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Slack based measure of efficiencies of public sector hospitals in Uttarakhand (India)

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Abstract

Purpose – The purpose of this paper is to determine the relative efficiencies of public sector hospitals in Uttarakhand, India.

Design/methodology/approach – The study use data of public hospitals collected from Directorate of Medical Health and Family Welfare, Government of Uttarakhand, Dehradun, India for the year 2011. The cross-sectional data analyses are carried out by applying data envelopment analysis (DEA) based slack based model.

Findings – The analysis found that out of total 36 hospitals only ten hospitals are relatively overall technical efficient. The average overall technical efficiency 54.10 per cent indicates that an average hospital has the scope of producing the outputs with the inputs 45.90 per cent lesser than their existing levels. The slack analysis results show that on average 12.57 per cent of beds, 13.16 per cent of doctors, 14.04 per cent of paramedical staff can be reduced and 17.53 per cent of out-door patients, 66.55 per cent of in-door patients, 208.23 per cent of major surgeries, 110.73 per cent of minor surgeries can be expanded if all the inefficient hospitals operate at the level of efficient hospitals.

Originality/value – The present study is undertaken to measure the relative efficiencies of public sector hospitals in Uttarakhand. There is dearth of studies being done on Indian healthcare sector and this study will help to utilize healthcare resources efficiently for formulating policy implications for public hospitals in Uttarakhand. For the robustness of DEA results, Jackknifing analysis is also conducted.

Keywords Efficiency, Public hospitals, Data envelopment analysis (DEA), Jackknifing analysis, SBM model, Uttarakhand

Paper type Research paper

1. Introduction

India is a developing country, which has made significant progress in the past several decades in improving health and well-being of its people. However, much progress remains to be achieved in increasing literacy, public awareness and providing quality healthcare services to the general masses. Indian Government is still under increasing pressure to improve the efficiency of healthcare system. The increasing resources crunch, coupled with the inefficient use of funds, has put the public sector in a position of comparative disadvantage. It is observed that public health investment over the years has been comparatively low. Its percentage in terms of gross domestic product (GDP) has declined from 1.30 per cent in 1990 to 0.90 per cent in 1999. However, it has increased to 1.25 per cent in 2007 and further to 1.30 per cent in 2011. The aggregate expenditure on

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the health sector in India is 5.2 per cent of the GDP of which public sector constitutes only 17 per cent (Government of India 2011-2012, Economic Survey). Public sector hospitals, which provide un-priced services outside the market mechanism, bristle with the conceptual difficulty of such a precise delimitation of inputs and outputs. The problem becomes more acute in the absence of relevant data pertaining to the inputs and outputs. As such, this difficulty is partially by-passed by some performance measurement techniques which do provide scope for testing alternative input and output definitions using different combinations of inputs and outputs. One approach towards this end has been to examine the performance status of public hospitals on the basis of which policy decisions on the future course of action could be taken. It is in this context that this paper applies data envelopment analysis (DEA) to measure the technical and scale efficiencies of public sector hospitals of Uttarakhand with a view to identify inefficient hospitals and input reduction required to make them efficient.

DEA is a linear programming based non-parametric technique for evaluating the relative efficiencies of homogeneous decision making units (DMUs) (Ramanathan, 2003) which utilize multiple inputs and multiple outputs. DEA, initially developed by Charnes, Cooper and Rhodes (Charnes *et al.*, 1978), is basically a generalization of Farrell's (1957) work on technical efficiency. It constructs a non-parametric peace-wise frontier over the data and using this frontier it computes a maximal performance measure for each DMU relative to that of all other DMUs with the restriction that each DMU lies on the efficient frontier or is enveloped by the efficiency frontier. The DMUs which lies on the efficiency frontier and attains the efficiency value equal to 1 are called efficient DMUs. On the other hand, the DMUs which are enveloped by the frontier and attain an efficiency value between 0 and 1 are called inefficient DMUs. Based on the original CCR-DEA model (Charnes *et al.*, 1978), various theoretical extensions have been developed.

A more flexible model developed by Banker *et al.* (1984), called BCC model relaxes the assumption of constant returns to scale (CRS) to variable returns to scale (VRS). These models are basic DEA models. The models in DEA are categorized as radial model and non-radial models. A radial model deals with proportional changes of inputs or outputs. The CCR model (Charnes *et al.*, 1978), the first DEA model, is a radial model and evaluates the CCR efficiency of a DMU which reflects the preoperational input (output) reduction (augmentation) rate that is common to all inputs (outputs). There are two major drawbacks of this model. First one is that in real life situation, not all inputs (outputs) act in a proportional way and second one is that while reporting the efficiency scores is neglects the input-output slacks. Therefore the radial models may mislead the decisions of those decision makers who select the efficiency score as the only index for measuring the performance of their DMUs. On the other hand the non-radial model put aside the assumption of proportionate change in inputs and outputs, and deals directly with slacks. Therefore, this paper applies a non-radial model named slack based model (SBM) developed (Tone, 2001) to assess the efficiency of public sector hospitals in Uttarakhand State of India.

