THE IMPACT OF STRUCTURAL REFORM ON THE PERFORMANCE OF REGIONAL ELECTRICITY COMPANIES: AN IRANIAN SURVEY

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by

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Declaration

This Thesis entitled **"The Impact of Structural Reform on the Performance of Regional Electricity Companies: An Iranian Survey"** submitted by me for the award of the degree of **Doctor of Philosophy**, is an original work and has not been submitted so far, in part or in full, for any other degree or diploma of any university.

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Dedicated

to

my family

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Chapter 1

Introduction

1-1- Statement of problem

In the modern economy, the electricity industry is an important infrastructural industry. The product of this industry is vital for social activities and electricity consumption is considered an indicator of development. This industry is capital intensive and needs a large amount of investment. In addition, it is a strategically important industry and this has led many governments to take charge of this sector. Hence, evaluation of efficiency of the electricity industry is necessary.

Since the late 1980s, a wave of reform has transformed the institutional framework, organization, and operating environment of the infrastructure industries, including that of the electricity sector, in many developed and developing countries. A number of countries are implementing or evaluating some form of power sector reform. Although the structure of the power sector and the approaches to reform vary across the countries, the main objective is to improve the efficiency of the sector.

In Iran, too, the government has reformed the organizational structure of the state owned companies affiliated to the ministry of energy [MOE]. In 1993, in an effort to improve the levels of efficiency of regional electricity companies [RECs], Iran moved towards restructuring its electricity sector, starting by transferring the distribution of 20 KV (and less) to newly established electricity distribution companies. The number of these new companies was increased from 24 in 1993 to 30 in 1995. At the moment 42 non–governmental electricity distribution companies are active in Iran. Most of these companies are limited to a single province and in some cases, due to vastness of some provinces their operation may be limited to some parts or cities thereof.

Distribution companies are working with RECs in the areas of:

- Customer services;
- Planning, design and monitoring;
- Operation;
- Modification and improvement;
- Development and establishment.

The MOE has realized the necessity of evaluating the performance of the distribution companies, but there exists little work on evaluation of efficiency of Iranian electricity distribution companies.

One of the most interesting approaches is based on the econometric estimation of a frontier cost function for a sample of firms. The efficient frontier is then used as a benchmark against which the relative performance of a single firm during a given time period is measured.

1-2- Industrial efficiency

The theory of the firm is one of the most important parts of microeconomics and the efficiency of the firm has a great share in the theory of the firm. Following Barthwall (2000) we will examine "the term efficiency from the point of view of the firms and industries and call it industrial efficiency. Let us take a firm as a technical unit engaged in the production of a commodity. Its job is to transform a set of given inputs into some output defined by the production function. In this case, the emphasis will be on achieving maximum productive efficiency. Productive efficiency has been defined in terms of two main components: technical efficiency and allocative efficiency".[1]

1-3- Average functions versus frontier functions

Typical microeconomics texts develop models of production and cost in the following sequence. They begin with a production function and producers are assumed to operate on their production function, maximizing outputs obtainable from the inputs they use. First order conditions for cost minimization are then introduced, and producers are assumed to satisfy these conditions, allocating inputs efficiently and ending up on their cost functions.

The basic model has been outlined by Forsund, Lovell, and Schmidt (1980) as follows: "A firm employs n inputs $X = (x_1, x_2, ..., x_n)'$ available at fixed prices vector W $= (w_1, w_2, ..., w_n)' > 0$ to produce a single output y that can be sold at fixed price $p > 0$. The production function $f(X)$ shows the maximum output obtainable from various input vectors. Under certain regularity conditions an equivalent representation of efficient production is provided by the cost function $c(y, W) = \min_{X} \{W' X / f(X) \geq y, X \geq 0\}$, which shows the minimum expenditure required to produce output y at input prices W. Using Shephard's lemma, the vector of cost minimizing input demands can be obtained as $X(y, W) = \nabla_W c(y, W)$, provided $\nabla_W c(y, W)$ exists".[2] This can be shown diagrammatically as following:

[1] Barthwall, R.R. (2000), Industrial Economics: An Introductory Textbook, Second Edition, New Age International (P) Ltd, New Delhi.

[2] Forsund, F. R., C. A. K. Lovell, and P. Schmidt (1980), "A Survey of Frontier Production Functions and of their Relationship to Efficiency Measurement," Journal of Econometrics 13(1), PP. 5 – 25.

In the figure 1.1, the isoquant II' shows the most efficient combination of the inputs x_1 and x_2 used to produce a given level of output y. Whenever, the firm acts on this isoquant, we call it technically efficient. However, this efficiency is incomplete without allocative efficiency. Now assume that ***AB*** is the isocost line in the diagram indicating the combinations of the two inputs that can be purchased from a given amount of money and given fixed prices. If the firm acts at a point such as ***R***, where the isocost line is tangent to the isoquant, then we call it productive efficient, i.e., technically and allocatively efficient.

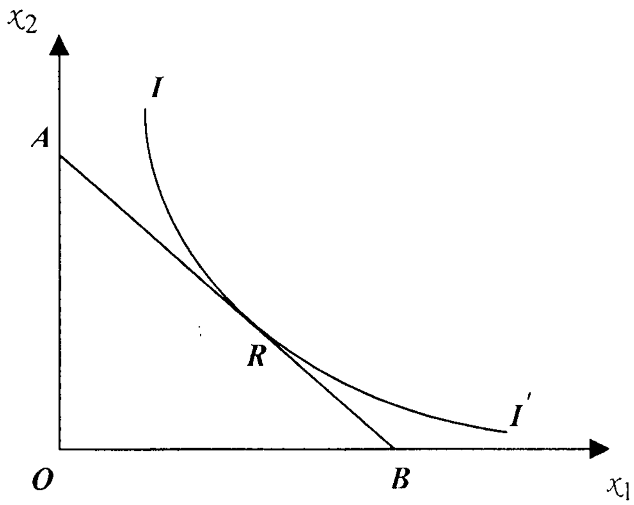

Figure 1.1: Productive efficiency

Now economists have admitted the possibility that firms do not operate at points of "technical efficiency". Empirical evidence suggests that not all producers are technically efficient. Further, technical efficiency alone will not ensure cost efficient production because of the possibility of allocative inefficiency.

In the words of Forsund, Lovell, and Schmidt (1980) "suppose that the firm is observed at production point (y°, X°). Such a point is said to be technically efficient if

$y^{\circ} = f(X^{\circ})$, and technically inefficient if $y^{\circ} < f(X^{\circ})$". Both technical inefficiency and allocative inefficiency result in inoptimal input usage, which is costly, and so $W' X^{\circ} \geq c(y^{\circ}, W)$. "It follows that observed expenditure $W' X^{\circ}$ coincides with minimum cost $c(y^{\circ}, W)$ if, and only if, the firm is both technically and allocatively efficient. Similarly it follows that observed input usage X° coincides with cost minimizing input demand $X(y^{\circ}, W)$, if, and only if, the firm is both technically and allocatively efficient. A combination of technical and allocative inefficiency causes $x_k^{\circ} > x_k(y^{\circ}, W)$ for at least some inputs, but may cause $x_l^{\circ} \leq x_l(y^{\circ}, W)$ for some other inputs".[3] This is shown graphically in figure 1.2.

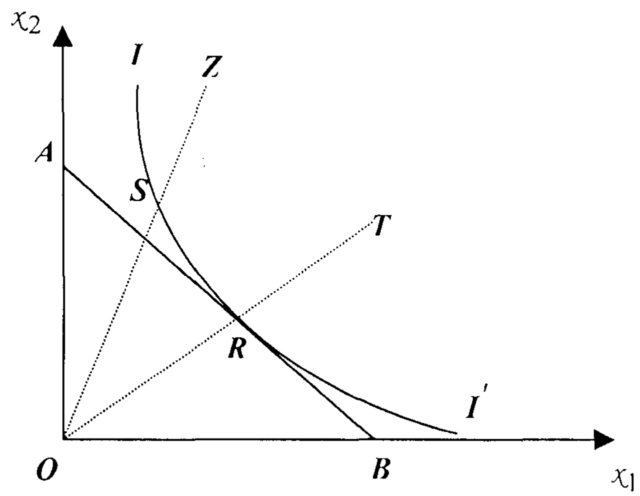

Figure 1.2: Technical and allocative inefficiency

If the firm acts at a point such as ***R***, it is both technically and allocatively efficient, but if it produces at a point such as ***S***, it is technically efficient, but allocatively

[3] Forsund, F. R., C. A. K. Lovell, and P. Schmidt (1980), "A Survey of Frontier Production Functions and of their Relationship to Efficiency Measurement," Journal of Econometrics 13(1), PP. 5 – 25.

inefficient. On the other hand if the firm acts in a point such as *T*, it is technically inefficient, but it is allocatively efficient. Finally at the point such as *Z*, the firm is both technically and allocatively inefficient.

1-4- The measurement of efficiency

As Jha and Sahni (1993) point out, the literature on the measurement of productive efficiency utilizes both frontier and non–frontier approaches.[4] Basically two approaches have developed for measuring efficiency: the econometric approach and the mathematical programming approach. Both methodologies involve the estimation of "best practice" frontiers, with the efficiency of specific firms, measured relative to frontiers. The alternative methodologies give significantly different estimates of efficiency. Thus, the choice of approach can have a significant effect on the results. Murillo–Zamorano (2004) emphasizes "the choice of estimation methodology has been controversial, with some researchers [e.g. Berger (1993)] preferring the econometric approach and some others [e.g. Seiford and Thrall (1990)] the mathematical programming approach. In some researchers' opinion [e.g. Murillo–Zamorano (2004)], no approach is strictly preferable to any other".[5] The essential differences between the two approaches have been summarized by Lovell (1993) as following:[6]

1. "The econometric approach is stochastic, and attempts to distinguish the effects of noise from the effects of inefficiency. The mathematical programming approach

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[4] Jha R., and B. S. Sahni (1993), Industrial Efficiency: An Indian Perspective, Wiley Eastern Limited, New Delhi.

[5] Murillo–Zamorano, L. R. (2004), "Economic Efficiency and Frontier Techniques," Journal of Economic Surveys 18(1), PP. 33 – 77.

[6] Lovell, C. A. K. (1993), "Production Frontiers and Productive Efficiency," in H. O. Fried, C. A. K. Lovell, and S. S. Schmidt, eds., The Measurement of Productive Efficiency: Techniques and Applications, Oxford University Press, New York.

is non–stochastic, and treats the combination of noise and inefficiency together as inefficiency.

2. The econometric approach is parametric[7], and prone to confusing the effects of misspecification of functional form [of both technology and inefficiency] with inefficiency. The programming approach is non–parametric, and therefore, less prone to this type of specification error".

The ideal solution would be to make the programming approach stochastic, and to make the econometric approach more flexible in its parametric structure.

We will concentrate only on econometric frontier methods, but it must be noted that although Farrell's (1957) work and Aigner and Chu's (1968) work are included in mathematical programming approach, they will be used in our work since they are the first works which have been done in the area of the measurement of efficiency, and other works [even in econometric approach] rely on these two works.

The measurement of efficiency has been one of the main motivations for the study of frontier functions. The use of frontier models has become increasingly widespread for a variety of reasons. First, the notion of a frontier is consistent with the underlying economic theory of optimizing behavior. Second, deviations from a frontier have a natural interpretation as a measure of the efficiency with which economic units pursue their technical or behavioral objectives. Finally, information about the structure of the frontier and about the relative efficiency of economic units has many policy applications. The frontier is used to measure the efficiency of productive units by comparing observed

[7] Parametric frontier functions require the definition of a specific functional form for the technology. Unless panel data are available, an explicit distribution for the inefficiency error term must be imposed as well in order to obtain estimates of individual firm efficiencies. The functional form requirement causes both specification and estimation problems.

and potential outputs [or observed and potential inputs]. The underlying idea of defining an efficient frontier function against which to measure the current performance of productive units has been maintained during the last fifty years. In that time, different techniques have been utilized to either calculate or estimate those efficient frontiers. The literature on the obtaining of frontier functions to measure efficiency of firms has been developed in different directions. Also the different approaches to production and cost frontiers are used to obtain the components of productive efficiency, i.e. technical and allocative efficiency components.

It must be noted that we will consider only single output models. The assumption of a single output is convenient and fits the problem at hand.

1-5- Objective and hypotheses

The objective of this study is to analyze the cost structure of Iranian RECs with reference to their cost efficiency, over the period 1989–1990 (1368) to 2002–2003 (1381)[8]. We will obtain the cost efficiency of each of the RECs for each year, and evaluate their performance. We will also examine the impact of structural reform on RECs, through the variation of cost efficiency of these companies throughout the time period 1989–2002.

The specific hypotheses of this study, which will be tested, are summarized as following:

1. There is no significant difference in the efficiency level of different Iranian RECs.
2. Most of the 16 RECs have experienced low level of cost efficiency throughout the sample period. By low level of cost efficiency we mean an efficiency level of less than 50 percent.

[8] Iranian Solar Hegira year begins on 21st of March of Christian year and ends on 20th of March of next year.

3. The efficiency level of RECs has improved during the period under consideration, as a result of the structural reform measures undertaken.

1-6- Chapter organization

The rest of this thesis is organized as follows. In Chapter 2, literature reviews of measurements of technical efficiency, cost efficiency and its decomposition into technical and allocative efficiency, and empirical studies on the measurement of cost efficiency of power distribution companies are presented. Our methodology of estimation including specification of a frontier average cost function for RECs and estimation approaches is developed in chapter 3. In chapter 4, background on the Iranian electricity industry and the discussion of data are provided. Chapter 5 contains the estimation results of the average cost frontier model and discussion about the measured cost efficiency of RECs and their improvements. Finally, chapter 6 concludes and offers suggestions for future research.

Chapter 2

Literature Review

2-1- Introduction

This chapter is organized as following: Section 2–2 presents production frontier techniques developed for the measurement of technical efficiency. Section 2–3 provides an overview of the cost frontier approaches to measurement of cost efficiency and its decomposition into technical and allocative efficiency components. Finally, Section 2–4 surveys empirical studies of the measurement of cost efficiency of power distribution companies over the entire world.

2-2- Production frontier and measurement of technical efficiency

As Forsund, Lovell, and Schmidt (1980) point out, "most applications of the frontier methodology have been to estimating production frontiers. Estimation of production frontiers yields information only on technical efficiency".[1] In the words of Kumbhakar and Lovell (2000) "a production frontier characterizes the minimum input bundles required to produce various outputs, or the maximum output producible with various input bundles, and a given technology".[2] Production frontier models could be discussed in the two main ways: non–statistical frontiers and statistical frontiers.

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[1] Forsund, F. R., C. A. K. Lovell, and P. Schmidt (1980), "A Survey of Frontier Production Functions and of their Relationship to Efficiency Measurement," Journal of Econometrics 13(1), PP. 5 – 25.
[2] Kumbhakar, S. C., and C. A. K. Lovell (2000), Stochastic Frontier Analysis, Cambridge University Press, Cambridge.

