BMJ Open

Efficiency evaluation of public hospitals in Saudi Arabia: An application of Data Envelopment Analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2019-031924
Article Type:	Research
Date Submitted by the Author:	31-May-2019

Complete List of Authors:	Alatawi, Ahmed; Liverpool School of Tropical Medicine, Health Economics, department of Clinical Sciences Koronakos, Gregory; University of Pireaus, Department of Informatics Niessen, Louis; Liverpool School of Tropical Medicine, Health Economics; University of Warwick, Dept of Health Sciences Khan, Jahangir; Liverpool School of Tropical Medicine, Health Economics; International Centre for Diarrhoeal Disease Research Bangladesh, Health Systems and Population Studies Division

Keywords:	Technical efficiency, Data Envelopment Analysis, Saudi Arabia, Public hospital, General hospital efficiency

Title

Efficiency Evaluation of Public Hospitals in Saudi Arabia: An Application of Data Envelopment Analysis

Authors: Ahmed Alatawi[*,a], Gregory Koronakos [b], Louis Niessen[a,c], Jahangir Khan[a,d]

Affiliations: [a] Liverpool School of Tropical Medicine, Health Economics, department of clinical sciences, Liverpool, United Kingdom.
[b] University of Piraeus, Department of Informatics, Piraeus, Greece.
[c] University of Warwick, Division of Health Sciences, Coventry, United Kingdom.
[d] International Centre for Diarrheal Disease Research Bangladesh, Health Systems and Population Studies Division, Dhaka, Bangladesh.

1- **Ahmed Alatawi***, MSc, Pharm.D. **(Corresponding author)**
PhD Candidate - Health Economist
Health Economics Group, Department of Clinical Sciences, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
Mobile: +4407491496786
Fax: +44(0)151 705 3370
Email: Ahmed.alatawi@lstmed.ac.uk

2- **Gregory Koronakos**, PhD
Postdoctoral in Operational Research
University of Piraeus, Department of Informatics.
Karaoli & Dimitriou 80, 185 34, Piraeus, Greece. Email: gkoron@unipi.gr

3- **Louis Niessen**, Professor
Chair of Health Economics.
Health Economics Group, Department of Clinical Sciences, Room 1966-206, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
Tel: +44 (0)151 705 3779. Email: louis.niessen@lstmed.ac.uk

4- **Jahangir Khan**, PhD
Senior Lecturer in Health Economics
Health Economics Group, Department of Clinical Sciences, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
Tel: +44 (0)151 702 9345. Email: jahangir.khan@lstmed.ac.uk

Word count: 5,160
Keywords: Technical efficiency, Data envelopment analysis, Saudi Arabia, Public hospitals, General hospitals efficiency.

Abstract

Objective: This study empirically estimated the technical efficiency, and causes of inefficiency, in public (ministry of health-affiliated) hospitals in Saudi Arabia.

Design: This study used data envelopment analysis (DEA) to estimate hospital efficiency, using input-orientation technology. The analysis adopted both CRS and VRS (constant and variable return to scale) as DEA models that used four inputs and six output variables from ministry of health databases for 2017. PIM-DEA 3.2 software was used for data analysis.

Setting: Ministry of health-affiliated general hospitals in the Kingdom of Saudi Arabia (KSA).

Results: Findings identified 75.8% (69 of 91) of public hospitals as technically inefficient. The average overall efficiency score was 0.76 (SD 0.23), indicating that hospitals could have inputs reduced by 24% without reduction in service provision. Small hospitals, with an average efficiency score of 0.79 (SD 0.23), were more efficient than medium-sized and large hospitals. Hospitals in central Saudi Arabia, with an average efficiency score of 0.83 (SD 0.18), were more efficient than those located in other geographic locations. More than half of all hospitals (62.6%) were operating sub-optimally in terms of the scale efficiency; efficient scale of operation was in medium-sized hospitals. Slack analysis identified overuse of physician's numbers (22.4%) and shortage of inpatient (14.2%) and outpatient (12.2%) services, as major causes of inefficiency.

Conclusion: Most hospitals in this study were technically inefficient and operating at sub-optimal scale size. Changes of the production capacity are required through improvement of the scale efficiency. This demands long-term effort and the co-operation of administrative authorities and health regulators at all levels of health care system. Policy adjustments are needed, to facilitate optimal use of medical capacity.

Strengths and limitations of this study:

• We selected inputs and outputs that cover all variable dimensions that should be included in the efficiency model and agreed in the literature.

• The hospital mortality rate was included in output variables as an indicator of the health service quality and outcomes in the studied hospitals.