As Uttarakhand is a newly established state and situated mostly in hilly areas, there is a necessity to examine the status of the state in all the sectors including healthcare sector. From the establishment of the State, there are no major studies in public health sector. Only a few DEA-based studies relative to efficiency measurement have been conducted in Indian public and private healthcare sectors. Some relevant studies conducted on both the healthcare sectors are reviewed. Agarwal *et al.* (2007) examine the year-wise performance of government sector hospitals of Uttaranchal for the period 2001-2004 using DEA-CCR and BCC output-orientated models. Dash *et al.* (2010) assess the technical efficiencies of district hospitals in Tamil Nadu. Lakshmana (2010) examine a district level analysis on existing healthcare infrastructure for children in Karnataka. Mogha *et al.* (2012) use DEA-CCR and BCC output-oriented models for assessing the performance of 55 private sector hospitals in India for the year 2010. Mogha *et al.* (2014) also assess the year-wise technical and scale efficiencies of Indian private sector hospitals for the six years period from 2004-2005 to 2009-2010. Mogha *et al.* (2014) uses the new slack model to assess the efficiencies and super efficiency scores of 27 public sector hospitals in Uttarakhand, a state of India, for the year 2011. Sheikhzadeh *et al.* (2012) measured technical, scale, allocative and cost efficiencies of public and private hospital services using DEA in East Azerbaijani Province of Iran. Kirigia and Asbu (2013) assessed the technical and scale efficiency (SE) of public community hospitals in Eritrea. Kirigia *et al.* (2008) assess the technical efficiencies under CRS and VRS assumptions of 28 public municipal hospitals in Angola. They also assess the total factor productivity (TFP) of these 28 hospitals for three years period from 2000 to 2002. Ismile (2010) assess the technical efficiencies of Sudan's state level health institutions using DEA-based CCR and BCC models. Jandaghi *et al.* (2010) evaluate the efficiency of Qom public and private hospitals using DEA-based CRS and VRS assumptions. Mirmirani (2008) use DEA to assess the healthcare efficiency in transition economics for the period 1997-2001.

The purpose of this study is to evaluate the performance of public sector hospitals in Uttarakhand by providing a mathematical technique to analyse the efficiency with which service is rendered. This study estimates the relative efficiencies of the hospitals, evaluates the reference set and sets the target for the inefficient hospitals. The paper is organized as follows: Section 2 contains methodology, Section 3 contains empirical results and discussions and Section 4 contains Jackknifing analysis followed by the conclusion in the last.

2. Methodology

This paper measures the overall technical efficiency (OTE), which reflects the ability of a DMU to obtain the maximum outputs from the given set of inputs, pure technical efficiency (PTE), which refers to the proportion of OTE attributed to the efficient conversion of inputs into outputs given the scale size and SE, which measures the impact of scale size on the efficiency scores, of 36 public sector hospitals of the Uttarakhand State.

DEA is a non-parametric linear programming model that estimates the magnitude of departure from efficiency frontiers for each DMU. DEA is chosen over other methods because:

(1) it handles multiple inputs and multiple outputs;

(2) it does not require a prior weights' information;

(3) it does not require any specific assumptions about the fractional form between inputs and outputs;

(4) it emphasizes individual observations rather than statistical estimates;

(5) it is the dynamic analytical decision-making tool that indicates possibilities for improving relative efficiencies;

(6) it uses benchmarking approach to measure DMUs efficiency relative to the other in their group;

(7) it can assist in identifying best practice or efficient and inefficient DMUs within the group; and

(8) the DEA results can allow policy makers to develop policies that can assist the relative inefficient DMUs to improve their performance.

However, the radial CCR model (Charnes *et al.*, 1978), and BCC model (Banker *et al.*, 1984) suffers from one shortcoming; they neglects the slacks in the evaluation of efficiencies. To overcome this shortcoming efficiency scores can be computed using a non-radial and non-oriented model known as "SBM" given by Tone (2001).

2.1 Selection of homogeneous hospitals

We measure OTE of public sector hospitals using the data collected from the Directorate of Medical Health and Family Welfare, Government of Uttarakhand, Dehradun, India (2011). We have selected government hospitals of Uttarakhand, having bed strength 24 or above. As per the availability of data, a total of 36 district hospitals, base hospitals and combined hospitals are selected. Detailed list of selected hospitals is given in the Appendix.

All the hospitals (district, base and combined) selected in this study are of same structure, because all the selected hospitals are of secondary level government funded public hospitals. Since, in a district, there can be only one district hospital in the main centre. It is possible that there can be other secondary level public hospitals in that district which have different names like base hospitals and combined hospitals. So, all the selected hospitals in the study are homogenous.

2.2 Selection of input and output variables

We estimate the efficiency of government sector hospitals of Uttarakhand, using data of 36 hospitals collected from Directorate of Medical Health and Family Welfare, Government of Uttarakhand, Dehradun, India (2011). The data are collected in yearly format, i.e., from January to December for every year. On the basis of input-output variables selected by earlier studies (Table I) and availability of data, this study measures the efficiencies using three input and four output variables.