Efficiency measurement began with Farrell (1957) who presented computational measures for productive inefficiency. He characterized total economic efficiency of a firm consisting of two components: "technical efficiency" and "allocative efficiency". Technical efficiency reflects to the ability of a firm to obtain maximal output from a given input vector [output–oriented] or the ability of a firm to minimize input use in the production of a given level of output [input–oriented]. Allocative efficiency reflects the ability of a firm to use the inputs in optimal proportions given their respective prices and the production technology. Farrell (1957) suggested the use of a non–parametric piecewise linear convex isoquant to estimate the production frontier and to measure the firm's inefficiency level as the deviation from the frontier. In the words of Forsund, Lovell, and Schmidt (1980), "Farrell (1957) simply constructs the free disposal convex hull of the observed input–output ratios by linear programming techniques; this is supported by a subset of the sample, with the rest of the sample lying above it. This procedure is not based on any explicit model of the frontier. Almost as an afterthought, he proposed computing a parametric convex hull of the observed input–output ratios. He acknowledged the undesirability of imposing restrictive Cobb–Douglas functional form on the frontier, but also noted the advantage of being able to express the frontier in a sample mathematical form".[3] Unfortunately Farrell did not follow up on his own suggestion, and Aigner and Chu (1968) were the first to follow Farrell's suggestion. They also introduced a parametric function with the Cobb–Douglas form that could be estimated through either linear or quadratic programming approaches. The empirical assumption required for a programming application is that disturbance is of one–sided,

[3] Forsund, F. R., C. A. K. Lovell, and P. Schmidt (1980), "A Survey of Frontier Production Functions and of their Relationship to Efficiency Measurement," Journal of Econometrics 13(1), PP. 5 – 25.

i.e. the observed points in the production space lie only on or beneath the frontier. Both the above studies use mathematical programming methods. The focus of this thesis is the econometric method, which assumes an explicit distribution form for the error term associated with technical inefficiency in the production process of a firm. Initially econometric studies used deterministic frontier functions. The deterministic frontiers envelope all the observations, identifying the distance between the observed production and the maximum production as technical inefficiency. The deterministic frontier model can be estimated by either maximum likelihood estimation [MLE] or least squares method. The work of Schmidt (1976), who observed that Aigner and Chu's criteria could be interpreted as the log–likelihood function for models in which the error term was distributed as half–normal for quadratic programming, and exponential for linear programming procedure, was the first attempt in maximum likelihood estimation approach. However, the "regularity conditions" for maximum likelihood estimation were violated. Greene (1980a) showed that the usual desirable asymptotic properties of maximum likelihood estimators still hold if the one–sided error term follows special case of gamma density function. There is also an alternative method of estimation, first noted by Richmond (1974) based on ordinary least squares results, called "modified" OLS, or MOLS[4]. One difficulty with the MOLS technique is that, the modification to the intercept is not independent of the distribution assumed for the technical inefficiency error term. Another difficulty is that, even after modifying the intercept, some of the residuals may still have the "wrong" sign so that these observation end up above the estimated production frontier. Corrected OLS, on the other side, makes no assumption concerning the functional form of the non–negative inefficiency component. It estimates the model

[4] "Modified" OLS, sometimes called "displaced" OLS, is based on method of moments approach.

by OLS, and then corrects the downward bias in the estimated OLS intercept by shifting it up until all corrected residuals are non–positive and at least one is zero. In response to the obvious shortcomings of the deterministic frontier approach, Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) simultaneously introduced a stochastic specification of the production frontier. Their stochastic frontier specifications involved a stochastic error term associated to random shocks outside the control of producers that can affect output and a non–negative random variable associated with technical inefficiency in the production process of the firm. The stochastic frontier specification is preferred to the deterministic frontier specification because it takes into account statistical noise resulting in more accurate specification and consequently more accurate efficiency estimates. The stochastic frontier model could be estimated by either MLE or MOLS method. Using the MLE approach, Aigner, Lovell, and Schmidt (1977) assumed a non–negative random variable associated with technical inefficiency following the half–normal and the exponential distributions. The specification of these distributional assumptions became one of the main criticisms in the stochastic frontier analysis that there is no a priori justification for the selection of any particular distributional form for the technical inefficiency term. This criticism led to the development of the specifications of more general distribution forms. Stevenson (1980) introduced the truncated normal model, and Greene (1990) proposed the gamma model. As Rungsuriyawiboon (2003) points out, these two specifications of general distributional forms are preferred to the half–normal and the exponential distributions for two reasons. The truncated normal and the two–parameter gamma distributions allow for a wider range of distributional shapes at the cost of computational complexity. Further, the half–normal and the exponential distributions have a mode at zero indicating the highest probability that the inefficiency terms are in the neighborhood of zero. As a result, both specifications are prone to producing relatively high technical efficiency.[5] Like its deterministic counterpart, stochastic production frontier can also be estimated by MOLS method. This strategy can be applied to each of the density functions just discussed. The problem of decomposing the estimated residuals into separate estimates of technical inefficiency and noise components of error term[6] was solved by Jondrow, Lovell, Materov, and Schmidt (1982) who introduced the conditional distribution of technical inefficiency component given composed error term, in which either the mean or the mode of this distribution could be used as an estimate of technical inefficiency component. In all of the described methods, the exponential of the negative of the technical inefficiency component value was considered to be the technical efficiency level of the firm. Hitherto, all of the described models were using cross–sectional data at a point of time. Subsequently Pitt and Lee (1981) and others developed panel data methods.

Panel data approaches have some advantages over cross–sectional data in the estimation of stochastic frontier analysis. Panel data provide more accurate estimates of efficiency for each producer than estimates from cross–sectional data. Another advantage is that panel data estimation techniques can be adapted to the efficiency measurement problem while not requiring the strong distributional assumptions of the non–negative technical inefficiency component. Finally, panel data make it possible to control for firm heterogeneity, which can lead to inconsistent estimation due to the problem of

[5] Rungsuriyawiboon, S. (2003), Dynamic Efficiency Model: An Analysis of Efficiency and Deregulation in the U.S. Electricity Industry, Ph.D. Thesis, The Pennsylvania State University, U.S.A.
[6] This problem persists regardless of which one of the methods, MLE or MOLS, we apply.

endogeneity. Pitt and Lee (1981) first introduced a panel data stochastic production function by extending the cross–sectional stochastic production frontier of Aigner, Lovell and Schmidt (1977). Schmidt and Sickles (1984) proposed that when panel data are available there is no need to specify a particular distribution for the inefficiency effects[7]. Non–negative random technical inefficiency component in the panel data model is classified into two models. This first model is defined as "time–invariant technical inefficiency component" where the technical inefficiency is allowed to vary across producers, but is assumed to be constant through time for each producer. Schmidt and Sickles (1984) described the estimation of parameters of such a model in a number of approaches such as fixed effects, random effects, and MLE. The truncated–normal distribution assumption for technical inefficiency [originally proposed by Stevenson (1980) in the cross–sectional data] was extended by Battese and Coelli (1988) into the panel data context. The second model is defined as "time–varying technical inefficiency component" where technical inefficiency is allowed to vary across producers and through time for each producer. As with the time–invariant technical inefficiency component model, two approaches to the estimation of a time–varying technical inefficiency component model have been pursued: an approach in which the technical inefficiency component is modeled using fixed or random effects and a MLE approach. Cornwell, Schmidt and Sickles (1990) specified that the intercept parameters for different firms in different time periods were a quadratic function of time, in which the time variables have firm–specific parameters. Lee and Schmidt (1993) specified that the intercept parameters for different firms in different time periods were defined by the product of individual firm

[7] The requirement of specification of a particular distribution for the inefficiency component was widely criticized in the empirical practice.

and time effects. Both of above studies used fixed effects and random effects approaches in their estimation process. Kumbhakar (1990) suggested the technical inefficiency effects vary systematically with time. Battese and Coelli (1992) suggested an alternative to the Kumbhakar (1990) model, in which the technical inefficiency effects are assumed to be an exponential function of time, involving only one unknown parameter. The papers of Kumbhakar (1990) and Battese and Coelli (1992) are based on MLE approach.

2-3- Cost frontier, measurement of cost efficiency and its decomposition into technical and allocative efficiency components

The cost frontier yields information on the extra cost of technical and allocative inefficiency, [though not the separate cost of each, without further assumptions]. Cost efficiency is provided by the estimation of cost frontier. While the estimation of technical efficiency requires information on input use and output provision, the estimation of cost efficiency requires information on input prices, output quantities, and total expenditure on the inputs used, and depending on the model, perhaps input quantities or input cost shares as well.

Except for some minor changes in signs, there is a high similarity between the methods applied for production frontiers with those of cost frontiers in the single equation cost function case. Specifically, Forsund and Jansen (1977) introduced a parametric cost frontier. They studied a production frontier by estimating its dual cost function through using linear programming approach. They also showed that maximum likelihood estimates are equivalent to their linear programming technique estimates, in which technical inefficiency component in their production function follows an exponential distribution. Greene (1980b) proposed a system of translog production function and set of factor cost shares, where it was assumed that factors are paid their marginal products and the production is characterized by constant returns to scale. By the same logic as applied for production function, Greene proposed a system of cost function and cost share equations to be estimated. By simplifying assumption of independence of error terms of cost function and cost share equations, he applied the MLE method to the jointed disturbances. With respect to the specification problem, the work of Schmidt and Lovell (1979) can be regarded as the first attempt to analyze the duality between stochastic frontier production and cost functions. With the availability of input quantity and cost share data, they proposed that overall cost inefficiency can be decomposed into their technical and allocative components. The decomposition of cost inefficiency can be done if the production function implied by the estimated cost function can be explicitly derived, which is the case for the Cobb–Douglas form since it is self–dual. One of the flexible functional forms for cost function, originally proposed by Christensen and Greene (1976) [which was based on the non–frontier strategy] is the translog function. The main problem for estimating a system of translog cost frontier and its related input cost share equations model is associated with selecting an appropriate way to represent the link between the allocative inefficiency in the error terms of the input cost share equations and cost frontier function. This problem referred as "Greene problem" was firstly noted by Greene (1980b) although no way to solve it was offered. Three "routes" have been used in the literature in order to solve this problem. The first group of solutions are called qualitative solutions. They directly ignore the mentioned relationship. An illustration of this approach can be found in Greene (1980b). The second group of solutions, the approximate solutions, model the relationships among the allocative inefficiency disturbances, by means of a function that approximate the real relationship in accordance with the a priori information that one has about its structure. The works of Schmidt (1984), Melfi (1984), Bauer (1985), Ferrier and Lovell (1990), and Kumbhakar (1991) are included in this group of solutions. Finally, analytic solutions look for the exact analytic relationship between the input and firm–specific allocative inefficiency error terms. That was the approach used in Schmidt and Lovell (1979, 1980) for the case in which the production structure is defined in accordance with a Cobb–Douglas technology. Kumbhakar (1997) introduced allocative inefficiency in a theoretically and econometrically consistent manner, by adapting Schmidt and Lovell's specification of Cobb–Douglas production frontier to a more flexible translog cost frontier framework. His approach is also applicable to any cost frontier functions. However, there are to date very few empirical studies using this approach[8]. The stochastic cost frontier analysis approach shows the computational difficulty for decompositions of overall cost efficiency in the estimation. This problem can be addressed by using stochastic estimation of the shadow price approach. A vast shadow price literature has emerged in recent years beginning with Lau and Yotopoulos (1971), Yotopoulos and Lau (1973), and Toda (1976). The shadow price approach estimates technical inefficiency modeled as a fixed effect whereas allocative inefficiency is measured through input–specific parameters that scale market prices[9]. A shadow cost function is expressed in terms of shadow input prices and outputs, where shadow prices are defined as input prices that make the technically

[8] There are also some other alternative dual approaches to the measurement of allocative efficiency, such as ones proposed by Kopp and Diewert (1982) and Zieschang (1983), but although they are analytically correct, they do not solve the econometric problem of formulating and estimating a translog cost system in the presence of both types of inefficiency. The "Greene problem" is an econometric problem, not an analytical problem. These studies demonstrate that the analytical problem has been solved. However the econometric problem remains.

[9] These parameters measure the divergences of the shadow price ratios from the observed price ratios.

efficient input vector the least cost solution for producing a given output. A firm's technology, technical and allocative inefficiency parameters can be estimated using a shadow cost system, where actual costs and input cost shares are expressed in terms of shadow costs. The studies by Atkinson and Cornwell (1994a), Atkinson and Cornwell (1994b), Balk (1997), Maietta (2002), and Kumbhakar and Karagiannis (2004) use the shadow price approach, in the panel data context.

2-4- Empirical background on the measurement of cost efficiency of electricity distribution utilities

A number of relative efficiency studies have addressed different aspects of the electricity industry. The focus of many of these is on economies of scale and density or the relationship between ownership and efficiency. This section briefly outlines a selected number of empirical studies of relative efficiency of electricity distribution utilities. A more complete overview of the relevant studies is given in table 2.1.

Fillippini (1998) uses a cost function to find economies of scale and density for 39 municipal electricity distribution utilities in Switzerland over the period 1988–1991. He applies the iterative Zellner's technique to a system of translog cost function and its related cost share equations in a qualitative form of relationship between the error terms of cost function and cost share equations. In this study total cost as dependent variable is regressed on total number of delivered electricity [as output], prices of inputs including capital, purchased power, and labor, load factor, the size of the service territory of the distribution utility, and finally the number of customers as determinant variables, where the cost share equations are added to cost function in order to improve the efficiency of the cost function parameters estimations. The study reports the presence of economies of density for different output levels and economies of scale for small and medium utilities. Also the study suggests that franchised monopoly is more efficient than side–by–side yardstick competition, and also concludes that mergers among the smaller utilities can result in cost saving.

Farsi and Fillippini (2003) report a cost efficiency study of 59 electricity distribution utilities in Switzerland over a nine–year period from 1988 to 1996 using different econometric methods such as corrected ordinary least squares, fixed effects, random effects, and maximum likelihood estimation. Besides variables explained in preceding study, they use some dummy variables to distinguish the utilities that operate a high–voltage transmission network, or those whose share of auxiliary revenues is more than 25 percent of total revenues, and finally the cases in which more than 40 percent of the service area is covered by forests. Different specifications are compared with regards to the estimation of cost frontier characteristics and inefficiency scores. The results point to some advantages for the fixed effects model in the estimation of cost function's characteristics. The summary statistics of inefficiency estimates are not sensitive to the specification. However, the ranking changes significantly from one model to another. These results suggest that a valid benchmarking analysis should be applied with special care, by using several specifications and performing a [mutual] consistency analysis.

Fillippini, Hrovatin, and Zoric (2002) apply stochastic frontier analysis in an efficiency study of 5 Slovenian electricity distribution utilities over the 1991–2000 period using maximum likelihood estimation method, where a half–normal distribution is assumed for cost inefficiency error term component. They exclude expenditure for purchased electricity from the total cost in order to separate the sale function of a utility from the delivery function. They also consider customer density as the ratio of the number of customers and the length of the distribution lines [or the size of the distribution area] instead of two separated variables; the number of customers, and the area size. Linear homogeneity of cost function in input prices is imposed by normalizing [net] total cost and input prices by one of the input prices, and the restricted functional form, i.e. [the logarithm of] Cobb–Douglas is utilized for cost function because of the availability of small data set. Based on the finding of the study, the presence of increasing returns to scale for Slovenian electricity distribution utilities can be confirmed. Further, they conclude that most of the utilities in their sample are too small and do not reach the minimum efficient scale. This problem could be solved through mergers of small utilities. Finally, their results suggest that the average cost inefficiency of distribution utilities in their sample is around 35 percent.

Fillipiini and Wild (1998) examine the scale and cost inefficiency of a sample of 30 Swiss municipal electricity distribution utilities over the period 1992–1996. They consider estimation of a stochastic frontier average cost function model using the approach suggested by Schmidt and Sickles (1984) for panel data. A translog average cost function with a similar set of variables in previous studies is estimated using panel data, while all input prices, [net] total cost, and [net] average cost are deflated to 1996 constant Swiss Francs using the consumer index price. The results indicate the existence of economies of output and consumer density and economies of scale. Moreover, the findings on cost inefficiency show that a majority of the distribution utilities are not producing at the minimum level of the cost.

Table 2.1: Empirical studies of relative efficiency of electricity distribution utilities

Author	Data	Dependent Variable(s)	Independent Variables
Claggett (1994)	108 Municipals and 49 Cooperative USA Distribution Utilities 1982 – 1989	Total Cost & Input Cost Shares (Translog Form)	Total Energy Sold Retail Number of Under & Over 50 KW Demand Customers Load Factor Service Area Size Labor Price Capital Price Purchased Power Price Dummies for Distribution of More Utilities Dummy for Organizational Form Dummy for Urban Environment
Farsi & Filippini (2003)	59 Swiss Electricity Distribution Utilities 1988 – 1996	Total Cost (Log of Cobb – Douglas Form)	Electricity Delivered Capital Price Labor Price Purchased Power Price Load Factor Number of Customers Service Area Size Dummy for High – Voltage Operation Dummy for High Auxiliary Revenues Dummy for Forest Service Area
Filippini (1998)	39 Swiss Municipal electricity Distribution Utilities 1988 – 1991	Total Cost & Input Cost Shares (Translog Form)	Electricity Delivered Capital Price Purchased Power Price Labor Price Load Factor Number of Customers Service Area Size
Fillippini & Hrovatin & Zoric (2002)	5 Slovenian electricity distribution utilities 1991 – 2000	Total Cost (Log of Cobb – Douglas Form)	Electricity Delivered Capital Price Labor Price Customer Density Load Factor
Fillipiini & Wild (1998)	30 Swiss municipal electricity distribution utilities 1992 – 1996	Average Cost (Translog Form)	Electricity Delivered Labor Price Capital Price Number of Customers Service Area Size
Jamasb & Pollitt (2002)	63 Distribution and Regional Transmission Utilities in 6 European Countries 1999	Total Cost (Log of Cobb – Douglas Form) & (Translog Form)	Electricity Delivered Number of Customers Network Length

Table 2.1: Continued

Author	Data	Dependent Variable(s)	Independent Variables
Fillipiini & Wild (1999)	45 Swiss Electricity Distribution Utilities 1992 – 1996	Average Cost (Linear Function with some variables appeared in Quadratic Form)	Electricity Delivered Labor Price Capital Price Share of Low – Voltage Sales Dummy for High – Voltage Operation Share of Other Revenues than Distribution Revenues Load Factor Customer Density Average Consumption Per Low and Medium – Voltage Customers
Fillipiini & Wild (2001)	59 Swiss Electricity Distribution Utilities 1988 – 1996	Average Cost (Linear Function with some variables appeared in Quadratic Form)	Electricity Delivered Labor Price Capital Price Dummy for High – Voltage Operation Share of Low – Voltage Sales Average Consumption Per Low – Voltage Customer Load Factor Customer Density Shares of Different Land Categories in the Service Area Share of Other Revenues than Distribution Revenues
Fillipiini & Wild & Kuenzle (2001)	59 Swiss Electricity Distribution Utilities 1988 – 1996	Average Cost (Linear Function with some variables appeared in Quadratic Form)	Electricity Delivered Labor Price Capital Price Dummy for High – Voltage Operation Share of Low – Voltage Sales Average Consumption Per Low – Voltage Customer Load Factor Customer Density Shares of Different Land Categories in the Service Area Share of Other Revenues than Distribution Revenues

Chapter 3

Methodology of Estimation

3-1- Introduction

As it was mentioned in the first chapter, one of the earliest attempted reforms by the MOE to enhance economic efficiency was the separation of distribution activity from RECs in 1993. After more than 10 years operation MOE had realized the necessity of evaluating the performance of the distribution companies. However, it was only in 1995 that inspectors were sent to evaluate their activities. The performances of the distribution companies [based on some qualitative and quantitative criteria] were ranked as excellent, very good and good. The published results showed that of the 29 electricity distribution companies in 1994, 5 companies had excellent performance, 22 of them ranked very good, and only 2 companies had experienced good performance. In the absence of any frontier analysis, MOE was inclined to rely on its own criteria. But its method of performance evaluation did not present quantitative measures of efficiency for each company. The frontier analysis could be used in order to monitor the performance of the electricity distribution companies. Stochastic frontier methods are one of the best ways for evaluating the performance of firms. As we saw in the second chapter, cost functions in the electricity distribution industries are well documented in empirical research. Based on the experience of other researchers and given the nature of the data available to us, we decided to apply stochastic average cost frontier approach on Iranian RECs data to obtain their cost efficiency in order to judge the success of structural reform in RECs through improvement of their performance. A frontier average cost function defines minimum average costs given output level, input prices, output characteristics and the existing production technology. It is unlikely that all firms will operate at the frontier. Failure to attain the average cost frontier implies the existence of cost inefficiency, including both technical and allocative inefficiency.

