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A novel power sector restructuring model based on Data Envelopment Analysis (DEA)

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ABSTRACT

This paper evaluates relative performance of the Electric Distribution Divisions (EDDs) of an Indian State, Uttarakhand for the period 2005–2008, through application of Data Envelopment Analysis (DEA). To improve the operational efficiency of EDDs, Uttarakhand Power Corporation Limited (UPCL) disintegrated several divisions into smaller ones over this period. However, microlevel examination revealed the ineffectiveness of this process during the period of analysis. Therefore, in the present work an alternative reorganization model for selecting the EDDs for disintegration and for selecting the optimum scale for disintegration is proposed based on the efficiency analysis of 2007. The model is verified by comparing the mean efficiency score of the EDDs derived using proposed model with that of existing ones. It is found that overall efficiency of proposed model is higher than the existing system. Reliability of the overall efficient EDDs is also examined to check the robustness of the CCR result for the same year. This study gives an assessment of UPCL to monitor and diagnose the changes in the efficiency of EDDs, so it will help regulators to formulate more effective policies on deregulation and disintegration and to determine the appropriate efficiency improvement measures when imposing yardstick competition on electric utilities.

1. Introduction

Electric utilities around the globe have made momentous transformation in the segmentation and privatization processes as energy is a motivational force for economic activity [1,2]. Moreover, the continuing liberalization and interconnection of energy markets thereby requires the contemplation of multiple interdependencies with other markets [3,4]. In order to regulate the electric distribution utilities, most of the countries have adapted benchmark regulations, either through application of the model firm or efficient firm concept. It corresponds to a utility whose investments are economically adapted to demand and operates under an optimal operational scale. Data Envelopment Analysis (DEA) has been established as one of the most advanced benchmarking methodology and practicable approach for evaluating relative efficiency of homogenous Decision Making Units (DMUs) [5]. DEA efficiency measurement technique is comparative in nature [6]. Presently it has grown to be an indispensable tool in the areas of operations research and management science. It has been applied to a wide range of managerial and economic problems both in public and private sectors [7,8]. There are number of articles [9–15] that employed DEA in the assessment of Electricity Distribution utilities. However, application of DEA for performance evaluation of electric utilities has been very limited in India. For example, Chitkara [16] applied DEA to evaluate the operational inefficiencies of generating units. He considered operational performance statistics of all coal based generating units belonging to National Thermal Power Corporation of India over the period 1991–1995. Thakur et al. [17] presented a DEA framework for assessing comparative performances of State Owned Electric Utilities (SOEUs), which are involved in generation, transmission and distribution of electricity in India. It was found that the bigger utilities display greater inefficiencies and have distinct scale inefficiencies.

In the present work DEA is applied to evaluate the relative efficiencies of the Electricity Distribution Divisions (EDDs) of the Uttarakhand Power Corporation Limited (UPCL), India for the period 2005–2008. For productive restructuring, UPCL needs an effective benchmarking model to assess the relative performance of EDDs that is able to accommodate the different types of inputs and outputs which are inherent in such systems simultaneously. Thereafter, performance of EDDs in terms of overall efficiency, technical efficiency and scale efficiency is explored for 2007. Reliability of the Constant Return to Scale (CRS) frontier divisions is examined for the same year.

Since UPCL is still in the process of restructuring the divisions through disintegration to improve the operational efficiency, hence it is relevant in practical context to investigate the reorganization of

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Nomenclature

DEA	Data Envelopment Analysis
UPCL	Uttarakhand Power Corporation Limited
EDD	Electricity Distribution Division
EDC	Electricity Distribution Circle
CCR	Charnes Cooper and Rhodes
BCC	Banker Charnes and Cooper
DMUs	Decision Making Units
NIRS	Non-Increasing Return to Scale
RTS	Return to Scale
VRS	Variable Return to Scale
CRS	Constant Return to Scale
DRS	Decreasing Return to Scale
IRS	Increasing Return to Scale
θ_0	relative efficiency score of particular DMU_0
y_{rj}	amount of output r produced by DMU_j
x_{ij}	amount of input i utilized by DMU_j
v_r	weight given to the output r
u_i	weight given to the input i
n	number of DMUs
m	number of inputs
s	number of outputs
λ_j	weight in the dual model for the inputs and outputs of the n units
$\hat{x}_{io}$	ith input change for the efficient DMU_O
$\hat{y}_{ro}$	rth output change for the efficient DMU_0
$\hat{x}_{ij}$	ith input change for the other inefficient DMU_j
$\hat{y}_{rj}$	rth output change for other inefficient DMU_j
I and O	input and output subsets respectively
α^*, β^*	optimal values

the divisions and propose some reorganization alternatives. Based on the efficiency analysis, this study investigates reorganization of inefficient EDDs to improve the operational efficiency of divisions.