Keeping in view the variables used in the previous studies and the availability of data, we have taken number of beds, number of doctors and number of paramedical staff (PMS) as input variables. Also, as indicated by Table I, the major services provided by a hospital are out-door and in-door patients. These variables are considered as output variables for the study. We have also considered two case-mix outputs, i.e., number of major and minor surgeries (Grosskopf and Valdmains, 1993). Although all the hospitals are owned by the state government and are similar in nature and structure, there are some minor differences in these hospitals. For example, some district male hospitals do not have maternity department and some district female hospitals do not have dental, orthopedic or eye departments. Therefore, to maintain homogeneity of output measure (variables), only number of major and minor surgery are taken as the case-mix outputs, as the surgical department is common to all the hospitals. Thus, for estimating TFP growth, three inputs, namely, number of beds, number of doctors and number of PMS and four outputs, namely, number of out-door patients, number of indoor patients, number of major surgeries and number of minor surgeries are considered for the study. The thumb rule "The number of DMUs is expected to be larger than twice the sum of inputs and outputs" (Tyagi *et al.*, 2009) is

S. no.	Author's	Inputs	Outputs
1	Osei *et al.* (2005)	Number of doctors, beds, other technical staff and subordinate staff	Number of maternal and child care (MCH), number of child deliveries and number of patients discharged
2	Zere *et al.* (2006)	Total recurrent expenditure, beds and nursing staff	Total outpatient visits and inpatient days
3	Agarwal *et al.* (2007)	Number of beds, number of doctors and number of paramedical staff	Number of out-door patients, number of in-door patients number of major surgery and number of minor surgery
4	Gannon (2008)	Number of beds and full-time equivalent people employed	Number of discharges and deaths, outpatient attendance, and day cases
5	Dash (2009)	Number of beds, number of nursing staff, and number of physicians	Number of inpatients, number of outpatients, and number of surgeries undertaken, emergency cases handled, medico legal cases, and deliveries
6	Tlotlego *et al.* (2010)	Number of clinical staff and number of hospitals beds	Number of outpatient visit and number of inpatient days
7	Pham (2011)	Total number of beds, total number of hospital's personnel including physicians and non-physicians	Outpatient visits, inpatient days and surgical operations performed
8	Nedelea and Fannin (2012)	Total staffed and licensed hospital beds and Full-time equivalent employee	Total hospital admissions, post admission days, total outpatient visits, emergency room visits, outpatient surgeries and total births
9	Sheikhzadeh *et al.* (2012)	Number of physicians, number of nurses, number of medical team having a bachelor degree or above, number of active beds and number of medical team having 14 years diploma or lower + number of non-medical and support staff	Number of emergency patients, number of outpatients, number of inpatients × average daily inpatients' residing
10	El-Seoud (2013)	Number of specialists, number of nurses, number of allied health and number of beds	Number of outpatient, number of patients admissions to hospital, number of laboratory tests, and number of beneficiaries of radiological imaging
11	Kirigia and Asbu (2013)	Number of doctors, number of nurses and midwives, number of laboratory technicians and number of operational beds and cots	Number of outpatient department visits and number of inpatient department discharges
12	Mogha *et al.* (2014)	Number of beds, number of doctors and number of paramedical staff	Number of out-door patients, number of in-door patients number of major surgery and number of minor surgery

Table I. Input-output variables used in the previous studies

applied for the selection of number of hospitals, inputs and outputs. These variables are defined in Table II.

Descriptive statistics of input and output variables are given in Table III. It is clear from the maximum and minimum values of input and output variables, and the value of standard deviations that there is a perceptible variation in the selected inputs and outputs across the hospitals. In some cases, the input used by some hospitals is 17 times more than that used by the other hospital, whereas variation in output produced is very high across the hospitals as discusses earlier.

Table II.
Definition of input and output variables

Variable	Definitions
Inputs	
Number of beds	The total number of beds actually used by the hospital within a year
Number of Doctors	The total number of full-time doctors and nurses employed in the hospital in a year
Number of PMS	The total number of full-time non-medical employees employed by the hospital in a year
Outputs	
Out-door patients	Total number of outpatients who visits to the hospitals within a year without any stay in the hospital
In-door patients	Total number of inpatients stayed in hospital beds and received inpatient services within a year
Major surgeries	Total number of major ambulatory surgical operations of inpatients in a hospital within a year
Minor surgeries	Total outpatients surgeries in a hospital within a year

Table III.
Descriptive Statistics of Inputs and Outputs for the year 2011

	Inputs			Outputs			
	Number of beds	Number of doctors	Number of paramedical staff	Number of out-door patients	Number of in-door patients	Number of major surgery	Number of minor surgery
Max.	402	55	140	715,221	22,111	4,128	2,834
Min.	24	6	11	5,491	485	76	231
Mean	93.667	18.972	39.833	126,792.8	7,221.417	562.944	692.361
SD	66.967	9.284	25.403	122,708.6	5,634.788	738.654	522.973

Correlation analysis also has been worked out to know the relation between input and output variables. Correlation matrix between input and output variables is given in Table IV. It is observed that the outputs have positive correlations with the input variables.

2.3 Selection of the model

Since in the basic CCR and BCC models the efficiency is measured either by changing inputs or by changing outputs, i.e., either input-oriented model or output-oriented model are used for the measurement. When both inputs and outputs can simultaneously be changed, i.e., the firm is able to reduce inputs and augment outputs simultaneously, a non-oriented SBM model is used. It is known as the Additive Model or a SBM and this is based on input and output slacks. This model allows managers to work on both inputs and outputs to achieve efficiency. Generally, in case of public hospitals it is difficult to choose the orientation (input or output) for the evaluation of efficiencies. It is not admirable to reduce input levels or increase output levels regarding public sector hospitals. So, in this study, a non-oriented and non-radial model known as SBM-DEA model has been used (Cooper *et al.*, 1997; Tone, 2001).