The rest of this chapter proceeds as follows: Section 3–2 represents the general stochastic average cost frontier model used in this work. In the section 3–3 we specify the frontier average cost function for RECs. Finally section 3–4 introduces the concept and implication of economies of scale in our work.

3-2- The stochastic average cost frontier model

In this work we consider the estimation of a stochastic average cost frontier using the approach suggested by Cornwell, Schmidt and Sickles (1990) for panel data. To illustrate this econometric approach, consider the average cost function

$$\ln Ac_{it} = \ln Ac(y_{it}, W_{it}; \alpha) + v_{it} + u_{it} \qquad -\infty \leq v_{it} < +\infty \quad \text{and} \quad 0 \leq u_{it} < +\infty$$

or in the form of separated intercept

$$\ln Ac_{it} = \alpha_{0t} + \ln Ac'(y_{it}, W_{it}; \alpha) + v_{it} + u_{it}$$

In this specification the error term is composed of two components: the first v_{it} is a two–sided disturbance capturing the effect of random noise, which is usually assumed to follow a normal distribution; the second u_{it} is a one–sided non–negative cost inefficiency component.

The regularity conditions require that the average cost function be concave and linearly homogeneous in input prices, and non–decreasing in input prices.

Now define $\alpha_{it} = \alpha_{0t} + u_{it}$, where α_{0t} is the average cost frontier intercept common to all firms in period t, and α_{it} is the intercept for firm i in period t. Cornwell, Schmidt and Sickles (1990) proposed α_{it} be a flexibly parameterized function of time, with parameters that vary over firms given by

$$\alpha_{it} = \Omega_{i1} + \Omega_{i2}t + \Omega_{i3}t^2 = Z_t'\delta_i$$

Where $Z_t = \begin{bmatrix} 1 \\ t \\ t^2 \end{bmatrix}$ and $\delta_i = \begin{bmatrix} \Omega_{i1} \\ \Omega_{i2} \\ \Omega_{i3} \end{bmatrix}$. This quadratic specification allows cost inefficiency component to vary through time and in a different manner of each firm. Now the model could be written as

$$\ln Ac_{it} = \alpha_{it} + \ln Ac'(y_{it}, W_{it}; \alpha) + v_{it}$$

$$\ln Ac_{it} = \ln Ac'(y_{it}, W_{it}; \alpha) + \Omega_{i1} + \Omega_{i2}t + \Omega_{i3}t^2 + v_{it}$$

$$\ln Ac_{it} = \ln Ac'(y_{it}, W_{it}; \alpha) + Z_t'\delta_i + v_{it}$$

There are different estimation strategies, such as fixed effects approach and random effects approach.

In the fixed effects approach, the Ω_{i1} are estimated as coefficients of firm dummies, and the Ω_{i2} and Ω_{i3} as coefficients of producer dummies interacted with t and t^2. After obtaining estimates of the α_{it}, define $\hat{\alpha}_{0t} = \min_i \{\hat{\alpha}_{it}\}$, as the estimated intercept of the average cost frontier in period t. The cost efficiency of each firm in period t is then estimated as $c\mathcal{E}_{it} = \exp\{-\hat{u}_{it}\}$, where $\hat{u}_{it} = (\hat{\alpha}_{it} - \hat{\alpha}_{0t}) \geq 0$.

In the random effects approach it is assumed that the coefficient $\alpha_{it} = Z_t' \delta_i$, δ_i is the outcome of a random process with mean vector δ_0, i.e. $\delta_i = \delta_0 + \varepsilon_i$, where δ_0 is a constant vector and ε_i is a random vector. Then the model could be written as

$$\ln Ac_{it} = \ln Ac'(y_{it}, w_{it}; \alpha) + Z_t' \delta_0 + Z_t' \varepsilon_i + v_{it}$$

$$\ln Ac_{it} = \ln Ac'(y_{it}, w_{it}; \alpha) + Z_t' \delta_0 + \psi_{it}$$

where $\psi_{it} = Z_t' \varepsilon_i + v_{it}$ is a composite error term. The model should be estimated by random coefficients method, because it includes both fixed coefficients and random coefficients. After estimating the mean vector of the random process, δ_0, the predictions of the individual random coefficients vectors, δ_i's are obtained by econometric packages such as Limdep. The estimation of intercepts and cost efficiency proceeds as in the fixed effects approach discussed above.

As mentioned in the previous chapter, different approaches can be used to estimate a frontier average cost function with panel data. Different approaches can produce different inefficiency scores and rankings. Many studies have compared the inefficiency scores obtained from different models. Some authors conclude that different approaches are likely to generate rather similar efficiency rankings, especially at the top and bottom of the distribution. However, some others have argued that with complex production functions, all models show a poor performance. Overall the results suggest that the reliability of different models depends on the nature of production. It has been argued that in industries such as electricity distribution, the production technology is rather complex and depends on a variety of external parameters associated with the production environment and demand characteristics. Hence the reliability of inefficiency scores is crucial. In particular, if the estimated inefficiency scores are sensitive to the benchmarking method, a more detailed analysis to justify the adopted model is required. To crosscheck our estimation results we have also estimated different models by fixed effects and random effects in the two functional forms of the [logarithm of] Cobb–Douglas and translog. We find that, as expected, the best model is the fixed effects average cost. However, the results of other estimations are also presented for comparison[1].

One of the main advantages of stochastic frontier analysis method is its ability to control for unobserved heterogeneity among companies. In particular, panel data models are highly suitable for data exhibiting such behavior. This turns out to be an important issue in network industries like electricity distribution sector, where different companies deal with the network at different junctures and face different consumer densities and topographical conditions. Those factors as well as other potentially unobserved characteristics do affect the production costs but are not necessarily indicative of different efficiencies. The inefficiency measures may therefore be affected by these confounding factors. In this case companies that face more difficult conditions may be classified as inefficient producers. Therefore, given that the electricity distribution utilities provide

[1] These results are available in section 5.2 and appendix A.

service via a network, an analysis of their cost structure must take account of the fact that the same quantities of electricity can be distributed on differently shaped service areas and that different quantities of electricity can be distributed on the same service area. For this reason, the average cost model specification should incorporate a number of network characteristics, which capture the heterogeneity dimension of the distribution system. Hence, in our average cost frontier model specification we introduce as an explanatory variable the customer density of the service area of a utility. This variable is expected to capture part of the heterogeneity dimension of the distribution process.

3-3- Specification of the frontier average cost function for RECs

16 Iranian RECs are responsible for the transmission and distribution of reliable electricity for all of the residential, commercial, industrial, agricultural, and public service uses. The ultimate goal of these companies is distribution and delivering the electricity for all kind of electricity uses. The costs of operating a transmission and distribution system are the costs of building and maintaining the system of serve lines, mains and transformers. These costs depend upon:

- The total KWH electricity delivered;
- The price of inputs including labor and capital;
- The total number of customers served;
- The size of the distribution area;
- The dispersion of consumers in the service area;
- The length of transmission and distribution lines.

The total KWH delivered can be interpreted as an output indicator, whereas the total number of customers, the size of the distribution area and the length of transmission and distribution lines can be classified as network characteristic variables.

The specification used here draws basically from the model proposed by Fillippini (1998). This study and most of the empirical research in this area estimated a cost function, which includes the expenditure on purchased electricity in the total costs. But as Fillippini and Wild (1998) emphasize, such studies do not separate the sale function of a utility from the delivery function, and therefore are not ideal for benchmarking rates[2]. Hence, we will exclude the expenditure on purchased electricity from the total costs. For the purpose of our analysis we specify the following average cost frontier model for RECs.

$$Ac = \frac{c}{y} = Ac\,(y, w_l, w_k, CD, LF)$$

Where c represents total cost, Ac is average cost, and y is output. w_l and w_k are the prices of labor and capital, respectively. CD is the customer density, and finally LF is the load factor which should capture the impact of the intensity of use on average cost[3].

The estimation of above average cost function requires the specification of a functional form. The translog model and the [logarithm of] Cobb–Douglas model are two main functional forms used in the literature. The translog model offers an appropriate

[2] In this study we adopted a simple unbundling of costs between the network activities and the purchasing activities: only the costs of electricity purchasing belong to the supply, all the other costs belong to the network. This seems a reasonable approach because the supply activities in comparison to the network operation need only a limited amount of resources in terms of labor and capital.

[3] Size of the service territory is also one of the variables which could be included in the model, in which its value remains constant over time for a firm, but since the fixed effects approach for the estimation of the model cannot estimate the effect of time–invariant factors, this variable is discarded from the list of the variables. For the purpose of comparability we avoid using of this variable in the random effects model too.

functional form for answering questions about economies of scale. It does not impose any technological restrictions and allows the economies of scale to vary with output. In contrast, the [logarithm of] Cobb–Douglas model assumes that economies of scale are invariant to output change. Linear homogeneity in input prices is imposed by normalizing money values, i.e. average cost and input prices, by one of the input prices. Here the price of capital acts as the numeraire.

For the purpose of our analysis we specify four models. First in the fixed effects approach, we estimate the [logarithm of] Cobb–Douglas specification of the above average cost function as

$$\ln(\frac{Ac}{w_k})_{it} = \Omega_{i1} + \Omega_{i2}t + \Omega_{i3}t^2 + \alpha_y \ln y_{it} + \alpha_l \ln(\frac{w_l}{w_k})_{it} + \alpha_c \ln CD_{it} + \alpha_f \ln LF_{it} + v_{it}$$

Then in the fixed effects approach the translog approximation[4] of the above mentioned average cost function is estimated as

$$\ln(\frac{Ac}{w_k})_{it} = \Omega_{i1} + \Omega_{i2}t + \Omega_{i3}t^2 + \alpha_y \ln y_{it} + \alpha_l \ln(\frac{w_l}{w_k})_{it} + \alpha_c \ln CD_{it} + \alpha_f \ln LF_{it} +$$

$$\alpha_{yy}\frac{1}{2}[\ln y_{it}]^2 + \alpha_{ll}\frac{1}{2}\left[\ln(\frac{w_l}{w_k})_{it}\right]^2 + \alpha_{cc}\frac{1}{2}[\ln CD_{it}]^2 + \alpha_{ff}\frac{1}{2}[\ln LF_{it}]^2 + \alpha_{yl}\ln y_{it}\ln(\frac{w_l}{w_k})_{it}$$

$$+ \alpha_{yc}\ln y_{it}\ln CD_{it} + \alpha_{yf}\ln y_{it}\ln LF_{it} + \alpha_{lc}\ln(\frac{w_l}{w_k})_{it}\ln CD_{it} + \alpha_{lf}\ln(\frac{w_l}{w_k})_{it}\ln LF_{it} +$$

$$\alpha_{cf}\ln CD_{it}\ln LF_{it} + v_{it}$$

[4] A translog function requires the approximation of the underlying cost function to be made at a local point, which in our case, is taken at the point $(1,1,...,1)'$ so that at the expansion point, the logarithm of each variable is a convenient zero. Thus, all independent variables are normalized by dividing by 1, which turns out the same values for these variables.

In both models Ω_{i1} are estimated as coefficients of producer dummies, and the Ω_{i2} and Ω_{i3} as coefficients of producer dummies interacted with variables time and time squares. Having 16 companies, it implies 48 dummy variables in both of the above specifications.

Correspondingly in the random effects model, [the logarithm of] Cobb–Douglas specification can be written as

$$\ln(\frac{Ac}{w_k})_{it} = \delta_{01} + \delta_{02}t + \delta_{03}t^2 + \alpha_y \ln y_{it} + \alpha_l \ln(\frac{w_l}{w_k})_{it} + \alpha_c \ln CD_{it} + \alpha_f \ln LF_{it} + \psi_{it}$$

Finally using a translog specification, the average cost function is estimated as

$$\ln(\frac{Ac}{w_k})_{it} = \delta_{01} + \delta_{02}t + \delta_{03}t^2 + \alpha_y \ln y_{it} + \alpha_l \ln(\frac{w_l}{w_k})_{it} + \alpha_c \ln CD_{it} + \alpha_f \ln LF_{it} +$$

$$\alpha_{yy}\frac{1}{2}[\ln y_{it}]^2 + \alpha_{ll}\frac{1}{2}\left[\ln(\frac{w_l}{w_k})_{it}\right]^2 + \alpha_{cc}\frac{1}{2}[\ln CD_{it}]^2 + \alpha_{ff}\frac{1}{2}[\ln LF_{it}]^2 + \alpha_{yl}\ln y_{it}\ln(\frac{w_l}{w_k})_{it}$$

$$+ \alpha_{yc}\ln y_{it}\ln CD_{it} + \alpha_{yf}\ln y_{it}\ln LF_{it} + \alpha_{lc}\ln(\frac{w_l}{w_k})_{it}\ln CD_{it} + \alpha_{lf}\ln(\frac{w_l}{w_k})_{it}\ln LF_{it} +$$

$$\alpha_{cf}\ln CD_{it}\ln LF_{it} + \psi_{it}$$

These two last models are estimated through random coefficients approach, where constant, time, and time squares are considered as variables having random coefficients, and the other variables, fixed.

After estimating all four models, we found, as expected, that the average cost translog model estimated by fixed effects model was the best. Cost efficiency scores were obtained from this model and the performances of the companies were evaluated based on these scores.

3-4- Economies of scale

A major development in the specification of cost functions for the electric power distribution industry has been the distinction between economies of output and customer density and economies of scale. The inclusion of the number of customers and the size of the service territory allows for the distinction of economies of output density, economies of customer density and economies of scale. But since we did not separately include the number of customers and the size of the service territory in our average cost model specification, we are unable to distinguish between economies of output density, economies of customer density and economies of scale. In this work, we define economies of scale [$\mathcal{ES}$] as the proportional decrease in average cost brought about by a proportional increase in output, holding all input prices, customer density, and the load factor fixed. This is equivalent [in absolute value] to the elasticity of average cost with respect to output. Economies of scale [$\mathcal{ES}$] can thus be defined as:

$$\mathcal{ES} = \frac{\partial \ln Ac}{\partial \ln y}$$

We will talk of economies of scale if $\mathcal{ES}$ is smaller than 0, and accordingly, we will talk of diseconomies of scale if $\mathcal{ES}$ is greater than 0. In the case of $\mathcal{ES} = 0$ no economies or diseconomies of scale exist. Economies of scale exist if the average cost of a REC decreases as the volume of electricity delivered in a service territory of a given customer density increases. This measure [$\mathcal{ES}$] is relevant for analyzing the impact on cost of merging two adjacent companies.

Chapter 4

Industry Background and Discussion of Data

4-1- Background of power industry in Iran

4-1-1- History

The very first light bulb in Iran was turned on in 1900, some 21 years after the year 1879 when it was invented by Thomas Edison. At that time the first power generator, a 12 H.P. and 110 V, was installed at "Bala Khiaban" in Mashhad to provide lighting for Imam Reza's holly shrine. Shortly after that the first official permission for installation of electric power generator for public utilization of electricity was issued to an Iranian merchant named Haj Amino Zarb. He installed a 400 KW second generator on "Cheragh Bargh" Avenue, at Tehran in 1905, and a few streets of Tehran were electrified.