• This is the first research study of technical efficiency used input and output variables extracted from official databases of the Ministry of Health in Saudi Arabia.

• Data envelopment analysis was used to determine the extent of inefficiency and analyse the slacks in public hospitals.

Introduction

Increasing demand for healthcare, and the expenditure required to provide efficient, equitable and effective healthcare systems, are global concerns. The Kingdom of Saudi Arabia (KSA) has experienced these recently, alongside substantial population growth, increased life expectancy and the proliferation of lifestyle-related disease. These have increased the demand for health services at a time of scant resource.[1,2,3]

Under article 31 of the national constitution, the KSA government guarantees free medical care to all citizens.[4] Thus, government finances the public sector annually, largely from revenue derived from oil and gas production.[5] Table 1 shows the proportion of national budget allocated to the KSA's ministry of health (MOH).[6]

The MOH is the primary provider of healthcare services in KSA, administering 60% of all provision. [7] It is the dominant provider of health services in the public sector.[7,8] Other government agencies, including the ministry of defence, the national guard and universities, share the remaining of healthcare provision, as does the private sector.[5] The MOH delivers primary, secondary and tertiary healthcare through 2,361 primary healthcare centres and 282 hospitals, administering 43,080 beds throughout the country.[6] Other MOH functions include strategic planning, formulation of health policy, supervision of all health service delivery programs and the monitoring and management of all other health-related activities.[7]

Table 1: *Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal)*

Year	Government Budget Billion SR	MOH Budget Billion SR	Percentage of MOH to the government budget	No. of Hospitals	No. of Beds
2013	820	54.3	6.63%	268	38970
2014	855	59.9	7.02%	270	40300
2015	860	62.3	7.25%	274	41297
2016	840	58.9	7.01%	274	41835
2017	890	67.7	7.61%	282	43080

Source; Ministry of Health; Statistical yearbook, 2017.

During 2015, KSA government spending on health was 71.3% of the country's total health expenditure, which corresponds to 4.1% of GDP for that year.[9] Healthcare expenditure in KSA increased by 24.7% between 2013 and 2017.[1,2,6] While public spending on health in KSA is remarkably high in comparison to many high-income countries (71.3% for KSA versus 61.2% for high-income countries), the number of hospital beds is considerably lower. [3,9] Just 2.7 hospital beds per 1,000 people are allocated in KSA, whereas the average corresponding figure in other high-income countries is 8.9.[3,9] A previous study suggested that demand for healthcare services in KSA would increase by 145% by 2025 and require twice the number of hospital beds.[10]

Although much has been done to promote the efficient use of resources, this has proven insufficient to meet the rising demand for healthcare in KSA.[11] Providers seem to find it very challenging to deliver adequate provision using current resources.[4] There seems to be an imbalance between health service availability and health spending, so better use of resources is necessary if KSA is to have an efficient and appropriate health system.[11]

Governments worldwide assess the efficiencies of their health sectors, to ensure that public funds are effectively utilized.[12] Efficiency evaluations have used a range of benchmarks and efficiency concepts, including technical, allocative, cost and overall efficiency.[12] Of these, the technical efficiency approach is most commonly used. This is based on Farrell's theory of 1957, which introduced a measure of technical efficiency based on comparison of the inputs and outputs of set entities, called decision making units (DMUs).[13]

Hospital efficiency is crucial to the efficiency of the health system generally, as hospitals are key consumers of health resources.[14,15] Hanson et al. (2002) found that public hospitals consume around 40% of the total state health budget in many sub-Saharan African countries.[14] Public hospitals used almost 44% of national health spending in the United Kingdom in 2012/13.[16] In general, there is a scarcity of studies and empirical works on the efficiency of public hospitals, and that rarity is particularly acute in the context of KSA.[17] Systematic review of public hospital efficiency studies in the Gulf region and similar countries has shown the number of studies to be limited, as efficiency analysis is a novel approach to research in the Gulf, including KSA.[17]

The study presented here estimates the technical efficiency of MOH-administered general hospitals in KSA. It measures the efficiency of hospitals with respect to their capacities and geographic locations, and seeks to identify the causes of inefficiency, and estimates the target levels required of inefficient hospitals if they are to be efficient. This research provides information useful to decision-makers seeking to reform health policy, to optimise the use of health resources in public hospitals and consequently improve the efficiency of healthcare systems.