2.4 The SBM-DEA model

In order to illustrate the model, let us assume that there are n DMUs ($DMU_j, j=1, 2, \ldots, n$) with m inputs (x_{ij}, $i=1, 2, \ldots, m$) and s outputs (y_{rj}, $r=1, 2, \ldots, s$) for each DMU.

	No. of beds	No. of doctors	No. of PMS	No. of out-door patients	No. of in-door patients	No. of major surgery	No. of minor surgery
No. of beds	1						
No. of doctors	0.876						
	0.000*	1					
No. of PMS	0.900	0.906					
	0.000*	0.000*	1				
No. of out-door	0.873	0.776	0.796				
patients	0.000*	0.000*	0.000*	1			
No. of in-door	0.595	0.559	0.583	0.612			
patients	0.000*	0.000*	0.000*	0.000*	1		
No. of major	0.473	0.492	0.619	0.391	0.477		
surgery	0.004*	0.002*	0.000*	0.018**	0.003*	1	
No. of minor	0.508	0.527	0.629	0.443	0.576	0.959	
surgery	0.002*	0.001*	0.000*	0.007*	0.000*	0.000*	1

Note: *,**Significant at 1 and 5 per cent level, respectively

Table IV. Correlation matrix between inputs and outputs for the year 2011

Let u_i and v_j are the weights corresponding to the ith input and jth output. Then the SBM-DEA model can be described as follows.

Model 1:

$$\left.\begin{array}{l} Min\rho_k = \dfrac{1-(1/m)\sum_{i=1}^{m} s_{ik}^{-}/x_{ik}}{1+(1/s)\sum_{r=1}^{s} s_{rk}^{+}/y_{rk}} \\ \text{subject to :} \\ \displaystyle\sum_{j=1}^{n}\lambda_{jk}x_{ij}+s_{ik}^{-} = x_{ik}, \forall i \\ \displaystyle\sum_{j=1}^{n}\lambda_{jk}y_{rj}-s_{rk}^{+} = y_{rk}, \forall r \\ \lambda_{jk} \geqslant 0, s_{ik}^{-} \geqslant 0, s_{rk}^{+}, \forall i,r,j,k \end{array}\right\}$$

Table V describes the used notations in the model.

We calculate OTE for every sample hospital by using Model 1 for the sample year. The detailed information of SBM-DEA results is given in Table VI.

If the optimal value λ_{jk}^{*} of λ_{jk} is non-zero, then the jth hospital represents the reference set (peers) for the kth hospital and the corresponding optimal value is known as the peer weight of the jth hospital.

In the objective function of Model 1, the numerator value evaluates the mean reduction rate of inputs or input inefficiency of kth hospital. Similarly, the reciprocal of denominator evaluates the mean expansion rate of outputs or output inefficiency of kth hospital. Thus, the value of ρ_k can be interpreted as the product of input and output inefficiencies. This model is known as SBM-CRS model (Tone, 2001).

Symbol	Description
n	Total number of DMUs (hospitals)
m	Total number of inputs
s	Total number of outputs
i	Index of input
r	Index of output
j	Index for DMU
k	Index of specific DMU whose efficiency is being assessed
x_{ik}	Observed amount of the ith input of the kth hospital
y_{rk}	Observed amount of the rth output of the kth hospital
λ_{jk}	Multipliers used for computing linear combinations of inputs and outputs in the assessment of kth hospital
ρ	The efficiency score of a hospital by SBM model
ρ^*	The optimal efficiency score of a hospital by SBM model
s_{ik}^-	Non-negative slack or potential reduction of the ith input for the kth hospital
s_{rk}^+	Non-negative slack or potential increase of the rth output for the kth hospital
s_{ik}^{-*}	Optimal slack to identify an excess utilization of the ith input for the kth hospital
s_{ik}^{-*}	Optimal slack to identify a shortage utilization of the rth output for the kth hospital
$\overline{x_{ik}}$	Target for the ith input of the kth hospital after evaluation
$\overline{y_{rk}}$	Target for the rth output of the kth hospital after evaluation
λ_{jk}^*	Optimal value of λ_{jk}