At that time the municipality of Teheran was responsible for provision, installation, repair and maintenance of street lighting installations and to do so an office was established known as the "Office of Lighting". It was only in 1937 that the establishment of the "Electricity Organization" of the Tehran municipality took place and the Office of Lighting was replaced by it. The major development of the electricity industry commenced in the 1960s.

In 1962 the increasing demand for electricity led to the construction of the first hydroelectric power plant and the need for establishment of an independent organization to handle electric power affairs became pronounced. Hence, in 1962 the "Organization for Electric Power Affairs" was established. Subsequently in 1963 the ministry of water and power was established.

In 1965, the act of developing the "Non–Governmental Electric Power Organization" received the approval of Majles Shoray–e–Meli and Majles–e–Sena, the parliamentary system of that time.

Based on the second article of the law for the establishment of the "Iran Organization for Electric Power Affairs", in 1967, the ministry of water and power was authorized to divide the country into several regions regardless of provincial divisions to accelerate the development of an electric network in the country. Such a division necessitated the establishment of the regional electricity companies [RECs] in Iran.

In fact, till 1969 there was no independent organization for management of electric affairs in the country, and all decisions in this respect were made by the ministry for interior affairs and the budget and planning organization. Then those decisions were communicated to the organizations that were in charge of electrical energy affairs in various cities. In 1969, the Tavanir company was established to undertake the responsibility for development of generation and transmission facilities of electricity throughout the country.

In 1974, the responsibility for comprehensive energy planning and coordination of energy affairs in the country was given to the ministry of water and power and this ministry was renamed as the ministry of energy {MOE], and also some changes in the articles of association of the Tavanir company were made.

After the Islamic revolution in 1978, the restructuring of the electric power industry became once again the center of interest. In 1989 Tavanir was restructured as the "Organization for Management of Electric Power Generation and Transmission".

Eventually in the council of ministers' session dated 18.12.2002, based on the proposal of the MOE, the Tavanir company underwent another restructuring process and its articles of association were altered to make it a specialized holding company responsible for management of generation, transmission and distribution of electric power in Iran.

In the second half of the year 2002–2003 the "electricity market" was introduced. In this market, producers, i.e., power plants, sell to distribution companies, which act as intermediaries between producers and customers. The national dispatching centre is in charge of monitoring the market. Based on the readiness of power plants to generate electricity, their real–time price, and electricity demand, the market determines the price of electricity.

4-1-2- Current structure

The power industry in Iran, including power generation, transmission and distribution facilities is owned, operated and administrated by MOE through its executive organizations that include Tavanir, and Satkab, two specialized holding companies. In general, the MOE is responsible for all matters related to energy. These responsibilities include power generation and distribution, water supply and distribution, maintenance, repairs, collection and setting water and electricity tariffs.

Tavanir, an Iranian acronym for "Power Generation and Transmission Management Organization", is responsible for planning, coordination, supervision and evaluation of the power industry. It is responsible for overall management and distribution of electricity throughout the country. The Tavanir network of associated companies throughout Iran contains 16 RECs, which own 42 electricity distribution companies. RECs are in charge of supply, generation, transmission, distribution, and sale of electricity for all residential, commercial, industrial, agricultural, and public service uses. As mentioned above 42 non–governmental electricity distribution companies affiliated to 16 RECs maintain, operate, and develop the distribution network throughout the country. Most of these companies are active in a province. However, due to the vastness of some provinces, a company may be active in some parts of a province. These companies work under the regional management of their areas. Satkab[1] is another company formed in 2001 that acts as a purchasing company for the RECs. Organizational chart of electric power affairs of MOE of Iran is presented at figure 4.1.[2]

4-1-3- Characteristics of market

Installed capacity

With 34328 MW installed nominal capacity in 2003–2004, Iran ranks 21st among the 40 top countries and 1st among the developing nations, followed closely by Turkey. From the total 34328 MW installed nominal capacity, 97.4% belongs to MOE power plants and the remaining 2.6% to exclusive power plants owned by large industries.

The electricity supply industry has been based mostly upon thermal power plants in Iran. For instance, during 2003–2004 hydro power plants contributed only 4420 MW or 12.87% of total installed nominal capacity. Considering that the country had a mean

[1] Satkab is an Iranian acronym for "Electrical Power Manufacturing Company".
[2] All the tables and figures of the present chapter are presented at the end of the chapter.

annual rainfall below 250 mm during the last three decades, it is expected that thermal not hydro power generation will continue to dominate in the future.

Presently, there are four types of thermal plants, i.e. steam, gas turbine, combined cycle and diesel, with 14904, 7663, 6832, and 493 MW nominal capacity share or 43.41, 22.32, 19.90, and 1.43 percent respectively of total installed nominal capacity.

Power generation

The actual annual power generation in the same time period has amounted to 149676 million KWH. 98.2% of actual annual power generation belongs to MOE and the remaining 1.8% to large industries. This shows that captive power plants of large industries have a low utilization factor when compared with their installed capacity.

The greatest part of actual power generation is produced by thermal power plants, in which 92.4% of MOE's share is generated by 56 thermal power plants and the rest by 23 hydro power plants. Table 4.1 summarizes the allocation of actual power generation to the different kinds of power plants.

Fuel utilization

Electricity generation is a process, which requires another source of energy, such as wind or sun to be transformed into electricity. Nowadays, fossil fuels are the main source of energy for generating electricity. The electricity industry is an energy intensive industry and consumes large amounts of energy. The critical dependence of the Iranian economy on energy exports underlies the need for energy conservation. 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. Energy conservation is also desirable due to global warming and environmental problems. In electricity generation the primary mechanism to reduce fuel consumption can be inter–fuel substitution. The traditional sources of fuel for the power plants in Iran had been fuel oil and diesel oil. This, however, has changed drastically during the past decade with the emergence of natural gas, as a cheap alternative fuel. Table 4.2 shows the comparative consumption of different fuels in MOE power plants at present.

As the table shows, gas consumption in power plants is increasing. The increasing share of natural gas in thermal power plants reflects the growing awareness of natural gas availability and its advantages for generating electricity. Use of gas instead of liquid fuel in power plants reduces environmental pollution, decreases costs of repair, and maintenance, and facilitates operation of power plants. These advantages can not be ignored. Moreover gas consumption reduces the import of diesel oil and increases availability of fuel oil for export. However, shortage of natural gas in autumn and winter, due to increased residential consumption, makes power plants use more liquid fuel. This bottleneck could be avoided via better planning.

Transmission and distribution

The generated power is distributed through a national grid system that boasts 81528 kilometers of transmission and 509295 kilometers of distribution lines.

Power transmission lines, in the Iranian nationwide power network are 400 KV and 230 KV lines, normally used for bulk transmission of electricity for long distance supplies. In general most of the transmission lines are of the overhead types. It is only in Tehran that some 230 KV power transmission cables are installed in underground tunnels for feeding the central parts of the metropolis. The length of 400 KV and 230 KV transmission lines in the country, were 11361 and 22419 KM–circuit, respectively, in 2003–2004.

Sub–transmission lines are used for local transfer of bulk power to large consumption centers. Sub–transmission voltages used in the Iranian networks are normally 132 KV and 63 [or 66] KV. Total length of 132 KV and 63 [or 66] KV lines were 14972 and 32776 KM–circuit respectively.

Ultra distribution systems are used to transmit electric power within a city or across the country. They obtain their required power from regional power transmission stations. Basically power is distributed through medium voltage lines and low voltage lines. The normal medium voltage lines in Iran work at 33 KV, 20 KV and 11 KV voltage levels. However the 20 KV is the most commonly used. Total length of medium voltage lines in 2003–2004 was 278253 KM–circuit of which 268000 KM–circuit was the overhead type and the remaining 10253 KM–circuit was of the underground type. During the same period, total length of low voltage lines throughout the country was about 231042 KM–circuit of which 205510 KM–circuit was the overhead type and 25532 KM–circuit was underground cables.

Electricity consumption

Total electricity consumption in 2003–2004 amounted to 114625 million KWH, 33.1% of which belonged to residential units, 12% to public services, 6.5% to commercial sector, 32.2% to industrial sector, 12.1% to agricultural sector and the remainder to others.

There are about 18 million subscribers to Tavanir and the figure is growing at the rate of 4.9% per annum.

4-1-4- Challenges and future perspectives

Despite huge investments made in recent years in the Iranian power industry to boost the country's power generation and storage capacity, ever increasing growth in electricity consumption and the lack of financial sources have sounded the alarm for officials and decision makers in charge of the development of power industry in Iran. The growth rate of electricity consumption continues to increase. For example, it has increased from 7.8% in 2002–2003 to 9.1% in 2003–2004. Power consumption has been increasing due to factors such as implementation of the third five year economic development plan, completion of industrial projects, expansion of towns and cities, growth of industrial zones, supply of electricity to rural and agricultural areas, and promotion of social welfare.

In order to avert a potential shortage, Iran's power industry needs to take some measures including encouragement of the private sector to contribute to and invest in this industry. Basically three fundamental arrangements have been made to promote equilibrium between consumption and generation of electricity so far:

I- Capacity increasing in power generation sector

Tavanir has based plans of more electricity generation on the following policies.

- Orientation towards gas turbine and combined–cycle power plants, domestic production of these units, and boosting of their efficiency and productivity;
- Completion of hydro power plant projects and construction of the first pump storage power plant;
- Creation of a competitive environment for electricity generation and issuance of licenses for establishment of power plants by non–governmental sector.

It is predicted that maximum consumption demand will rise from 29000 MW in 2004–2005 to 61000 MW in 2013–2014. Therefore, power industry faces 32000 MW increase in peak load in the next 10 years. Proportionally about 40000 MW new capacity is predicted to be erected by government over the next 10 years. This monumental task will require a huge amount of investment. The officials of the Tavanir company confess that they are facing serious difficulties in financing power industry development projects, arguing that privatization is the only way for them to proceed with their development plans. Therefore, they have tried to encourage the private sector to make contributions to the development of this industry and reduce the government's intervention. In order to attain their goals they have sought to have the 38 year old power law revised.

The Iranian electricity supply industry has been mainly under the control of the government since 1967 when the nationalization law was ratified by the government. The provisions of the Iranian power law of 1967 were aimed at limiting the private sector activities and concentrating all activities regarding the power industry in the public sector. By considering the history of power industry in Iran, it can be seen that a number of private institutes had embarked on generating electricity before the power law was passed. At that time, the power law was passed so as to enable the government to interfere in the power sector. The 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 that providing ample supplies of electricity at reasonable rates was a basic necessity for economic development. It was hoped that a publicly owned monopoly would be able to operate the electricity supply industry on a large scale and would be cost efficient. However, despite the MOE receiving subsidies from the government in the form of low fuel prices for electricity generation, the costs recorded were high, and electricity tariffs did not keep up with the growth in costs, which far exceeded revenue.

Thirty–eight years later the power industry has undergone serious transformation in Iran and efforts are underway to reduce the government's role in the power industry and encourage the private sector's contribution to this sector. It is, therefore, necessary to have the current law revised. The government intends to enact a new law and open the way for the private sector to get involved in this industry. In an effort to reduce the governmental subsidy provided to the electricity industry, the government intends to increase the degree of decentralized decision making in the power sector. Lately, to encourage the private sector, the MOE has been concentrating on securing private sources of financing at home and abroad for independent power projects [IPP]. Two main forms of IPP are the B.O.T [build, operate and transfer] and B.O.O [build, operate and ownership] schemes. Under the B.O.T scheme, foreign companies enter into a long–term investment with sufficient assurances from the government to built, operate and then transfer the project after a period of 20 years, while under the B.O.O scheme, the investor is the owner of the project. The assurances from the government include, guarantee of the capital invested during the construction and operation, guaranteed minimum price for the product and purchasing of the product, and finally compensation in the case that production suffers due to water shortage or other natural disasters. More than 6180 MW and 12268 MW capacities are now being negotiated in B.O.T and B.O.O schemes, respectively.

II- Reduction of losses in nationwide grid

Due to wear and tear of the distribution networks, their equipment is dilapidated and the amount of electricity wasted is high. At present, this figure, in the transmission and distribution networks, stands at 17 percent. Electricity losses will influence the current cost and final price of electricity in either direct or indirect ways. Authorities in the power sector attempt to curb losses as much as possible. The importance of and sensitivity of the problem made the power industry design a comprehensive plan to reduce losses nationwide. RECs are competing to have the lowest losses throughout the country. As a first step towards solving the problem, it has been suggested that credits be allocated to setting up a system for measurement of energy swap. Then, we should optimize electricity transmission networks to reduce electricity losses. It is estimated that within the next 10 years, 150000 billion Rials should be invested in the transmission and distribution networks.

III- Consumption management

Compared to other countries, electricity is cheap and subsidized in Iran. As a result consumers fail to pay enough attention to saving electricity. The growing demand for electricity and the limited investment resources make consumption management a vital issue. Among significant activities for this purpose we can name creating a new understanding of consumption, coordination with industries, sensible tariffs, changing working time for businesses, encouraging low–energy appliances, and providing these appliances with lower prices and incentives.

Environmental protection is another objective followed by the power industry. 8000 MW of about 40000 MW new capacities to be established is in hydro power plants.

Research and development policies now aim at utilization of renewable energies. Increasing electricity demand, betterment of living standards, decrease of fossil fuel resources, global warming, environmental damages, and threats against health have drawn the attention of all countries towards renewable energy resources such as wind, solar and geothermal. Iran with its extraordinary vastness and geographical diversity is among the most–favored countries to capitalize on renewable energy resources. Following the MOE's policies, the "Iran New Energies Company" was founded and delegated the responsibility to collect the most up–to–date information about the modern technologies in the field of renewable energies, to identify Iran's potentials and to launch various solar, wind, and geothermal projects. These projects, which are about 520 MW new capacities, are anticipated to be fulfilled by 2011–2012.

Expansion of grid and connection to neighboring countries are other programs of the power industry. These activities focus on economic and political objectives, improvement of generated load, enhancement of load factor, as well as harmonizing supply and demand in country. At present Iran exchanges electricity with Turkmenistan, Azerbaijan, Armenia, Pakistan, and Turkey. Plans are being made to expand the Iranian grid to Afghanistan.

With the improvement in the production and storage of electricity, and optimization of distribution networks it is hoped "power failure" can be prevented.

4-2- Discussion of data

A balanced panel on 16 Iranian RECs for a 14–year time period, 1989–1990 to 2002–2003 with a total of 224 observations is used in this study. Table 4.3 presents the lists of RECs in this study with the related dummy variables used in the estimation process.

The data are mainly based on the information form the annual detailed statistics of electric power industry in Iran published by MOE. The financial data are obtained from the annual reports of the "Independent Auditing and Legal Inspection Organization". The necessary data include total cost, output, the prices of labor and capital, as well as the number of customers, the length of transmission and distribution lines, and load factor. All money values including total cost and input prices were deflated to 1990–1991 constant Iranian Rials using the Iranian global consumer price index.

For simplicity, total cost is equated to total expenditure of company excluding the expenditure for purchased and produced electricity. For those companies that produce part of their power the average price of input electricity is assumed to be equal to the price of purchased power. Output is represented by the quantity of KWH electricity delivered. Average cost represents the cost per KWH delivered electricity and is obtained through dividing the total cost by the total quantity of KWH electricity delivered. Labor price is defined as the average annual salary of the company's employees, which is estimated as the labor expenditure [in both transmission and distribution sections] divided by the total number of employees [in both transmission and distribution sections]. The capital price is calculated from the residual capital cost divided by the capital stock. Residual cost is total cost minus labor cost. Because of the lack of inventory data the capital stock is approximated by the total installed transformer capacity [in both transmission and distribution sections], measured in KVA. Customer density is measured as the ratio between the number of customers and the length of transmission and distribution lines measured in kilometers. Finally, load factor is defined as the ratio of company's peak demand on its maximum capacity. Table 4.4 presents a summary of descriptive statistics of the variables used to construct a panel data set in this study.

As we can see, with exception of the load factor and labor price, there is much variation in the data, such that for example in length of [transmission and distribution] lines and capital price the third quartile, with 224 observations has more than twice the value of the first quartile. This translates to the number of customers tripling and total cost quadrupling.

Some more detailed statistics of the variables used for estimation are presented in table 4.5, covering the 16 RECs from 1989–1990 to 2002–2003 by year.

