousef ISBN 1852372133 June 1998

93 Modelling Saudi Arabia Behaviour in the World Oil Market 1976-1996
Nourah AbdullRahman Al-Yousef ISBN 1852372125 June 1998

92 The Socio Economic Impact of Renewable Energy Technologies
Hayley Myles ISBN 1852372087 March 1998

91 Pressure Groups and Political Forces in Britain's Privatisation Programme
Colin Robinson ISBN 1852372079 February 1998
(final paper subs 96/97)

90 Environmental Information and the Demand for Super Unleaded Petrol in the United Kingdom
Roger Fouquet SBN 1852371951 June 1997

89 Petrol Price Asymmetries Revisited
Barry Reilly and Robert Witt ISBN 1852371919 August 1996

88 **Withdrawn 11/97**
Performance of Power Sectors in Developing Countries - A Study of Efficiency and World Bank Policy using Data Envelopment Analysis
David Hawdon ISBN 1852371900 August 1996

87 UK Energy Policy: Findings from Two Surveys
Peter J G Pearson and Roger Fouquet ISBN 1852371897 August 1996

SEEDS TECHNICAL PAPER
No.1 Using LAMBDA for DEA
David Hawdon and Ian M McQueen ISBN 1852371811 April 1996

86 An Analysis of UK Energy Demand Using Multivariate Cointegration
Lester C Hunt and Robert Witt ISBN 1852371803 December 1995

85 Freeing the Nuclear Industry
Colin Robinson ISBN 185237179X March 1996

84 The Efficiency of the National Electricity Board in Malaysia - An Intercountry Comparison
Jamaluddin bin Mohd Yunos and David Hawdon ISBN 185237165X January 1996

83 Privatisation: Saving the British Coal Industry?
Colin Robinson ISBN 1852371633 November 1995

82 Electricity Privatisation in England and Wales: Progress and Problems
Colin Robinson ISBN 1852371528 August 1995

SEEDS Number

SEEC OCCASIONAL PAPER
No 2 *The S.E.E.C. United Kingdom Energy Demand Forecast (1995-2000) Update*
Roger Fouquet, David Hawdon, Peter J G Pearson, Colin Robinson and Paul Stevens *ISBN 185237151X* *July 1995*

81 The Nuclear Review
David Hawdon (Ed), Elroy Dimson, Robin Jeffrey, Martin O'Neill, M.P., Colin Robinson and Mike Staunton ISBN 1852371501 April 1995

80 Regulation as a Means of Introducing Competition
Colin Robinson ISBN 185237148X February 1995

79 Privatising Nuclear Power: evidence for the review of future prospects for nuclear power
Colin Robinson ISBN 1852371455 November 1994

78 Energy, Externalities and Environmental Quality: Will Development Cure the Ills it Creates?
Peter J G Pearson ISBN 1852371447 October 1994

77 The Demand for Car Fuel Efficiency: An Hedonic Price Approach
Robert Witt ISBN 1852371439 October 1994

76 Economics and the Environment - the Shadow Price of Greenhouse Gases and Aerosols
David Maddison ISBN 1852371412 July 1994

75 End Use Elasticities
Joseph G Hirschberg ISBN 1852371404 June 1994

74 A Model of Relative Price Elasticities from the Second Moments of Demand
Joseph G Hirschberg ISBN 1852371390 June 1994

73 Liberalisation of the Energy Market: A Favourable Supply-side Shock for the UK Economy?
Colin Robinson ISBN 1852371382 June 1994

72 Recent Studies of the Demand for Energy in the UK
D Hawdon (Ed), Joyce Dargay, Roger Fouquet, Andrew Henley, Keith Miller and John Peirson ISBN 1852371331 November 1993

71 An Econometric Study of the Demand for Gasoline in the Gulf Cooperation Council Countries
M Nagy Eltony and Mohammad Almahmeed ISBN 1852371315 October 1993

SEEC OCCASIONAL PAPER
No 1 *The S.E.E.C. United Kingdom Energy Demand Forecast (1993-2000)*
Roger Fouquet, David Hawdon, Peter J G Pearson, Colin Robinson and Paul Stevens *ISBN 185237134X* *16 December 1993*

Details of SEEDS 1-70, prices and *annual Subscription Scheme* on request.