Table V. Description of notations used in Model 1

	SBM-CRS results			SBM	SBM		Peer
Code	OTE	Reference set	Peer weights	PTE	SE	RTS	Count
H1	0.375	H5, H7	0.500, 0.750	0.392	0.957	DRS	0
H2	0.657	H5, H7	1.00, 2.00	1	0.657	DRS	0
H3	1	H3	1	1	1	CRS	0
H4	0.374	H7, H12, H14	0.002, 0.704, 0.308	0.724	0.517	DRS	0
H5	1	H5	1	1	1	CRS	10
H6	0.574	H7, H14	0.500, 2.667	1	0.574	DRS	0
H7	1	H7	1	1	1	CRS	22
H8	0.353	H5, H7	0.500, 0.250	0.476	0.742	IRS	0
H9	0.669	H5, H7, H14	0.820, 0.211, 0.112	0.673	0.994	DRS	0
H10	0.246	H12, H14	1.690, 0.021	0.537	0.458	DRS	0
H11	0.487	H7, H12, H14	0.333, 0.167, 0.167	0.530	0.919	IRS	0
H12	1	H12	1	1	1	CRS	14
H13	0.241	H7	0.333	0.414	0.582	IRS	0
H14	1	H14	1	1	1	CRS	15
H15	1	H15	1	1	1	CRS	0
H16	0.336	H7, H12	0.500, 0.750	0.586	0.573	DRS	0
H17	1	H17	1	1	1	CRS	0
H18	1	H18	1	1	1	CRS	0
H19	0.173	H7	0.500	1	0.173	IRS	0
H20	0.460	H5, H12, H14	0.411, 1.401, 0.144	0.505	0.911	DRS	0
H21	0.174	H5, H7	1.00, 0.667	1	0.174	DRS	0
H22	0.314	H7, H14	0.500, 0.250	0.418	0.751	IRS	0
H23	0.319	H7	0.400	0.453	0.704	IRS	0
H24	0.373	H5, H7, H12, H14	0.102, 0.075, 2.278, 0.026	0.385	0.969	DRS	0
H25	0.208	H7	0.600	0.223	0.933	IRS	0
H26	1	H26	1	1	1	CRS	1
H27	1	H27	1	1	1	CRS	0
H28	0.391	H7, H12, H14	0.092, 0.115, 0.249	1	0.391	IRS	0
H29	0.214	H5, H12	0.001, 1.151	1	0.214	DRS	0
H30	0.245	H7, H12, H14	0.137, 2.780, 0.133	0.289	0.848	DRS	0
H31	0.495	H7, H12	2.00, 1.00	1	0.495	DRS	0
H32	0.212	H7, H12, H14	0.108, 2.124, 0.021	0.394	0.538	DRS	0
H33	0.269	H7, H12, H14	0.245, 2.115, 0.164	0.297	0.906	DRS	0
H34	0.393	H7, H12, H14	0.018, 1.373, 0.159	0.592	0.664	DRS	0
H35	0.273	H5, H12, H14	0.155, 1.213, 0.070	0.696	0.392	DRS	0
H36	0.669	H5, H7, H14, H26	0.022, 0.137, 0.309, 0.148	1	0.669	IRS	0
Mean	0.541			0.738	0.742		

Source: Authors' calculation

Table VI. Resulting efficiency scores of hospitals by SBM-DEA Model

Model 1 is a fractional programming problem. The theory of fractional linear programming (Cooper *et al.*, 1997) makes it possible to replace Model 1 with an equivalent linear programming problem. For this, let us multiply a scalar variable $t > 0$ to both the numerator and denominator of Model 1. This causes no change in ρ_k. We adjust t so that the denominator becomes 1. This gives the new constraint as:

$$t+(1/s)\sum_{r=1}^{s} ts_{rk}^{+}/y_{rk} = 1$$

So, the objective is to minimize the numerator. Thus we have the following model.

Model 2:

$$\left.\begin{array}{l} Min\tau_k = t-(1/m)\sum_{i=1}^{m} ts_{ik}^{-}/x_{ik} \\ \text{subject to :} \\ t+(1/s)\sum_{r=1}^{s} ts_{rk}^{+}/y_{rk} = 1 \\ \sum_{j=1}^{n}\lambda_{jk}x_{ij}+s_{ik}^{-} = x_{ik}, \forall i \\ \sum_{j=1}^{n}\lambda_{jk}y_{rj}-s_{rk}^{+} = y_{rk}, \forall r \\ \lambda_{jk} \geqslant 0, s_{ik}^{-} \geqslant 0, s_{rk}^{+}, \forall i,r,j,k \ \ and \ \ t>0 \end{array}\right\}$$

Model 2 given is a non-linear programming problem since it contains the non-linear terms ts_{ik}^{-} and ts_{rk}^{+}. Let us transform Model 2 into a linear programming problem. Let $S_{ik}^{-} = ts_{ik}^{-}, S_{ik}^{+} = ts_{ik}^{+}$ and $\delta = t\lambda$ then Model 2 becomes the following linear programming problem in$t, S_{ik}^{-}, S_{ik}^{+} \ \ and \ \ \delta$.

Model 3:

$$\left.\begin{array}{l} Min\ \tau_k = t-(1/m)\sum_{i=1}^{m} S_{ik}^{-}/x_{ik} \\ \text{subject to :} \\ t+(1/s)\sum_{r=1}^{s} S_{rk}^{+}/y_{rk} = 1 \\ \sum_{j=1}^{n}\delta_{jk}x_{ij}+S_{ik}^{-} = tx_{ik}, \forall i \\ \sum_{j=1}^{n}\delta_{jk}y_{rj}-S_{rk}^{+} = ty_{rk}, \forall r \\ \delta_{jk} \geqslant 0, S_{ik}^{-} \geqslant 0, S_{rk}^{+}, \forall i,r,j,k \ \ and \ \ t>0 \end{array}\right\}$$

Let an optimal solution of Model 3 be $(\rho^*, t^*, \delta^*, S_{ij}^{-*}, S_{ij}^{+*})$. Then the optimal solution of Model 1 is given by$\rho* = \tau^*, \lambda^* = \delta^*/t^*, s_{ij}^{-*} = S_{ij}^{-*}/t^*, s_{ij}^{+*} = S_{ij}^{+*}/t^*$.

The interpretation of results of the Model 1 can be given as follows:

The kth hospital is said to be Pareto efficient if all slacks are 0, i.e., $s_{ik}^{-*} = s_{rk}^{+*} = 0$ for all i and r, which is equivalent to $\rho_k^* = 1$.

The non-zero slacks and (or) $\rho_k^* \leqslant 1$ identify the sources and amount of any inefficiency that may exist in the kth hospital. The reference set shows how input can be decreased and output can be increased to make the kth hospital efficient.