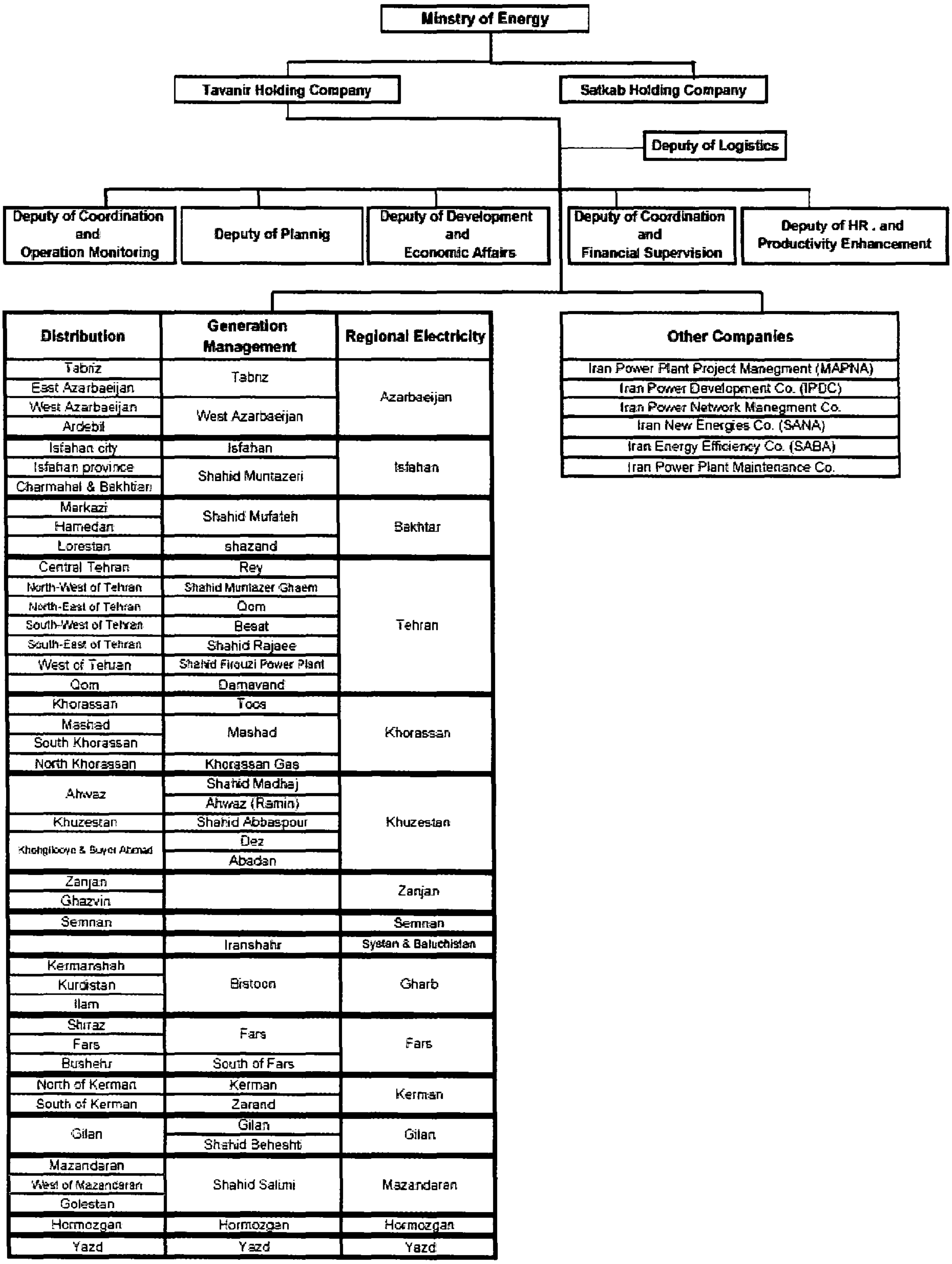

Figure 4.1: Organizational chart of electric power affairs of MOE of Iran

Table 4.1: Distribution of power generated by different kinds of power plants*

	MOE	Large Industries	Whole Country	% of Total
Steam	85403	2267	87670	58.57
Gas Turbine	17276	421	17697	11.82
Combined Cycle	32895	–	32895	21.97
Diesel	290	–	290	0.19
Hydro	11094	–	11094	7.41
Wind–Energy	30	–	30	0.02
Total	146988	2688	149676	100

*The generated power amounts are in million KWH

Table 4.2: Share of different fuels consumed in MOE power plants

	2001–2002	2002–2003	2003–2004
Natural Gas	71.36%	74.2%	82.6%
Fuel Oil	23.26%	20.8%	13.5%
Diesel Oil	5.38%	5%	3.9%

Table 4.3: Lists of RECs in this study

Number of Company	Company Name	Related Dummy Variables
1	Gilan	D11, D21, D31
2	Hormozgan	D12, D22, D32
3	Kerman	D13, D23, D33
4	Fars	D14, D24, D34
5	Mazandaran	D15, D25, D35
6	Semnan	D16, D26, D36
7	Systan & Baluchistan	D17, D27, D37
8	Bakhtar	D18, D28, D38
9	Khorassan	D19, D29, D39
10	Khuzestan	D110, D210, D310
11	Zanjan	D111, D211, D311
12	Yazd	D112, D212, D312
13	Azarbaeijan	D113, D213, D313
14	Gharb	D114, D214, D314
15	Isfahan	D115, D215, D315
16	Tehran	D116, D216, D316

Table 4.4: Descriptive statistics

Variable	Description	Unit	1.Quartile	Median	3.Quartile
c	Total Cost	Million Rials	5692.912	11073.669	25033.726
y	Output	Million KWH	1567.25	2930	5534.75
w_l	Labor Price	Million Rials	1.406	1.873	2.325
w_k	Capital Price	Million Rials	0.822	1.311	2.326
CU	Number of Customers	Thousand	295.025	641.8	1018.975
NL	Length of Lines	Kilometers	13734.75	23143.8	33525.43
LF	Load Factor		53.1	57.15	61.7

Table 4.5: Detailed statistics of the variables used for estimation

Variable	1989_1990	1990_1991	1991_1992	1992_1993	1993_1994	1994_1995	1995_1996	1996_1997	1997_1998	1998_1999	1999_2000	2000_2001	2001_2002	2002_2003
Ac														
Mean	2.993	2.762	2.589	2.937	6.144	6.514	4.712	4.03	3.774	3.412	3.176	3.126	5.412	8.528
S.D.	0.929	0.792	0.884	1.278	3.032	1.785	1.332	1.149	0.937	0.986	0.952	0.867	1.664	2.979
Min	1.749	1.529	1.329	1.77	1.56	3.659	2.9	2.601	2.506	2.278	2.031	1.981	2.482	5.265
Max	5.228	4.049	4.762	6.809	11.909	9.969	7.36	6.411	5.605	5.724	5.54	5.156	8.777	16.06
y														
Mean	2497	2812.875	3073.062	3336.187	3694.375	4048.437	4251.125	4529.187	4800.062	5145.187	5487.312	5916.625	6361.187	6873.13
S.D.	2841.984	3036.665	3317.8	3675.451	3924.711	4209.899	4355.498	4546.2	4764.754	4986.823	5288.841	5503.37	5762.576	6171.32
Min	445	477	538	566	608	633	770	934	1018	1172	1212	1289	1434	1535
Max	12070	12808	13955	15520	16454	17327	17910	18691	19782	20929	22412	23296	24340	26084
w_l														
Mean	1.429	1.532	1.593	1.763	1.962	1.902	1.767	1.819	1.974	1.984	2.106	2.362	2.551	2.6
S.D.	0.811	0.938	0.948	0.988	0.918	0.805	0.687	0.654	0.57	0.527	0.539	0.613	0.539	0.434
Min	0.592	0.478	0.487	0.653	0.699	0.672	0.76	0.793	1.271	1.336	1.575	1.669	1.79	1.972
Max	3.35	4.144	4.28	4.516	4.181	3.866	3.389	3.313	3.153	3.081	3.509	4.032	3.921	3.534
w_k														
Mean	0.686	0.66	0.62	0.84	2.599	3.021	2.022	1.725	1.59	1.416	1.281	1.277	2.445	4.251
S.D.	0.272	0.265	0.27	0.904	1.724	1.175	0.764	0.705	0.581	0.467	0.443	0.394	0.788	1.385
Min	0.296	0.302	0.28	0.278	0.314	1.406	1.023	0.969	0.941	0.948	0.737	0.736	0.641	2.174
Max	1.313	1.308	1.154	4.048	6.139	5.994	3.622	3.406	2.772	2.337	2.248	1.999	3.985	7.377
CD														
Mean	0.033	0.032	0.031	0.03	0.03	0.03	0.029	0.029	0.028	0.028	0.027	0.027	0.027	0.027
S.D.	0.017	0.014	0.013	0.012	0.011	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.013	0.012
Min	0.017	0.017	0.018	0.017	0.017	0.017	0.017	0.016	0.016	0.016	0.016	0.016	0.015	0.014
Max	0.075	0.071	0.07	0.068	0.068	0.068	0.069	0.072	0.071	0.07	0.07	0.071	0.072	0.069
LF														
Mean	56.462	55.225	56.056	56.95	60.025	58.112	56.281	55.221	55.328	55.256	55.681	56.378	57.05	56.781
S.D.	10.692	11.658	10.162	9.243	5.986	6.199	7.741	9.077	7.19	6.821	6.932	7.99	7.149	6.618
Min	20.2	21.1	25.1	30.1	53.1	45.1	35.1	27.6	34.2	36.1	36.8	37.3	39.1	40.2
Max	67.3	71.7	72.2	69.7	75.2	68.5	63.7	64.9	64.8	64.2	64.1	68.7	67	66.2

Chapter 5

Empirical Analysis

5-1- Introduction

As we mentioned earlier, data were obtained for 16 Iranian RECs for 14 years. We have presented in table 5.1[1] some selected measures of raw data of Iranian RECs in 1992–1993, the year just before the reform process started. As we can see the firm size ranges from 566 GWH in Semnan with 119 thousand customers and 96816 squared kilometers covered area to 15520 GWH in Tehran with 2417 thousand customers and 30433 squared kilometers covered area. Typically similar firms in other countries, e.g. European countries, serve more customers in an area of the same size. For example, for the year 1992–1993 in the 1st quartile of observations in Iran, the average consumption of electricity per customer is 3753 KWH and the average customer density is 2.52 customers per squared kilometers. On the other hand in the 1st quartile of observations in Switzerland, the average consumption customer is 5995 KWH and the average customer density is 14.92 customers per hectare. The situation in Iran differs from the European countries, because the population in Iran is concentrated mostly in the north of the country and the southern part is sparsely populated. However, development of infrastructure in this area is crucial for the economic development of Iran as the oil refineries and the mining industry are located in this area. From the data presentation we can see that for Iranian firms the areas of operation are geographically large, and the

[1] All the tables and figures of the present chapter are presented at the end of the chapter.

number of people serviced is small relative to global norms. Hence, we expect that firms operate on the downward sloping section of the average cost curve, where they experience increasing returns to scale. It means that these firms do not operate at a scale efficient size, and are economically inefficient. To improve the efficiency level of these firms, the MOE reformed the organizational structure of electricity transmission and distribution in 1993, by separating distribution activity from transmission activity. RECs continued to handle the transmission part. New companies were created to handle distribution. This enabled both sets of firms to specialize and consolidate their activities, thereby reducing costs of operation and improving efficiency. To examine this we estimate an average cost frontier model. As mentioned before, different functional forms and different approaches can be used to estimate such a frontier average cost function.

As mentioned in the previous chapters, between the two main functional forms commonly used in the literature, the [logarithm of] Cobb–Douglas form and the translog form, the latter is preferred because it does not impose any restrictions on the nature of the technology and offers an appropriate functional form for answering questions about economies of scale.[2] This is as explained above of particular interest in the Iranian case, where we wish to investigate the hypothesis that firms operate at a level where there are increasing returns to scale.

We have used the fixed effects approach rather than the random coefficients approach, as the fixed effects approach controls for unobservable firm specific effects, such as inefficiency, that are not captured by control variables. Another important advantage of the fixed effects specification is that the estimates are unbiased even if

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[2] In translog functional form, economies of scale vary with output, while it is assumed constant in the [logarithm of] Cobb-Douglas functional form.

explanatory variables are correlated with firm specific dummies, whereas in the random coefficients approach any correlation between random effects and other explanatory variables may result in biased estimates. Therefore, in network industries, such as the electricity distribution industry, with firm specific characteristics, in the absence of information regarding the unobserved heterogeneity among firms, the fixed effect approach is to be preferred.

However, as a check, we also estimate the model using the [logarithm of] Cobb–Douglas functional form and the random coefficients approach. As expected these results are inferior to those obtained from the fixed effects translog model.[3]

The Econometric packages, Eviews 3.0 and Limdep 7.0 were used to estimate the stochastic average cost frontier models in fixed effects and random coefficient shapes, respectively.

The rest of this chapter is organized as follows: Section 5-2 presents estimation results of different average cost frontier models. Regarding the parameters of the selected model, sections 5-3 and 5-4 provide the estimates of economies of scale and annual cost efficiency level of RECs. Section 5-5 discusses hypotheses testing.

5-2- Estimation results

In this section we report the econometric results obtained from estimating the average cost frontier models specified in section 3-3 and using the data described in section 4-2. In the first step we estimate the [logarithm of] Cobb–Douglas specification of our average cost function by fixed effects approach, in which three dummy variables for each of the 16 RECs are included in the model to capture the firm specific effects of

[3] Refer to the results presented in tables 5.2, 5.3, 5.5, and 5.6.

intercept, time and time squares variables. The estimated coefficients, standard errors, and $\mathcal{P}$–values for all the parameters of the model estimation are presented in table 5.2. The estimated function is not well behaved.

Average cost and the regressors are in natural logarithms, therefore, the [absolute values of the] coefficients are interpretable as average cost elasticities. The estimated coefficient of output is negative and this implies that an increase in the production of output will decrease average cost. A 1% increase in the delivery of power will decrease the average cost by approximately 0.89%. The labor and capital cost shares are positive; implying that the average cost function is monotonically increasing in input prices. In the model, labor costs account for approximately 31% of average cost, while capital accounts for the remaining 69% of average cost. These results are as expected. However, the coefficient of customer density though negative is small in magnitude and is not significant. The coefficient of the load factor is unexpectedly positive but it is also not significant. Although most of dummy variables capturing the firm specific effects related to time variable are insignificant, but their counterparts related to intercept and time squares variables are significantly different from zero, implying the existence of time–varying firm specific effects. As expected, this model is not a good fit and half of the structural parameters of the model do not have significant coefficients.

For comparison purposes, we present the results obtained from estimating a random coefficients version of the same specification of average cost function. The random coefficients model treats the differences between units as randomly distributed across cross–sectional units. Table 5.3 presents the estimated coefficients of the structural parameters and mean vector of random coefficients and their associated standard errors.

Recall that variables intercept, time, and time squares have random coefficients, and the estimated coefficients are the mean vector of their random process. The predictions of the individual random coefficient variables vectors are presented in table 5.4.

Although there are some differences in the size of the coefficients in comparison with the fixed effects model, they are similar in both models. The coefficients of the output and customer density of the random coefficients model are a little higher in absolute value than the ones of the fixed effects model, while there is an inverse situation with regard to the coefficients of the labor price and load factor. Again the coefficients of output and labor price are highly significant, while customer density and load factor coefficients are insignificant. Like the fixed effects model, the intercept coefficient and the coefficient of time squares variable are significantly different from zero, while the coefficient of time variable is insignificant. With the same reason as fixed effects model, this model can not be considered as a good model.

In the next step, in order to improve the flexibility of the model we run a translog specification of our average cost function with fixed effects approach. As discussed in section 5-1, this is the preferred approach given the nature of the problem under investigation and the data available. The results of the estimation are set out in table 5.5. As expected, the estimated function is well behaved. A majority of the reported coefficients, 9 out of 14, have the expected signs and are highly significant at the 0.10 level. Note that the coefficient of the variable $\ln LF$ is positive. We might conclude that again the estimated impact of load factor on average cost has the wrong sign. This conclusion would be incorrect, however; as in the translog model, the impact of load factor on average cost is computed through

$\frac{\partial \ln Ac}{\partial \ln LF} = \alpha_f + \alpha_{ff} \ln LF + \alpha_{yf} \ln y + \alpha_{lf} \ln(\frac{w_l}{w_k}) + \alpha_{cf} \ln CD =$ –0.038 in our model. This is in line with our expectations.

The impact of output on average cost is calculated as –1.01. This indicates that firms are not operating at optimum levels of capacity utilization. Increasing their operational size would enable them to become more efficient, and produce more at lower costs. This would benefit all concerned. The evidence does not support marked non–linearities in the impact of output on average cost, viz. α_{yy} is statistically insignificant. This suggests that there are only small variations in economies of scale, between firms, in the production process, and the firms are operating on the declining section of the average cost curve. The impact of labor price on average cost is 0.325, which indicates a monotonically increasing average cost function in input prices, with labor costs accounting for approximately 32.5% of average cost, and capital costs for the remaining 67.5%.

The elasticity of average cost with respect to customer density is 0.11. This also suggests that firms could benefit from restructuring, so that no firm is supplying exclusively to the sparsely populated southern region. Note that customer density affects the average cost mainly through interactions with labor price and load factor. This is as expected, because the data indicate that firms operating in the south of Iran are faced with low customer density, low wages and low load factor relative to firms in the north of Iran.