Methods

Data Envelopment Analysis

Hospital efficiency has hitherto been measured mainly by frontier analysis methods, either through non-parametric data envelopment analysis (DEA) or as parametric stochastic frontier analysis (SFA).[12] These methods compare hospital performance with an estimated efficient frontier comprising the best-performing hospitals.[18,19]

Data envelopment analysis has for many years been the most commonly-used technique for measuring relative efficiency in healthcare .[15,20] Systematic reviews of efficiency studies have often found DEA to be the predominant method of public hospital efficiency assessments among studies reviewed.[15,17,20] Hollingworth et al. (2003, 2008) found that DEA was used in around the half of studies, a further fifth used DEA in with some form of secondary regressions. [15,20] Another review[19], of efficiency in Iranian hospitals, found DEA was applied in all reviewed studies; three of those studies also used SFA to estimate efficiency scores. A systematic review of health system efficiency studies in OECD countries[21] found DEA applied in 64% of studies. Use of DEA is justified by its ability to handle multiple inputs and outputs in different units of assessment, and its functional flexibility of practical application.[12,22]

Data envelopment analysis is a non-parametric approach that uses linear programming technique to analyse the relative efficiencies of individual DMUs, based on their multiple inputs and outputs, evaluated as the ratio of the total weighted output to the total weighted input.[22,23] Several DEA models have been developed to analyze the efficiency based on Farrell's concept[13]. These include the CCR model developed by Charnes, Cooper and Rhodes[24], which assumes that production has constant returns to scale (CRS), and the BCC model developed by Banker, Charnes and Cooper[25], which assumes production has a variable return to scale (VRS).[13] The choice of CCR or BCC model depends on the context, level and perspective of analysis as well as the technology linking the inputs to outputs in the transformation process.[12]

Generally, the CCR model — whereby the efficiency frontier has a constant slope (CRS), which means that any change in the outputs is a result of proportional change in the inputs — is suggested when DEA analysis is conducted from the decision-maker's point of view that aims to measure efficiency regardless of managerial factors.[26] However, efficiency assessment by the CCR model may be affected if the DMUs are not operating on the optimal scale, since CRS does not distinguish between the scale and pure (managerial) technical efficiency.[27] If the efficiency analysis considers a managerial perspective, a BCC technology assumption will be appropriate to understand if a scale of operations or provider's practice affects productivity.[26,28] Scale efficiency is defined as a ratio of CRS to VRS efficiency scores and provides evidence whether the DMU is operating on the optimal scale size.[15,21] Furthermore, the efficiencies of DMUs can be comprehensively analysed using both CCR and BCC assumption for more realistic changes in production process, and implications in the real world.[12,23] Other systematic reviews[21,29] have reported similar findings where studies used both CCR and BCC assumptions in efficiency measurements.

The most commonly-used orientations in DEA analysis are input orientation (i.e. minimization of inputs with the given amount of outputs) and output orientation (i.e. inputs are held constant and outputs are proportionally increased).[23] Previous empirical studies[27] have argued that hospitals have relatively little control over their outputs (for example, expanding surgical operations), but more opportunities to reduce the inputs (e.g. medical devices), where they have the social responsibility to provide medical treatment to the public in general. Most studies thus adopted the input-oriented model for efficiency estimations of hospitals.[21,30] This argument is supported by systematic reviews of efficiency measurements.[29] However, few studies have applied output orientation in response to the strategic health plans of the countries aiming to expand healthcare provision during a specific period.[31,32,]

Considering the arguments in previous studies regarding orientation of efficiency analysis, this study used input orientation, both CCR (CRS) and BCC (VRS) models were applied. The current DEA analysis has formulated a linear fractional program as the following equation;

$$\max ho = \frac{\sum^{s} r = 1\ UrYr0}{\sum^{m} i = 1\ ViXi0}$$

Subject to

$$\frac{\sum^{s} r = 1\ UrYrj}{\sum^{m} i = 1\ ViXij} \leq 1; \qquad j = 1,\ldots,n$$

$Ur \geq 0$, r = 1, …, s. $Vi \geq 0$, i = 1, …, m,

where s is the number of outputs; Ur the weight of output r; Yr0 the amount of output r produced by the hospital j under evaluation; n is a number of hospitals; m the number of inputs; Vi the weight of input i; Xi0 the amount of input I, used by the hospital, j. Performance improvement management software (PIM-DEA version 3.2) was used for DEA analysis.[33]

Population and selection of sample

Public (MOH-affiliated) hospitals in KSA can be broadly classified into two groups, general hospitals and specialised hospitals. General hospitals provide a wide range of health services, while specialised hospitals deliver health services for a specific health condition or to a particular group of beneficiaries. As the application of DEA is based on a homogenous (comparative) sample that use similar inputs to produce similar outputs, we focused on examining the technical efficiency for general hospitals.[12]

Hollingsworth (2008) and Varabyova (2016) argued that sample hospitals should have similar types and health production activities, since the inclusion of divergent specialist units in the same sample will confound the results — frontier techniques are susceptible to outliers.[20,21] Specialised hospitals often lack types of secondary service, e.g. surgical operations rarely occur in psychiatric hospitals, and such hospitals, if included, will appear as inefficient while surgery is a considered as an output.[19,20,29] Specialised hospitals were therefore excluded from this analysis.