We estimate PTE for every sample hospital by using Model 3 through adjoining the convexity constraint $\sum_{j=1}^{n} \delta_{jk} = 1$.

After all these we calculate SE for every hospital using SE = OTE/PTE.

However some considerations are proven for the use of SBM-DEA model:

(1) a DMU is said to be SBM-efficient if and only if $\rho^* = 1$, i.e., when there is no input excess and no output shortfall in an optimal solution;

(2) a DMU can become efficient and improve its performance by deleting excess inputs and augmenting the output shortfalls; and

(3) the optimal SBM efficiency score ρ^* for any DMU is not greater than the optimal CCR efficiency score θ^*.

The results of SBM-CRS and SBM-VRS models are calculated using MATLAB.

3. Results and discussions

The efficiency scores (OTE, PTE and SE) of 36 public hospitals have been estimated for the year 2011. Table VI presents the efficiency scores obtained from SBM-CRS and SBM-VRS models along with reference sets and peer weights of the sample hospitals. The DEA analysis evaluates the set of hospitals which construct the efficiency frontier. The hospitals achieving the efficiency score equal to 1.00 constitute the efficiency frontier and those having the value less than 1.00 are inefficient.

3.1 OTE

Table VI evinces that out of 36 hospitals ten hospitals (H3, H5, H7, H12, H14, H15, H17, H18, H26 and H27) are relatively OTE as they scored OTE = 1, and thus they form the efficiency frontier. The remaining 26 hospitals are inefficient as they have efficiency scores less than 1. These hospitals are on the best practice frontier and thus form the “reference sets”, i.e., these hospitals can set an example of good operating practice for the remaining 26 inefficient hospitals to emulate. The average OTE score is work out to be 54.10 per cent, which reveals that on average a hospital can reduce its resources or increase outputs by 45.90 per cent to become efficient. The hospital H19 is the most technical inefficient hospital as its efficiency is found to be 17.30 per cent. Among the inefficient hospitals only four hospitals H2, H6, H9 and H36 have the efficiency score above the average efficiency score.

3.2 PTE

SBM-CRS model is based on the assumption of CRS which does not consider the scale size of hospital to be relevant in assessing OTE. Therefore, in order to know whether inefficiency in any hospital is due to inefficient production operation or due to unfavourable conditions displayed by the size of hospital, SBM-VRS model is also applied. SBM-VRS efficiency (PTE) is always greater than or equal to SBM-CRS efficiency (OTE). Hence number of hospitals on the frontier under SBM-VRS model is always greater than or equal to the number of hospitals on the frontier under SBM-CRS model.

The information about the results drowns from SBM-VRS model are also shown in Table VI. It is evident from the Table that out of 36 hospitals 18 (50 per cent) are pure technical efficient (VRS score = 1), while remaining 18 hospitals are inefficient as they scored efficiency score less than 1. The efficiency score obtained by this model measures how efficiently inputs are converted into output(s) irrespective of the size of the hospitals. The average PTE is worked out to be 73.80 per cent. This means that given the scale of operation, on average, hospitals can reduce its inputs or increase outputs by 26.20 per cent of its observed level to become pure technical efficient.

PTE is concerned with the efficiency in converting inputs to outputs, given the scale size of hospital, so, we observe that H2, H6, H19, H21, H28, H29, H31 and H36 are overall technical inefficient but pure technical efficient. This clearly evinces that these hospitals are able to convert its inputs into outputs with 100 per cent efficiency, but their OTE is low due to their scale size.

3.3 SE

A comparison of the results for SBM-CRS and SBM-VRS gives an assessment of whether the size of a hospital has an influence on its OTE. SE is the ratio of OTE to PTE scores. If SE is less than 1, then the hospital appears either small or big relative to its optimum scale size. SE score of the hospitals are shown in the last column of Table VI. Results show that out of 36 hospitals, ten hospitals are scale efficient while remaining 26 hospitals are scale inefficient. The average SE is found to be 74.20 per cent, which indicates that on average a hospital may be able to decrease its inputs or increase its outputs by 25.80 per cent beyond its best practice targets under VRS, if it were to operate at CRS.

3.4 Targets for inefficient hospitals

When a hospital is inefficient, DEA allows setting targets of its inputs and outputs so that it can improve its performance. Thus, each of the inefficient hospitals can become OTE by adjusting its operation to the associated target point determined by the efficient hospitals that define its reference frontier.

Input and output targets, according to the SBM-DEA model, can be set by using the relations given in in the following equations, respectively:

$$\overline{x_{ik}} = x_{ik} - s_{ik}^{-*} \tag{1}$$

$$\overline{y_{rk}} = y_{rk} + s_{rk}^{+*} \tag{2}$$

where the used notations in Equations (1) and (2) are given in Table V. The optimal input and output slacks for inefficient hospitals are given in Table VII. So, we can measure the targets for inputs and outputs for all inefficient hospitals. Table VIII presents the target values of all inputs and outputs for inefficient hospitals along with percentage reduction in inputs and percentage augmentation in outputs. It can be observed from Table VIII that on average a hospital has significant scope to reduce the inputs and expand the outputs relative to the best practice hospital.