Finally, the negative impact of the load factor variable indicates that a 1% improvement in the load factor will reduce the average cost by approximately 0.038%. The relatively small magnitude of this result may be due to the small variation of the load factor within the RECs in our sample.

In majority of the cases, dummy variables related to either time variable or time–squared variable are significant. This indicates the existence of time–varying firm specific effects, and in result, time–varying cost efficiency of companies. The obtained value of $\mathcal{F}$ –statistic indicates that overall the model is a good fit to the data. As we mentioned, the estimated function is well behaved. Eight of the fourteen structural parameter coefficients are significant at the 0.05 level, one is significant at 0.10 level, and five are not statistically significant.

For the sake of comparison, we estimated a random coefficients version of the translog specification of our model. Table 5.6 lists the estimated coefficients of the structural parameters and mean vector of random coefficients and their associated standard errors. Also, the predictions of the individual random coefficient variables vectors are presented in table 5.7. Although the estimates of the coefficients of output, labor price, customer density, and load factor are significantly different from zero, this model can not be selected as a good model, because of the following two main reasons: First, most of the interacted variables had to be excluded from the estimated regression, because of multicollinearity. This makes for an incomplete estimation of the translog specification, which we imposed for flexibility of the model. Secondly, all of the coefficients relating to firm specific variables including intercept, time, and time squared are insignificant. This is not indicated by the raw data and is also not consistent with the earlier estimations.[4] Hence, this model is set aside.

As expected, the translog model estimated by fixed effects approach has given us the best results empirically. Hence, the estimates of economies of scale and cost efficiency of RECs will be based on the results of this model.

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[4] See for example table 4.5 in section 4-2 for raw data and also table 5.12 in section 5-4 for cost efficiency.

5-3- Assessment of economies of scale

As we noted in chapter three, we are not able to introduce the distinction of economies of output density, economies of customer density and economies of scale, rather we can estimate only economies of scale as the proportional decrease in average cost brought about by a proportional increase in output, holding other explanatory variables fixed, which is equivalent to the effect of output on average cost computed as:

$$\mathcal{ES}=\frac{\partial \ln Ac}{\partial \ln y}=\alpha_y+\alpha_{yy}\ln y+\alpha_{yl}\ln(\frac{w_l}{w_k})+\alpha_{yc}\ln CD+\alpha_{yf}\ln LF$$

In the previous section we computed the above for all the companies in overall time period as -1.010, indicating increasing returns to scale for the RECs in our sample. This suggests that the majority of the Iranian RECs operate at an inappropriately low scale level. In other words, most of the companies in our sample are too small and do not reach the minimum efficient scale.

In order to gain a better idea of economies of scale in this industry, we calculate $\mathcal{ES}$ for small, medium, and large companies, in overall time period. For this purpose we attribute 1st quartile, median, and 3rd quartile's output values[5] for small, medium, and large companies, respectively. The resulting values of $\mathcal{ES}$ evaluated with all variables other than output level set to their sample mean values are -1.128, -1.015, and -0.899, respectively. We note that all indicators for $\mathcal{ES}$ are negative, which again suggest that most of the companies operate at sub optimal levels. But the magnitude of the $\mathcal{ES}$ differs across the groups suggesting that large firms suffer less of a disadvantage than smaller ones. To analyze the issue in more detail, we calculate $\mathcal{ES}$ for each of the 16 companies in

[5] These values are taken from table 4.4 in chapter four.

overall time period, and report the obtained results, ordered by the size of the companies, in table 5.8.

The results provide two important conclusions. First we find that each of the 16 companies face increasing returns to scale, and all of the companies operate at a low scale level, i.e., this industry is characterized by notable scale inefficiency. Secondly, the magnitude of the $\mathcal{ES}$ differs across the companies so that larger companies are better off than smaller ones from the economies of scale point of view. To examine this, we run the signed rank test for two independent samples, where the samples are small companies with 5 first observations and large companies with 5 last observations. We apply the Mann–Whitney test and Kolmogorov–Smirnov test, two commonly used tests in this area. These tests help us to determine whether two samples have come from identical populations. If it is true that the samples have come from the same populations, it is reasonable to assume that the means of the two samples are equal. The results, presented at table 5.9, show that there is a statistically significant difference between the means of the two samples.

In the next step, in order to observe the variations of $\mathcal{ES}$, resulted from the structural reform, we calculate $\mathcal{ES}$ for each of the 16 companies [and all companies] at pre–reform time period and post–reform time period. The obtained results are presented at table 5.10.

Considering pre–reform and post–reform values of $\mathcal{ES}$ for each of the 16 companies, it is observed that the magnitude of $\mathcal{ES}$ has improved at post–reform time period relative to pre–reform time period. To examine this statistically, we apply nonparametric tests for two related samples [paired samples] using Wilcoxon signed ranks test and sign test. These tests help us to test the null hypothesis that the two related variables [i.e., pre–reform $\mathcal{ES}$ and post–reform $\mathcal{ES}$] have the same distribution. The results, presented at table 5.11, show that the mentioned null hypothesis is rejected. This suggests that structural reform has had a positive effect on the performance of these companies. This is further analyzed in the next section by calculating cost efficiency for each company and testing whether efficiency of firms has improved over this period.

5-4- The estimation of cost efficiency

The estimation results reported in table 5.3 can be used to recover the level of cost efficiency of each company for each year along the lines suggested by Cornwell, Schmidt and Sickles (1990). This amounts to counting annually the most efficient company in the sample as 100% efficient and measuring the degree of cost efficiency of the other companies relative to the most efficient company. The cost efficiency indicator can be interpreted as the ratio of minimum feasible cost to observed cost. Complete statistics of the estimated cost efficiency scores of each individual company over time are reported in table 5.12. The results indicate that nearly all of the companies experienced increasing cost efficiency scores over the sample time period. This conclusion is buttressed by the observed slight increasing trend of annual mean cost efficiency of companies. The graph is presented in figure 5.1. In order to gain a better analysis of cost efficiency of sample companies, we divide the companies with respect to their cost efficiency levels into four categories: good, average, weak, and very weak. The good category refers to the companies with a cost efficiency level of 50% and above. The average category comprises companies, which have an efficiency level of 30%–50%. The cost efficiency levels of the companies included in the weak category are in the range of 20%–30% and finally the companies with cost efficiency levels below 20% are placed in the very weak category. Figure 5.2 presents plots of the cost efficiency level for all the companies over the time period.

Companies numbered 6, 7, 11, and 12 are ranked as good performers. Company number 6 has been the most efficient firm in the entire period, and the cost efficiencies of the remaining firms are measured relative to this company. The efficiency of company number 7 has increased up to 1997; thereafter it shows a slight decreasing trend, because of the increasing in the average cost of production after 1997. Company number 11 exhibits the expected behavior. Company number 12 exhibits decreasing cost efficiency, the reasons for which are not related to increase in input costs. A possible cause may be poor management. The average category contains four companies numbered 1, 2, 3, and 14, in which all except company number 1 experienced improved cost efficiency. The reason for a slight decrease in cost efficiency of company number 1 towards the end of the period could be the massive increase in total cost in these years. The reasons for this are unclear. There seems to have been some redefining of categories of costs for this company. Alternatively, it is possible that their accounting practices were changed as part of the general process of reorganization and restructuring. There does not seem to be any dramatic increase in input prices or a major surge in investment that could explain the sudden increase in outlay. Companies numbered 5, 8, 9, 13, and 15 are categorized as weak in terms of their cost efficiency levels. Except for company number 8, all the other companies have shown improvement in their performance. Company number 8 also has shown improvement after 1993, suggesting that reform helped turn around this company.

Lastly, the very weak category includes three companies numbered 4, 10, and 16, all of them showing an improvement in their cost efficiency levels.

Although cost efficiency scores of most of the companies in our sample have increased over time, 75 percent of companies [12 companies out of total 16 companies] continue to exhibit a high degree of inefficiency with cost efficiency levels below 40%. Partly this is due to poor management, but there are some other reasons too. First, some companies operate in regions characterized by difficult production conditions, which are not taken into account in our model specification. Secondly, relatively low cost efficiency scores indicate a high dispersion of cost inefficiencies across companies. It may be because Iranian RECs are not specializing enough. Each REC handles generation, transmission, distribution, and sale of electricity, where in the standard international practices [e.g. EU countries] RECs mostly undertake the transmission activity, and other activities are handled by other different companies. Finally, in average cost frontier framework, fixed effects approach assumes that the unobserved heterogeneity among firms is completely due to differences in efficiency. This assumption leads to an overestimation of inefficiency in fixed effects model for the following reasons. First, the fixed firm specific effects capture both observed and unobserved time–invariant factors. Moreover, since the fixed effects do not follow any distribution and efficiency is estimated compared to the best observed practice [the firm with the minimum fixed effect], the estimators are sensitive to outliers. In fact, the problem of outlier firms is transferred from the average cost function to efficiency estimators, leading to a high degree of inefficiency for some firms.

5-5- Hypotheses testing

There are three main hypotheses, which were tested in this study. The first tested whether the efficiency level of different Iranian RECs are equal. To do this, we tested the hypothesis that the mean cost efficiency level of company number 1 over time is equal to that of company number 2, and it is equal to that of company number 3, and so on against the alternative that this is not the case. For this purpose, we use the Wald–statistic, which is asymptotically distributed as chi–squared with the degrees of freedom equal to the number of companies. The calculated value for the Wald –statistic to test the mentioned hypothesis is 11696.35, which is considerably more than the 95 percent critical value of 26.30 obtained from the chi–squared table with 16 degrees of freedom. Hence, the hypothesis of equal efficiency levels is not accepted.

We also wished to test whether the 16 RECs have been operating at low cost efficiency levels. To do this, we tested for each REC the hypothesis that its mean cost efficiency level over time is less than 50%. The calculated t –values for the 16 RECs are presented in table 5.13. From the table we see the null hypothesis is rejected for companies numbered 6, 7, 11, and 12 only, all other firms operated at efficiency levels below 50% over the entire period from 1989 to 2002.[6] This result is consistent with the graphs of figure 5.2.

Calculating average cost efficiency level of our sample companies we find that it was only 31.74% in 1989–1990 and 37.37% in 2002–2003. This leads us to our third conjecture. Based on figure 5.1 and preliminary data analysis we expect the impact of structural reform to be positive, i.e., to improve the cost efficiency of the firms. To

[6] The t –value for company number 6 can not be computed because of its fixed value of cost efficiency, but its cost efficiency level is 100% all over the time period, which is more than 50% of null hypothesis.

examine the improvement of cost efficiency of companies we run for each REC the signed rank test for two independent samples, where the samples are pre–reform time period with 5 observations and post–reform time period with 9 observations. We apply the Mann–Whitney and Kolmogorov–Smirnov tests, two commonly used tests in this area. These tests help us to determine whether two samples have come from identical populations. If it is true that the samples have come from the same populations, it is reasonable to assume that the means of the two samples are equal. The results, presented in tables 5.14 to 5.29, show that there is a statistically significant difference between the means of the two samples for all companies except for company number 6.[7] However, it must be noted that these tests show only the differences of the means of the two samples, and not necessarily the directions of changes. Regarding figure 5.2, except companies numbered 11 and 12, all other companies show increasing cost efficiency in most years of the time period under consideration. Cost efficiency level of company number 6 is also fixed at 100% as the most efficient firm. Combining these trends of cost efficiency levels of companies with the results of signed rank test shows that structural reform has improved the cost efficiency of all companies except companies numbered 11 and 12. Hence, our third hypothesis on the positive impact of structural reform on the performance of RECs is accepted for the majority of firms. This completes our hypotheses testing.

[7] It is the case for company number 6 because of its fixed value of cost efficiency at 100% level all over the time period.

Table 5.1: Selected measures of raw data of Iranian RECs in 1992–1993

Company Name	Electricity Delivered (Million KWH)	Customers (Thousand)	Area Covered (Squared Kilometers)	Length of Lines (Kilometers)
Gilan	1542	453	13952	15029
Hormozgan	1435	140	71193	7032
Kerman	2256	375.4	181714	21196
Fars	3064	740	144993	27389
Mazandaran	2369	736	44726	20212
Semnan	566	119	96816	4682
Systan & Baluchistan	660	154	178431	8354
Bakhtar	3067	660	77345	28869
Khorassan	4122	1065	313000	30904
Khuzestan	6854	589	80992	19804
Zanjan	1194	298	37332	12780
Yazd	767	197	73467	5929
Azarbaeijan	3740	1141	100825	27341
Gharb	1405	505	73608	19480
Isfahan	4818	981	123222	28726.51
Tehran	15520	2417	30433	35421

Table 5.2: Average cost frontier parameter estimates

[Cobb–Douglas specification and fixed effects approach]

Parameter	Estimate	Standard Error	t – Statistic	$\mathcal{P}$ – Value
α_y	-0.896137	0.132653	-6.755494	0.0000
α_l	0.311004	0.010700	29.06538	0.0000
α_c	-0.062303	0.159958	-0.389492	0.6974
α_f	0.090394	0.076508	1.181496	0.2390
D11	6.917120	1.023415	6.758863	0.0000
D12	7.708314	1.034120	7.453982	0.0000
D13	7.343096	1.064706	6.89683	0.0000
D14	7.714547	1.113409	6.928762	0.0000
D15	7.570484	1.061140	7.134290	0.0000
D16	6.251097	0.917408	6.813868	0.0000
D17	6.497983	0.977238	6.649333	0.0000
D18	7.570582	1.074012	7.048884	0.0000
D19	7.493225	1.138748	6.580230	0.0000
D110	8.725181	1.189236	7.336794	0.0000
D111	6.785332	1.030033	6.587493	0.0000
D112	6.282392	0.949840	6.614159	0.0000
D113	7.798857	1.086801	7.175974	0.0000
D114	7.247351	1.036359	6.993086	0.0000
D115	8.434805	1.136942	7.418852	0.0000
D116	8.877703	1.262968	7.029238	0.0000
D21	0.011169	0.023760	0.470083	0.6389
D22	-0.108348	0.024001	-4.514270	0.0000
D23	0.004568	0.028018	0.163027	0.8707
D24	0.005284	0.023434	0.225501	0.8219
D25	0.006834	0.025771	0.265200	0.7912
D26	-0.000484	0.026004	-0.018611	0.9852

Table 5.2: Continued

Parameter	Estimate	Standard Error	t – Statistic	$\mathcal{P}$ – Value
D27	-0.009052	0.026090	-0.346957	0.7290
D28	0.026364	0.037252	0.707715	0.4801
D29	-0.003110	0.022925	-0.135644	0.8923
D210	-0.118087	0.028550	-4.136154	0.0001
D211	-0.012391	0.025061	-0.494414	0.6216
D212	0.016019	0.023930	0.669398	0.5041
D213	0.011742	0.036980	0.317513	0.7512
D214	-0.015379	0.025043	-0.614108	0.5400
D215	-0.109573	0.029697	-3.689713	0.0003
D216	-0.021163	0.023800	-0.889206	0.3751
D31	0.002865	0.001427	2.00719	0.0463
D32	0.008271	0.001454	5.688984	0.0000
D33	0.001538	0.001565	0.982943	0.3270
D34	0.002555	0.001434	1.782200	0.0765
D35	0.000634	0.001506	0.420624	0.6746
D36	0.002444	0.001439	1.698564	0.0912
D37	0.003683	0.001453	2.535167	0.0121
D38	0.001017	0.001720	0.591473	0.5550
D39	0.003334	0.001437	2.320813	0.0215
D310	0.007681	0.001632	4.707432	0.0000
D311	0.003147	0.001428	2.203719	0.0289
D312	0.003071	0.001480	2.075326	0.0394
D313	0.000016	0.001988	0.008385	0.9933
D314	0.002950	0.001469	2.008729	0.0461
D315	0.006566	0.001536	4.275593	0.0000
D316	0.002538	0.001425	1.781520	0.0766
$R^2 = 0.973$		$\mathcal{F}$ – Statistic = 121.83		$\mathcal{D.W}$ – Statistic = 1.68

Table 5.3: Average cost frontier parameter estimates

[Cobb–Douglas specification and random coefficients approach]

Parameter	Estimate	Standard Error	t – Statistic	$\mathcal{P}$ – Value
α_y	-0.976676	0.060887	-16.041	0.0000
α_l	0.286428	0.005511	51.971	0.0000
α_c	-0.131615	0.085633	-1.537	0.1243
α_f	0.030414	0.051961	0.585	0.5583
δ_{01}	8.060147	2.332499	3.456	0.0005
δ_{02}	-0.014522	0.025156	-0.577	0.5638
δ_{03}	-0.003218	0.000827	3.891	0.0001

Table 5.4: Predictions of the individual random coefficient vectors [Cobb–Douglas]