Similarly, small hospitals (with 50 beds or fewer) provide primary care services while lacking secondary and tertiary health services, and consequently miss a significant number of output variables (e.g. inpatient services, patient discharge, surgical operations, laboratory testing) compared to bigger hospitals. This study eliminated smaller hospitals, to ensure greater homogeneity in performance evaluation across comparable units.[12,23]

Ultimately, the homogenous sample used in the analysis included 21,528 out of 398,68 (54%) of the total active hospital beds provided by the MOH in KSA. We included in the assessment 97 general hospitals and removed six hospitals, due to missing data. The data of hospital inputs and outputs for 2017 was collected by the lead author from official statistical, informational and research databases of Administration of Statistics and Information and Administration of Research and Studies, which affiliated of the MOH, following approval from the designated authority. Data collection took place from May to July 2018.

The sample hospitals were in 64 cities, affiliated to 20 administrative districts, located in five geographic regions, namely central, west, east, south and north regions. Hospitals were classified into four groups based on their capacity (number of beds): small (fewer than 200 beds), lower-medium (200 to 299 beds), upper-medium (300 to 499 beds) and large (500 or more beds) hospitals, following Gok's[26] categorization. Figure 1 illustrates number of hospitals and hospital-beds in each category of capacity and locations.

Figure 1 to be inserted here

Inputs and outputs

Selection of input and output variables is a crucial step in performance measurement, because the results of any efficiency assessment depend significantly on the variables used in the estimation models.[34] The literature has focused on labour (e.g. health professionals) and capital (e.g. number of beds), as input variables, while some studies included consumable resources.[12,34] The main categories of output used in healthcare-related efficiency studies were healthcare activities (e.g. number of outpatient visits, inpatient services, number of surgeries) and health outcomes (e.g. mortality rate).[12, 19,21]

In the analyses performed for this study, hospital input and output variables for the DEA model were selected in the light of previous theoretical and empirical studies, and availability of data in the KSA context. Thus, four inputs and six outputs were chosen.

The input variables chosen were: (1) number of hospital beds; (2) number of full-time physicians; (3) number of full-time nurses and (4) number of full-time allied health personnel (I.e. pharmacists, midwives, medical technicians, medical radiologists, physiotherapists) employed in the hospital. The output variables used in this study were: (1) outpatient visits (number of patients receiving outpatient treatment within a year); (2) discharged patients (number of patients receiving inpatient treatment within a year); (3) total number of surgical operations during the year; (4) number of radiological investigations conducted in hospital during the year; (5) number of laboratory tests during the year; (6) hospital mortality rate (ratio of inpatient deaths during hospitalization to the total number of inpatients that year). The last output variable was an indicator of health service quality and health outcomes in hospital, as argued by Sahin and Ozcan[35]. The inverse value for the mortality rate (one divided by mortality rate) was included as an output value in the model, considering the assumptions of linear programming of efficiency model, meaning that hospitals with higher mortality rate would have a smaller ratio as output values.[35]

The number of hospitals (DMUs in DEA context) should be at least two times larger than the sum of input and output variables.[36] However, Hollingsworth (2014)[22] suggested that the number of units used in efficiency assessment should be at least three times the combined counts of input and output variables. The current study assessed 91 hospitals, more than three times the combined number of input and output variables.

Patient and Public Involvement

No patients were involved in this study, and we used secondary data from MOH databases.

Results

Descriptive statistics, concerning the inputs and outputs of 91 general hospitals during 2017, are presented in Table 2. The average hospital size was 236.57 beds, with a range of 100 to 711 beds. Full-time physicians ranged from 38 to 894, with a mean of 212. The number of nurses was an average 495, but ranged from 74 to 1,930. Full-time allied health personnel ranged from 37 to 1,149, with an average of 280.