4. Stability of efficiency scores (Jackknifing analysis)

DEA is run, after dropping out the most efficient firm with the highest peer count one at a time, in order to test whether there are extreme outliers who may have affected the frontier and efficiency scores. The procedure, known as Jackknifing analysis, test for the robustness of DEA results in regard to outliers (Mostafa, 2007). In this analysis five

	Inputs			Outputs			
Code	Number of beds	Number of doctors	Number of PMS	Number of out-door patients	Number of in-door patients	Number of major surgeries	Number of minor surgeries
H1	29.75	0.00	19.75	0.00	13,710.00	989.25	1,322.00
H2	0.00	1.00	0.00	13,321.00	364.00	164.00	0.00
H3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H4	0.00	4.48	15.41	0.00	0.00	638.97	298.31
H5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H6	96.67	0.00	17.17	0.00	3,238.00	1,184.00	1,723.33
H7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H8	38.25	0.00	10.25	0.00	10,731.75	637.50	507.75
H9	29.37	0.00	20.85	0.00	0.00	229.74	371.40
H10	0.00	1.78	7.16	0.00	1,609.80	1,436.46	811.81
H11	0.00	4.33	21.33	0.00	6,360.00	0.00	358.67
H12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H13	41.67	4.33	0.00	0.00	9,875.67	733.00	701.33
H14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H16	0.00	7.50	1.50	18,619.75	0.00	1,324.75	912.00
H17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H19	16.00	2.00	8.00	9,137.00	5,690.00	453.50	144.50
H20	0.00	1.03	0.00	0.00	599.46	1,179.91	842.40
H21	13.33	4.00	5.67	7,442.33	2,236.67	224.00	63.00
H22	0.00	9.50	8.00	0.00	7,724.75	803.00	733.50
H23	33.20	4.40	15.20	10,881.20	4,341.40	540.00	263.00
H24	0.00	0.24	0.00	0.00	0.00	1,944.82	1,426.06
H25	126.40	18.80	38.00	6,695.80	9,204.60	677.20	906.40
H26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H28	0.00	5.61	5.51	0.00	0.00	344.28	183.60
H29	15.31	13.92	0.00	0.00	1,093.97	954.72	490.45
H30	7.32	0.00	5.02	0.00	0.00	2,688.51	2,039.40
H31	9.00	1.00	0.00	18,167.00	0.00	186.00	87.00
H32	0.00	0.26	13.58	0.00	0.00	2,075.26	1,483.46
H33	0.00	6.61	8.48	0.00	0.00	2,311.38	1,740.11
H34	0.00	2.12	2.81	0.00	0.00	1,141.37	695.03
H35	0.00	1.76	0.00	0.00	1,814.69	1,105.07	695.66
H36	0.00	3.87	0.00	0.00	0.00	290.12	96.47
Mean	12.67	2.74	6.21	2,340.67	2,183.19	673.79	524.91

Source: Authors' calculation

Table VII.
Slacks in inputs and outputs under SBM-CRS Model

firms namely, H7, H14, H12, H5 and H26 which have peer counts 22, 15, 14, 10 and 1, respectively are dropped, one at a time. In the case of CRS assumption, to measure the change in efficiency scores and ranking of firms, we calculate Karl Pearson and Spearman rank correlation coefficient of OTE scores under five analyses such as JA1, JA2, JA3, JA4 and JA5. In JA1 analysis, we have included all 36 hospitals and calculated OTE scores. In further analysis like JA2, JA3, JA4, JA5 and JA6 the excluded hospitals are H7, H14, H12, H5 and H26, respectively. Karl Pearson and Spearman rank correlation coefficients are given in Tables IX and Table X, respectively.

It is observed that Karl Pearson coefficient of correlation ranges from 0.918 to 1.00 at 1 per cent level of significance. It suggests that the efficiency scores are

Code	Inputs: Number of beds	Inputs: Number of doctors	Inputs: Number of PMS	Outputs: Number of out-door patients	Outputs: Number of in-door patients	Outputs: Number of major surgeries	Outputs: Number of minor surgeries
H1	22.54	0.00	32.92	0.00	225.05	124.75	201.22
H2	0.00	14.29	0.00	73.46	17.23	36.69	0.00
H4	0.00	29.86	41.65	0.00	0.00	351.08	63.07
H6	24.05	0.00	12.26	0.00	16.19	98.50	121.11
H8	31.88	0.00	26.97	0.00	334.74	158.58	75.45
H9	19.58	0.00	37.90	0.00	0.00	34.70	48.11
H10	0.00	12.70	23.87	0.00	80.85	784.95	164.33
H11	0.00	24.07	41.03	0.00	212.92	0.00	41.46
H13	41.67	27.08	0.00	0.00	616.84	172.88	131.34
H16	0.00	34.09	4.69	41.70	0.00	421.89	148.05
H19	42.11	28.57	42.11	53.80	1,173.20	242.51	31.14
H20	0.00	5.16	0.00	0.00	7.30	305.68	141.58
H21	55.56	66.67	51.52	135.54	417.29	294.74	27.27
H22	0.00	39.58	19.05	0.00	249.83	224.30	133.61
H23	48.12	36.67	46.06	41.11	122.22	165.64	41.88
H24	0.00	1.18	0.00	0.00	0.00	425.56	243.35
H25	63.20	55.29	51.35	10.86	189.90	78.56	127.48
H28	0.00	43.15	25.06	0.00	0.00	334.25	57.20
H29	30.62	63.25	0.00	0.00	84.09	672.34	126.08
H30	6.10	0.00	9.29	0.00	0.00	765.96	386.25
H31	14.52	11.11	0.00	52.82	0.00	101.64	19.68
H32	0.00	1.43	28.29	0.00	0.00	951.95	346.60
H33	0.00	22.04	15.14	0.00	0.00	623.01	281.57
H34	0.00	14.13	10.05	0.00	0.00	401.89	134.70
H35	0.00	12.55	0.00	0.00	60.35	762.11	182.59
H36	0.00	25.78	0.00	0.00	0.00	128.94	17.80
Mean	12.57	13.16	14.04	17.53	66.55	208.23	110.73