Parameter / Company no.	δ_{i1}	δ_{i2}	δ_{i3}
1	3.52002	-0.01971	0.003502
2	6.72066	-0.04113	0.006443
3	-0.78386	-0.0853	0.004373
4	-0.51498	0.012517	0.001952
5	14.5832	0.090914	-0.00034
6	-2.36186	-0.04665	0.00467
7	5.92065	0.097818	0.00344
8	8.5069	0.033906	0.00084
9	1.7649	-0.07724	0.003533
10	9.21527	-0.11563	0.006102
11	18.1004	0.063613	0.003991
12	5.314	-0.01872	0.002841
13	7.73495	-0.08129	0.004042
14	8.85363	-0.01812	0.00481
15	10.9744	-0.02774	0.003662
16	10.8012	0.062696	0.002255

Table 5.5: Average cost frontier parameter estimates

[Translog specification and fixed effects approach]

Parameter	Estimate	Standard Error	t – Statistic	$\mathcal{P}$ – Value
α_y	-2.452810	1.246338	-1.968014	0.0508
α_l	0.958391	0.319512	2.999551	0.0031
α_c	-2.427617	2.019053	-1.202354	0.2310
α_f	6.400178	2.465498	2.595897	0.0103
α_{yy}	0.181335	0.122946	1.474924	0.1422
α_{ll}	0.176342	0.014216	12.40412	0.0000
α_{cc}	0.146329	0.289075	0.506197	0.6134
α_{ff}	-0.823823	0.398814	-2.065681	0.0405
α_{yl}	-0.088607	0.012519	-7.078024	0.0000
α_{yc}	-0.047456	0.161988	-0.292962	0.7699
α_{yf}	-0.038483	0.109515	-0.351399	0.7257
α_{lc}	0.108671	0.030150	3.604381	0.0004
α_{lf}	0.103466	0.058254	1.776111	0.0776
α_{cf}	0.793657	0.311347	2.549103	0.0117
D11	-3.42639	9.163221	-0.373928	0.7089
D12	-3.13416	9.172640	-0.341686	0.7330
D13	-2.82105	9.109063	-0.309697	0.7572
D14	-2.53641	9.177331	-0.276378	0.7826
D15	-2.77457	9.182462	-0.302159	0.7629

Table 5.5: Continued

Parameter	Estimate	Standard Error	$t-$ Statistic	$\mathcal{P}-$ Value
D16	-4.5633	9.098387	-0.501551	0.6167
D17	-4.07649	9.146894	-0.445670	0.6564
D18	-2.76848	9.182853	-0.301483	0.7634
D19	-2.65625	9.183359	-0.289246	0.7728
D110	-1.76348	9.166892	-0.192375	0.8477
D111	-3.9572	9.174924	-0.431306	0.6668
D112	-4.47055	9.103826	-0.491062	0.6240
D113	-2.52541	9.190418	-0.274787	0.7838
D114	-3.21839	9.177458	-0.350685	0.7263
D115	-2.02431	9.192661	-0.220209	0.8260
D116	-1.473201	9.229895	-0.159612	0.8734
D21	0.029418	0.018880	1.558167	0.1211
D22	0.019456	0.024038	0.809398	0.4195
D23	-0.047389	0.037386	-1.267535	0.2068
D24	0.026072	0.017887	1.457604	0.1469
D25	0.040910	0.019788	2.067357	0.0403
D26	0.059816	0.032373	1.847687	0.0665
D27	-0.003025	0.027982	-0.108123	0.9140
D28	0.071756	0.027616	2.598340	0.0102
D29	-0.005745	0.017749	-0.323674	0.7466
D210	-0.047618	0.026496	-1.797186	0.0742
D211	0.078194	0.022565	3.465280	0.0007
D212	0.090844	0.028117	3.230970	0.0015

Table 5.5: Continued

Parameter	Estimate	Standard Error	$t-$ Statistic	$\mathcal{P}-$ Value
D213	0.056833	0.040103	1.417179	0.1584
D214	0.023688	0.020110	1.177878	0.2406
D215	-0.036376	0.025489	-1.427122	0.1555
D216	0.001021	0.024055	0.042444	0.9662
D31	0.002290	0.001069	2.142908	0.0336
D32	0.001996	0.001565	1.275059	0.2041
D33	0.004283	0.001881	2.276240	0.0241
D34	0.001192	0.001291	0.923179	0.3573
D35	-0.000656	0.001138	-0.576811	0.5649
D36	0.000719	0.001379	0.521603	0.6027
D37	0.004300	0.001252	3.434711	0.0008
D38	-0.001519	0.001388	-1.094964	0.2752
D39	0.003094	0.001233	2.509678	0.0131
D310	0.004169	0.001436	2.903968	0.0042
D311	-0.000215	0.001173	-0.183379	0.8547
D312	0.000340	0.001313	0.259119	0.7959
D313	-0.002679	0.002185	-1.226083	0.2219
D314	0.001288	0.001128	1.142257	0.2550
D315	0.002646	0.001187	2.230367	0.0271
D316	0.001102	0.001070	1.029974	0.3046
$R^2 = 0.987$	$\mathcal{F}-$ Statistic = 203.351		$\mathcal{D.W}-$ Statistic = 1.748	

Table 5.6: Average cost frontier parameter estimates

[Translog specification and random coefficients approach]

Parameter	Estimate	Standard Error	$t-$ Statistic	$\mathcal{P}-$ Value
α_y	0.664248	0.292498	2.271	0.0232
α_l	0.280834	0.002900	96.822	0.0000
α_c	-5.546553	0.534293	-10.381	0.0000
α_f	-0.917064	0.361028	-2.540	0.0111
α_{yy}	-0.111687	0.030792	-3.627	0.0003
α_{ll}	0.179944	0.004544	39.597	0.0000
α_{cc}	-1.619119	0.153184	-10.570	0.0000
α_{ff}	0.604774	0.089274	6.774	0.0000
α_{yl}	–	–	–	–
α_{yc}	–	–	–	–
α_{yf}	-0.190337	0.023339	-8.155	0.0000
α_{lc}	–	–	–	–
α_{lf}	–	–	–	–
α_{cf}	–	–	–	–
δ_{01}	-5.443517	782.27939	-0.007	0.9944
δ_{02}	-0.012050	-0.067567	-0.178	0.8584
δ_{03}	-0.003890	-0.003930	0.990	0.3223

Table 5.7: Predictions of the individual random coefficient vectors [Translog]

Company no. \ Parameter	δ_{i1}	δ_{i2}	δ_{i3}
1	132.181	-0.01457	0.00232
2	114.916	-0.01388	0.005501
3	-144.618	-0.14875	0.010353
4	-65.5595	0.074354	0.000976
5	-196.798	-0.07158	0.009165
6	423.256	-0.03949	0.005531
7	-2165.71	0.383493	-0.00937
8	-982.568	0.049235	0.001909
9	639.338	0.106077	-0.01162
10	433.411	-0.02841	-0.00306
11	-12.1358	0.011583	0.003823
12	-82.0388	-0.11465	0.007523
13	187.672	-0.00454	0.00016
14	-346.55	0.211586	-0.00247
15	-0.07834	0.134209	-0.00679
16	1439.12	-0.00726	0.008888

Table 5.8: Economies of scale ordered by the size of the companies

Number of Company	Size of the Company	Economies of Scale
6	566	-1.207
7	660	-1.098
12	767	-1.180
11	1194	-1.132
14	1405	-1.089
2	1435	-1.093
1	1542	-1.104
3	2256	-0.971
5	2369	-1.036
4	3064	-0.949
8	3067	-0.950
13	3740	-0.902
9	4122	-0.873
15	4818	-0.894
10	6854	-0.932
16	15520	-0.758

Table 5.9: Mann–Whitney and Kolmogorov–Smirnov test results [size differences]

Mann-Whitney Test

Ranks

	Grouping	N	Mean Rank	Sum of Ranks
Overall Period Economies of Scale	1	5	3.00	15.00
	2	5	8.00	40.00
	Total	10		

Test Statistics[b]

	Overall Period Economies of Scale
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-2.611
Asymp. Sig. (2-tailed)	.009
Exact Sig. [2*(1-tailed Sig.)]	.008[a]

a. Not corrected for ties.

b. Grouping Variable: Grouping

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	Grouping	N
Overall Period Economies of Scale	1	5
	2	5
	Total	10

Test Statistics[a]

		Overall Period Economies of Scale
Most Extreme Differences	Absolute	1.000
	Positive	1.000
	Negative	.000
Kolmogorov-Smirnov Z		1.581
Asymp. Sig. (2-tailed)		.013

a. Grouping Variable: Grouping

Table 5.10: Variations of $\mathfrak{ES}$

Number of Company	Pre–Reform	Post–Reform
1	-1.160	-1.072
2	-1.229	-1.016
3	-1.072	-0.915
4	-1.069	-0.882
5	-1.128	-0.985
6	-1.307	-1.151
7	-1.166	-1.059
8	-1.054	-0.892
9	-0.985	-0.810
10	-1.030	-0.877
11	-1.254	-1.064
12	-1.289	-1.119
13	-1.010	-0.841
14	-1.192	-1.031
15	-1.042	-0.812
16	-0.801	-0.733
All Companies	-1.112	-0.954

Table 5.11: Wilcoxon signed ranks and sign test results [reform effects]

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
POST - PRE	Negative Ranks	0[a]	.00	.00
	Positive Ranks	16[b]	8.50	136.00
	Ties	0[c]		
	Total	16		

a. POST < PRE

b. POST > PRE

c. PRE = POST

Test Statistics[b]

	POST - PRE
Z	-3.516[a]
Asymp. Sig. (2-tailed)	.000

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Sign Test

Frequencies

		N
POST - PRE	Negative Differences[a]	0
	Positive Differences[b]	16
	Ties[c]	0
	Total	16

a. POST < PRE

b. POST > PRE

c. PRE = POST

Test Statistics[b]

	POST - PRE
Exact Sig. (2-tailed)	.000[a]

a. Binomial distribution used.

b. Sign Test

Table 5.12: Annual cost efficiency levels (%) of the individual companies

Number of Company	1989_1990	1990_1991	1991_1992	1992_1993	1993_1994	1994_1995	1995_1996	1996_1997	1997_1998	1998_1999	1999_2000	2000_2001	2001_2002	2002_2003
1	33.02	33.88	34.65	35.33	35.91	36.38	36.75	37	37.14	37.16	37.06	36.85	36.52	36.09
2	24.91	25.83	26.73	27.58	28.39	29.14	29.84	30.48	31.06	31.56	31.99	32.35	32.62	32.81
3	19.43	21.39	23.39	25.4	27.38	29.31	31.15	32.87	34.44	35.82	37	37.95	38.64	39.07
4	13.62	14.07	14.52	14.96	15.41	15.86	16.3	16.74	17.18	17.61	18.03	18.45	18.86	19.26
5	17.06	17.46	17.91	18.43	19.02	19.68	20.41	21.24	22.15	23.17	24.31	25.57	26.97	28.52
6	100	100	100	100	100	100	100	100	100	100	100	100	100	100
7	65.21	68.7	71.86	74.62	76.94	78.77	80.06	80.79	80.95	80.53	79.54	78.01	75.95	73.42
8	16.46	16.37	16.36	16.42	16.55	16.76	17.05	17.43	17.89	18.44	19.1	19.87	20.77	21.8
9	15.82	16.77	17.7	18.59	19.42	20.21	20.92	21.55	22.1	22.56	22.92	23.17	23.31	23.35
10	6.75	7.44	8.14	8.85	9.55	10.23	10.9	11.52	12.1	12.61	13.06	13.43	13.72	13.92
11	53.6	52.78	52.06	51.44	50.93	50.52	50.21	49.99	49.87	49.83	49.9	50.05	50.3	50.64
12	88.39	85.79	83.32	80.99	78.79	76.7	74.72	72.85	71.08	69.41	67.83	66.33	64.92	63.58
13	13.11	13.29	13.56	13.92	14.4	14.99	15.72	16.59	17.63	18.86	20.31	22.03	24.05	26.44
14	27	27.95	28.89	29.83	30.77	31.71	32.63	33.54	34.44	35.33	36.19	37.03	37.86	38.65
15	8.67	9.5	10.35	11.25	12.17	13.12	14.08	15.07	16.05	17.04	18.01	18.97	19.91	20.8
16	4.82	5.11	5.41	5.72	6.05	6.39	6.74	7.11	7.49	7.88	8.29	8.72	9.16	9.61

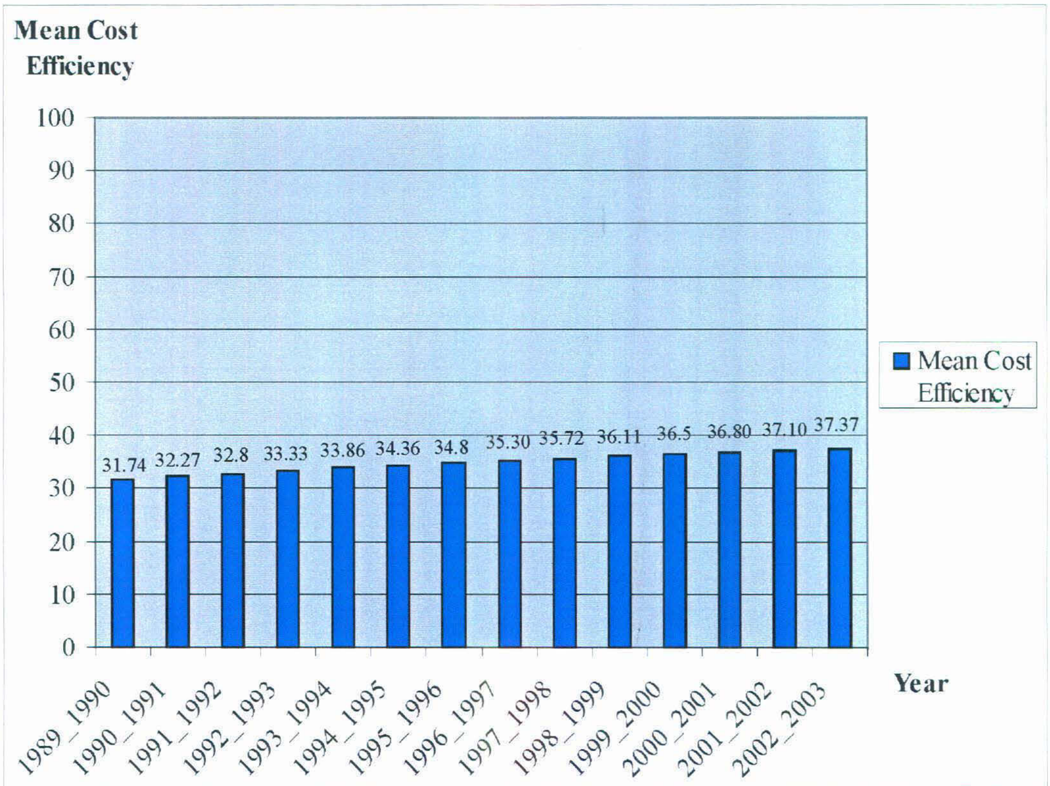
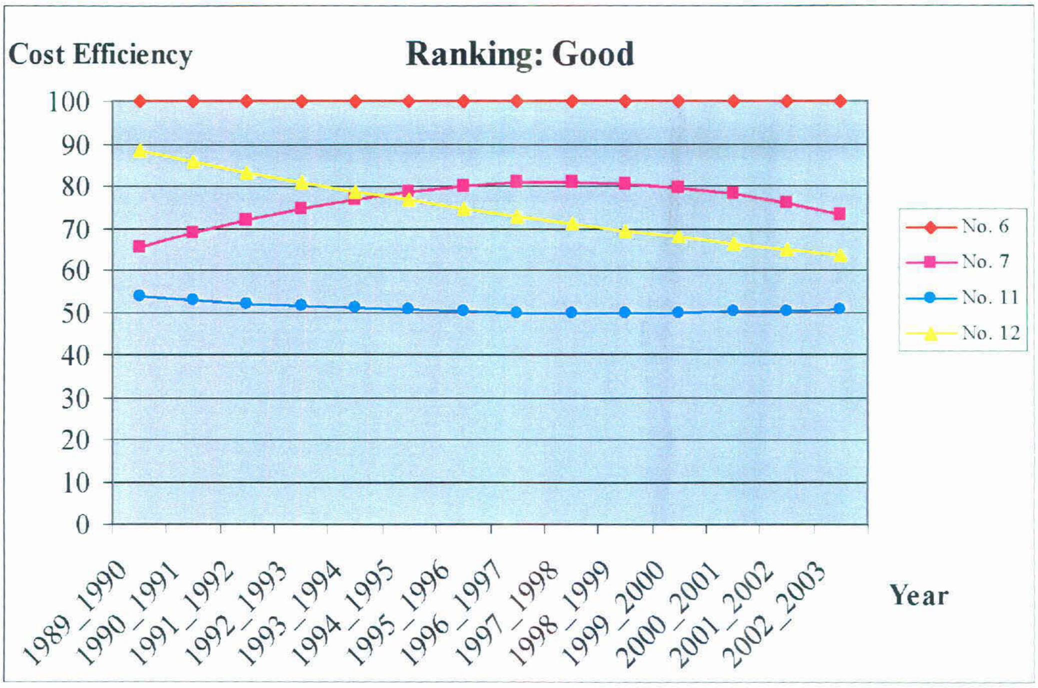