This paper is organized as follows. After the introductory section, methodology for the DEA analysis and reliability has been discussed in Section 2. Section 3 discusses the selection of input and output and Section 4 includes results and discussion. Reorganization for the inefficient EDDs is presented in Section 5. In Section 6 verification of the proposed model is presented. Section 7 concludes with the findings of this paper.

2. Methodology

2.1. Data Envelopment Analysis

DEA is a nonparametric approach for generating the efficiency frontier for the DMUs. It is a linear programming method that deals with the multiple inputs and multiple outputs without pre-assigned weights and without imposing any functional form on the relationships between variables [5].

In mathematical terms the input-oriented CCR model is given as

$$\mathrm{Max}\theta_0 = \frac{\sum_{r=1}^{s} v_r y_{ro}}{\sum_{i=1}^{m} u_i x_{io}} \tag{1}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} v_r y_{rj}}{\sum_{i=1}^{m} u_i x_{ij}} \leqslant 1, \quad j = 1,\ldots,n$$
$$u_i, v_r \geqslant 0, \quad \forall\, i, r$$

Instead of the fractional form of Eq. (1), efficiency score is usually calculated based on its linear form with dual problem as:

$$\mathrm{Min}\theta_0$$
$$\text{s.t.} \sum_{j=1}^{n} \lambda_j x_{ij} - \theta_0 x_{io} \leqslant 0, \quad i = 1,\ldots,m$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{ro} \geqslant 0, \quad r = 1,\ldots,s \tag{2}$$
$$\lambda_j \geqslant 0, \quad j = 1,\ldots,n$$

According to Banker et al. [18], when the *DMUs* do not perform at optimal scale, the CCR model can be modified to account for VRS conditions by adding a convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ to Eq. (2).

Further to investigate Return to Scale (RTS) properties of DMUs, Non-Increasing Return to Scale (NIRS) condition i.e. $\sum_{j=1}^{n} \lambda_j \leqslant 1$ is appended to Eq. (2).

To illustrate different assumptions of DEA model, it has been considered case of single input and output as depicted in Fig. 1. Line OC from the origin represents the CRS frontier.

The addition of equality constraint as $\sum_{j=1}^{n} \lambda_j = 1$ in CRS DEA model ensures that *DMUs* operating at different scales are recognized as efficient and this model is known as VRS model. The piece wise linear frontier ABCD represents the VRS frontier line. It can be noticed that DMU_C is identified as efficient in CRS model, whereas *DMUs B*, *C*, and *D* lie on the VRS frontier. Thus, DMU_B and DMU_D are identified as inefficient due to their scale efficiency. DMU_E is inefficient in both the assumptions and its efficiency can be given as: overall efficiency (OE) = HG/HE, technical efficiency (TE) = HF/HE and scale efficiency is the ratio of OE/TE i.e. HG/HF. The minimum and maximum value of these efficiencies is considered in between zero and one respectively.

The NIRS condition of DEA frontier is also plotted in Fig. 1. The return to scale for test DMU_O can be determined by observing NIRS and VRS efficiency score. For example, in case of DMU_E, both the scores are unequal, thus DMU_E is at increasing return to scale condition. And for the case of DMU_J, both the efficiency scores are equal, thus DMU_J is at decreasing return to scale condition.

2.2. Reliability

The deterministic approach of DEA is used for reliability analysis. Skepticism about its stability and the extent of perturbation in

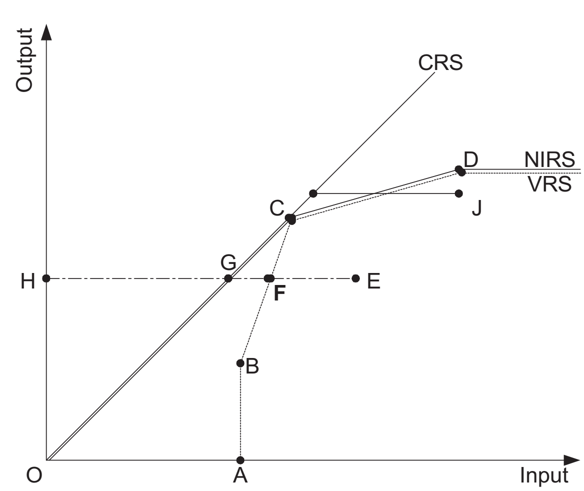

Fig. 1. Graphical illustration of different models of DEA (input-oriented DEA using a single input to produce a single output).