Source: Authors' calculation

Table VIII. Percentage reduction in inputs and augmentation in outputs for inefficient hospitals under SBM-CRS Model

	JA1	JA2	JA3	JA4	JA5	JA6
JA1	1					
JA2	0.951*	1				
JA3	0.962*	0.933*	1			
JA4	0.982*	0.924*	0.973*	1		
JA5	0.964*	0.983*	0.918*	0.940*	1	
JA6	1.00*	0.951*	0.962*	0.981*	0.961*	1

Note: *Significant at 1 per cent level of significance

Table IX. Karl Pearson's coefficients of correlation

	JA1	JA2	JA3	JA4	JA5	JA6
JA1	1					
JA2	0.974*	1				
JA3	0.987*	0.966*	1			
JA4	0.989*	0.957*	0.974*	1		
JA5	0.988*	0.981*	0.973*	0.973*	1	
JA6	1.00*	0.974*	0.988*	0.988*	0.988*	1

Note: *Significant at 1 per cent level of significance

Table X. Spearman rank correlation of coefficients stable even after the exclusion of most efficient hospitals. In addition, the high and positive rank correlation coefficient (0.957-1.00) shows that the rankings of hospitals are stable.

5. Conclusions

This paper measures the relative efficiencies (OTE, PTE and SE) of 36 public sector hospitals of Uttarakhand using SBM-DEA model. The study finds that 10 (27.78 per cent) hospitals have the maximum degree of OTE. Average OTE (54.10 per cent) of the hospitals indicates that on average 45.90 per cent of the technical potential of hospitals is not in use, i.e., these hospitals have the scope of producing the more outputs with lesser inputs than their existing level.

The results of SBM-VRS model show that out of 36 hospitals, 18 (50 per cent) are pure technical efficient as they efficiently convert their inputs into outputs. However, out of them eight hospitals are technical inefficient due to scale-size effect. The hospital H19 has the least SE (17.30 per cent), implying that H19 has the maximum effect of scale size on its efficiency score. It indicates that this hospital can improve its OTE by enhancing its scale of operation.

The target setting results show that all the inputs have the significant scope of reduction and outputs have significant scope of augmentation. SBM model suggests that on average, inefficient hospitals may be able to reduce 12.57 per cent of beds, 13.16 per cent of doctors, 14.04 per cent of PMS, and to expand 17.53 per cent of out-door patients, 66.55 per cent of in-door patients, 208.23 per cent of major surgeries and 110.73 per cent of minor surgeries can be expanded if all the inefficient hospitals operate at the level of efficient hospitals.

6. Limitations of the study

The present study estimates the efficiencies for one calendar year only which can be extended for time series analysis of efficiencies and TFP. Further, the study can be extended to find the determinants of inefficiency and also comparison of efficiencies can be made between CHCs, PHCs, secondary level hospitals and tertiary level hospitals.

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Appendix

Code	Distt. name	Hospital name
H1	Pauri	District Male Hospital
H2	Pauri	District Female Hospital
H3	Pauri	Base Hospital Srinagar
H4	Pauri	Combines Hospital Srinagar
H5	Pauri	Combines Hospital Kotdwar
H6	Dehradun	Doon Male Hospital
H7	Dehradun	Female Hospital Dehradun
H8	Dehradun	Coronation Hosptial
H9	Dehradun	SPS Hospital Rishikesh
H10	Dehradun	St Merry. Hospital Mussoorie
H11	Haridwar	HMG Hospital Haridwar
H12	Haridwar	CR Female Hospital
H13	Haridwar	Mela Hospital Haridwar
H14	Haridwar	Combined Hospital Roorkee
H15	Nanital	B.D. Pandey Male Hospital
H16	Nanital	B.D. Pandey Female Hospital
H17	Nanital	Base hospital Haldwani
H18	Nanital	Female Hospital Haldwani
H19	Nanital	G.B. Pant Hospital Nanital
H20	Nanital	Combined Hospital Ramnagar
H21	Nanital	Combined Hospital Padampuri
H22	Almora	District Hospital Male
H23	Almora	District Hospital Female
H24	Almora	Combined Hospital Ranikhet
H25	Almora	Base Hospital Almora
H26	US Nagar	L.D. Bhatt hospital Kashipur
H27	US Nagar	District Hospital Rudrapur
H28	Tehri	District Hospital Baurari Tehri
H29	Tehri	Combined Hospital Narendnagar
H30	Pithoragarh	DH male Pithoragardh
H31	Pithoragarh	DH Female Pithoragardh
H32	Chamoli	District Hospital Gopeshwar
H33	Uttarkashi	District Hospital Uttarkashi
H34	Rudraprayag	District Hospital Rudraprayag
H35	Champawat	Combined Hospital Tanakpur
H36	Bageshwar	District Hospital Bageshwar

Table A1. Full name of the selected hospitals

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