Figure 5.1: Plot of mean cost efficiency levels of companies over time



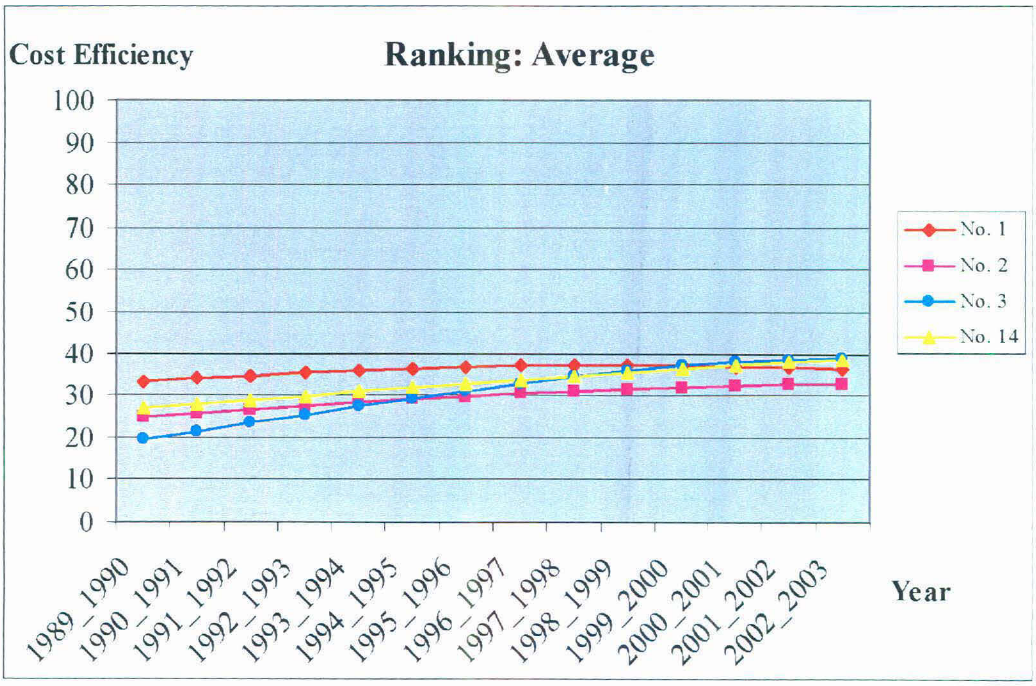
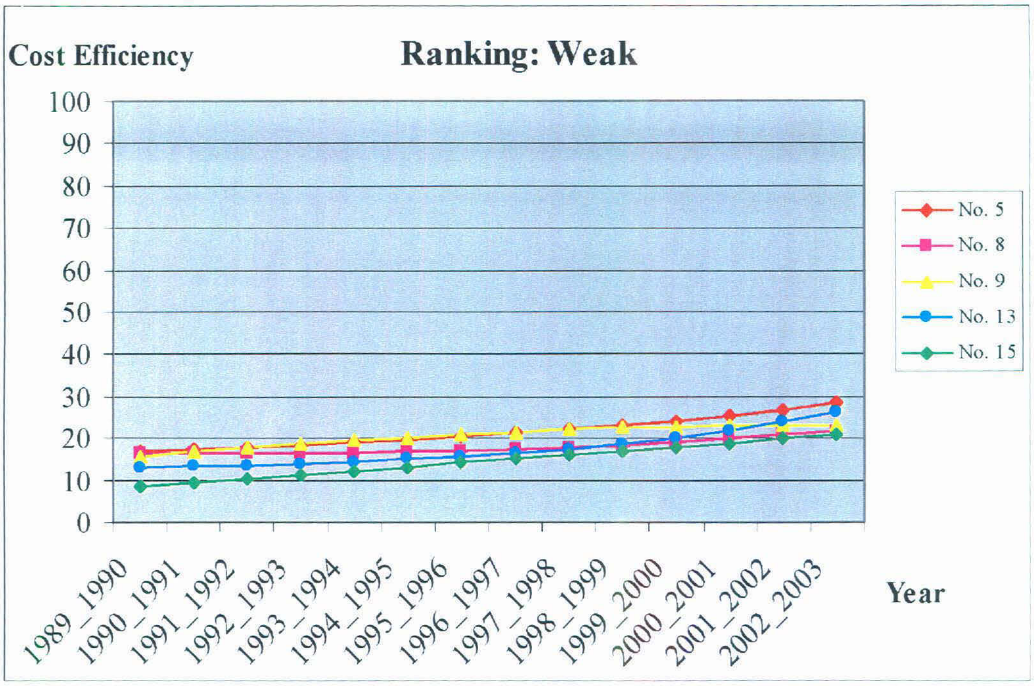


Figure 5.2: Plots of cost efficiency levels of companies over time



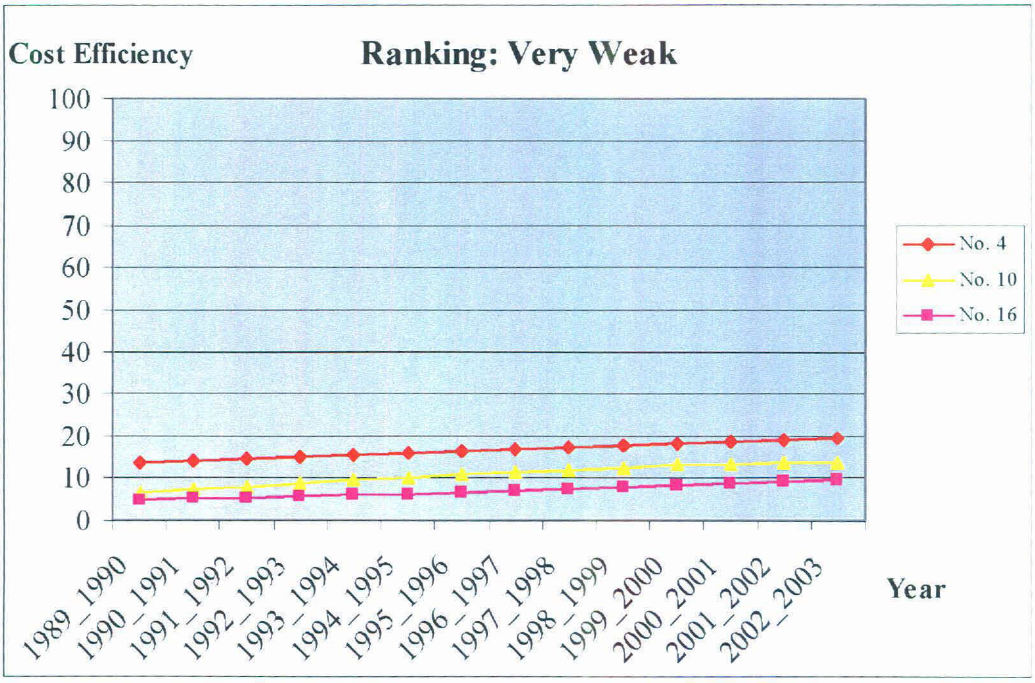


Figure 5.2: Continued

Table 5.13: Calculated t–values for companies

Number of Company	t–value
1	-40.20
2	-28.97
3	-10.69
4	-68.77
5	-28.92
6	–
7	20.16
8	-66.66
9	-42.89
10	-60.48
11	2.73
12	11.55
13	-28.4
14	-16.87
15	-33.36
16	-104.2

Table 5.14: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 1]

Mann-Whitney Test

Ranks

	T1	N	Mean Rank	Sum of Ranks
CEIT1	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT1
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T1

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T1	N
CEIT1	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT1
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T1

Table 5.15: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 2]

Mann-Whitney Test

Ranks

	T2	N	Mean Rank	Sum of Ranks
CEIT2	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT2
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T2

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T2	N
CEIT2	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT2
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T2

Table 5.16: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 3]

Mann-Whitney Test

Ranks

	T3	N	Mean Rank	Sum of Ranks
CEIT3	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT3
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T3

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T3	N
CEIT3	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT3
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T3

Table 5.17: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 4]

Mann-Whitney Test

Ranks

	T4	N	Mean Rank	Sum of Ranks
CEIT4	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT4
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T4

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T4	N
CEIT4	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT4
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T4

Table 5.18: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 5]

Mann-Whitney Test

Ranks

	T5	N	Mean Rank	Sum of Ranks
CEIT5	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT5
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T5

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T5	N
CEIT5	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT5
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T5

Table 5.19: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 6]

Mann-Whitney Test

Ranks

	T6	N	Mean Rank	Sum of Ranks
CEIT6	1	5	7.50	37.50
	2	9	7.50	67.50
	Total	14		

Test Statistics[b]

	CEIT6
Mann-Whitney U	22.500
Wilcoxon W	67.500
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000[a]

a. Not corrected for ties.

b. Grouping Variable: T6

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T6	N
CEIT6	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT6
Most Extreme Differences	Absolute	.000
	Positive	.000
	Negative	.000
Kolmogorov-Smirnov Z		.000
Asymp. Sig. (2-tailed)		1.000

a. Grouping Variable: T6

Table 5.20: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 7]

Mann-Whitney Test

Ranks

	T7	N	Mean Rank	Sum of Ranks
CEIT7	1	5	3.60	18.00
	2	9	9.67	87.00
	Total	14		

Test Statistics[b]

	CEIT7
Mann-Whitney U	3.000
Wilcoxon W	18.000
Z	-2.600
Asymp. Sig. (2-tailed)	.009
Exact Sig. [2*(1-tailed Sig.)]	.007[a]

a. Not corrected for ties.

b. Grouping Variable: T7

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T7	N
CEIT7	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT7
Most Extreme Differences	Absolute	.778
	Positive	.000
	Negative	-.778
Kolmogorov-Smirnov Z		1.394
Asymp. Sig. (2-tailed)		.041

a. Grouping Variable: T7

Table 5.21: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 8]

Mann-Whitney Test

Ranks

	T8	N	Mean Rank	Sum of Ranks
CEIT8	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT8
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T8

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T8	N
CEIT8	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT8
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T8

Table 5.22: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 9]

Mann-Whitney Test

Ranks

	T9	N	Mean Rank	Sum of Ranks
CEIT9	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT9
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T9

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T9	N
CEIT9	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT9
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T9

Table 5.23: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 10]

Mann-Whitney Test

Ranks

	T10	N	Mean Rank	Sum of Ranks
CEIT10	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT10
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T10

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T10	N
CEIT10	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT10
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T10

Table 5.24: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 11]

Mann-Whitney Test

Ranks

	T11	N	Mean Rank	Sum of Ranks
CEIT11	1	5	12.00	60.00
	2	9	5.00	45.00
	Total	14		

Test Statistics[b]

	CEIT11
Mann-Whitney U	.000
Wilcoxon W	45.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T11

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T11	N
CEIT11	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT11
Most Extreme Differences	Absolute	1.000
	Positive	1.000
	Negative	.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T11

Table 5.25: Mann–Whitney and Kolmogorov–Smirnov test results company no. 12]

Mann-Whitney Test

Ranks

	T12	N	Mean Rank	Sum of Ranks
CEIT12	1	5	12.00	60.00
	2	9	5.00	45.00
	Total	14		

Test Statistics[b]

	CEIT12
Mann-Whitney U	.000
Wilcoxon W	45.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T12

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T12	N
CEIT12	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT12
Most Extreme Differences	Absolute	1.000
	Positive	1.000
	Negative	.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T12

Table 5.26: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 13]

Mann-Whitney Test

Ranks

	T13	N	Mean Rank	Sum of Ranks
CEIT13	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT13
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T13

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T13	N
CEIT13	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT13
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T13

Table 5.27: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 14]

Mann-Whitney Test

Ranks

	T14	N	Mean Rank	Sum of Ranks
CEIT14	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT14
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T14

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T14	N
CEIT14	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT14
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T14

Table 5.28: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 15]

Mann-Whitney Test

Ranks

	T15	N	Mean Rank	Sum of Ranks
CEIT15	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT15
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T15

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T15	N
CEIT15	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT15
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T15

Table 5.29: Mann–Whitney and Kolmogorov–Smirnov test results [company no. 16]

Mann-Whitney Test

Ranks

	T16	N	Mean Rank	Sum of Ranks
CEIT16	1	5	3.00	15.00
	2	9	10.00	90.00
	Total	14		

Test Statistics[b]

	CEIT16
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-3.000
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.001[a]

a. Not corrected for ties.

b. Grouping Variable: T16

Two-Sample Kolmogorov-Smirnov Test

Frequencies

	T16	N
CEIT16	1	5
	2	9
	Total	14

Test Statistics[a]

		CEIT16
Most Extreme Differences	Absolute	1.000
	Positive	.000
	Negative	-1.000
Kolmogorov-Smirnov Z		1.793
Asymp. Sig. (2-tailed)		.003

a. Grouping Variable: T16

Chapter 6

Summary and Conclusions

6-1- Summary

Since the late 1980s, a wave of reform has transformed the institutional and organizational framework of the electricity industry in many countries. In Iran, too, in line with the government policy to reduce government's undertaking and to enhance economic efficiency, the MOE has reformed the organizational structure of the state owned companies affiliated to the ministry. One of these reforms was the separation of distribution activity from RECs in 1993. The objective of this thesis is to analyze the cost structure of 16 Iranian RECs regarding their cost efficiency, over the period 1989–2002, and to examine the impact of structural reform in RECs through the variation of their cost efficiency, and to judge whether the structural reform in RECs has improved their performance or not.

In the first chapter we described the importance of the power sector in a developing economy such as Iran. We also defined the concept of industrial efficiency and its components. A brief history of the developments in the measurement of "efficiency" was also given. Farrell (1957) introduced for the first time the frontier concept in production function and described how the efficiency of firms can be determined using frontier functions. Since then, the frontier concept has been used frequently in the measurement of industrial efficiency. Finally we described different methods for the estimation of frontier production and cost functions.

The second chapter summarizes the existing theoretical literature on the methods of measurement of components of industrial efficiency [i.e. technical and allocative efficiencies] via frontier production and cost functions. A brief discussion of existing empirical studies of the measurement of cost efficiency for electricity distribution throughout the world was also given.

The third chapter discusses the model used in this thesis. The specification of the model was presented and constraints imposed, such as, linear homogeneity of average cost function in input prices were described. The extraction of the economies of scale parameter was also described.

Chapter four presented a brief history of the power industry in Iran, and its current structure. The distinguishing characteristics of the Iranian power market were described viz. the installed capacity, amount of power generated, fuel utilized, transmission and distribution network, and electricity consumption. This chapter also presented the data used in the thesis.

Chapter five presented the empirical results. In addition to the presentation of the estimated models, the values of economies of scale and annual cost efficiency for each company were calculated based on the results of the translog specification model estimated by fixed effects approach, chosen as the best model. Then the companies were categorized into four categories; good, average, weak, and very weak, according to their cost efficiency levels. Finally, we tested our three hypotheses:

1. There is no significant difference in efficiency levels of different Iranian RECs.
2. The majority of the RECs have operated at cost efficiency levels of less than fifty percent throughout the sample period.

3. The efficiency level of RECs has improved during the period under consideration, as a result of the structural reform measures undertaken.

6-2- Findings

The average cost frontier model is applied to the panel data set for the 16 Iranian RECs during the time period 1989–2002 to estimate time–varying cost efficiency of these companies. Our main findings are:

- We found increasing returns to scale for all companies in our sample including small, medium, and large ones, where the larger companies are better off than smaller ones from the economies of scale point of view. This implies that majority of the companies are too small and do not reach the minimum efficient scale. The problem of scale inefficiency could be solved through mergers of small companies. Also we found that, for all companies, the magnitude of economies of scale has improved at post–reform time period relative to pre–reform time period.
- Twelve of the sixteen companies have operated with cost efficiency levels less than forty percent.
- We found that the companies exhibit variation in their cost efficiency levels over the time period, i.e. time–variant cost efficiency. There are statistically significant differences in the companies' performances between the pre–reform and the post–reform periods. The direction of the changes in cost efficiency has been positive for most of the companies. This suggests that the efficiency levels of companies have increased over the period considered, which in turn suggests that structural reform has improved the efficiency of the majority of RECs in our sample.

Thus it seems that the industry needs reorganization. Firm size and activity both need to be adjusted to allow firms to enjoy the benefits of economies of scale and specialization. Since a majority of the companies are too small and do not reach the minimum efficient scale, they should be merged with other companies to enable them to operate at optimal size. Also firms involved in electricity distribution should be completely separated from firms responsible for transmission activity as the nature of the two activities is disparate. They require different kinds of equipment and organization on the part of the firms providing these services. Moreover, many of the transmission and distribution equipment and installations already in operation are very old and inefficient. They should be replaced or upgraded as required. This would improve both efficiency and reliability of the transmission and distribution networks.

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