Table 2: *Descriptive statistics of the inputs and outputs of the 91 hospitals*

	Mean	**Standard Deviation**	**Min**	**Max**
Inputs				

Hospital beds	236.6	137.6	100	711
Physicians	212.3	168.7	38	894
Nurses	495.2	403.6	74	1,930
Allied Health Personnel	280.1	219.1	37	1,149
Outputs				
Outpatient visits	72,986.5	72,475.3	1,785	466,608
Discharged patients	26,016.4	55,856.4	19	503,216
Surgical operations	2,638.4	2,151.2	172	9,464
Laboratory tests	965,840.8	1,095,415.6	794	5,512,774
Radiology Investigations	53,531.4	46,788.7	107	221,980
Hospital mortality rate	0.0224	0.0212	0.0003	0.125

Turning to outputs, the average number of patient visits to outpatient departments was 72,986 and ranged from 1,785 to 466,608 visits. Discharged patients receiving inpatient services during 2017 averaged 26,016, ranging from 19 to 503,216. Surgical operations ranged from 172 to 9,464 with a mean of 2,638 surgeries per hospital. Means for laboratory and radiology tests were 965840 and 53531 respectively, during 2017. Average mortality rate was 2.24%.

Table 3 presents the results of DEA model, summary statistics of average technical (TE), pure technical (PTE) and scale (SE) efficiency scores, and the return to the operation scale of hospitals in each category.

Table 3: *Technical efficiency scores, constant, increasing and decreasing returns to the scale*

	Technical efficiency	**Pure technical efficiency**	**Scale efficiency**	**CRS [N (%)]**	**IRS [N (%)]**	**DRS [N (%)]**
All hospitals (n=91)						
Mean	0.76	0.87	0.87	34 (37.4)	40 (44)	17 (18.6)
Std. Dev.	0.23	0.18	0.18			
Min	0.11	0.30	0.19			
No. full score	22 (24.2%)	47	25			
Large hospitals: >=500 beds (n= 8)						
Mean	0.65	0.75	0.87	2 (25)	1 (12.5)	5 (62.5)
Std. Dev.	0.27	0.30	0.13			
Min	0.28	0.30	0.59			
No. full score	1 (12.5)	4	1			
Upper-medium hospitals: 300-499 beds (n= 22)						
Mean	0.76	0.80	0.94	7 (31.8)	5 (22.7)	10 (45.5)
Std. Dev.	0.19	0.19	0.07			
Min	0.39	0.41	0.76			

No. full score	3 (13.6)	7	3			
Lower-medium hospitals: 200-299 beds (n= 22)						
Mean	0.73	0.79	0.90	10 (45.5)	10 (45.5)	2 (9.1)
Std. Dev.	0.25	0.19	0.18			
Min	0.11	0.50	0.22			
No. full score	4 (18.2)	4	4			
Small hospitals: <200 beds (n= 39)						
Mean	0.79	0.96	0.82	15 (38.5)	24 (61.5)	0 (0)
Std. Dev.	0.23	0.09	0.22			
Min	0.19	0.67	0.19			
No. full score	13 (33.3)	31	13			

The average, overall technical efficiency score for MOH general hospitals was 0.76, with a standard deviation (SD) of 0.23, which indicates that these hospitals could reduce use of all their inputs on average by 24% without any reduction in the number of services provided. The distribution of technical, pure technical and scale efficiency scores is given in Figure 2.

Figure 2 to be inserted here

The lowest technical efficiency score reported was 0.11, but 22 hospitals out of 91 (24.2%) were technically and scale efficient, indicating the inputs were optimally used. Among hospitals failing to reach the full efficiency score, 55 hospitals (60.4%) achieved efficiency scores of at least 0.50 efficiency (Figure2) and 14 hospitals (15.4%) reported efficiency scores below 0.50.

Average pure technical efficiency and scale efficiency scores were both 0.87, with (SD 0.18). Although 47 hospitals (52%) reported an efficient score on VRS (pure efficiency), only 25 (27%) hospitals reported full scores on the scale efficiency.

Return to the scale was measured by DEA, which indicated whether the rate of increase in outputs was made by the equal rate of increase in inputs. This revealed three scale-operation situations. These were: 1) constant return to scale (CRS) in 34 hospitals (37.4% of the sample), where equal increase in all production factors (inputs) led to the same amount of increase in production (outputs) — in other words, these hospitals were operating on the optimum, or most productive, scale size (MPSS); 2) increasing returns to scale (IRS) in 40 hospitals (44%), where the increase in all production factors resulted in more production, and 3) decreasing returns to scale (DRS) in 17 hospitals (18.6%), meaning an equal increase in all production factors led to less production. However, hospitals that were operating on either IRS or DRS needed to alter their capacity to operate on the optimum scale size, which was required to achieve technical efficiency.

From the capacity perspective, small hospitals had higher levels of technical and pure technical efficiencies than medium-sized (both lower- and upper-medium) and large hospitals. Table 3 shows that small hospitals had, on average, overall technical efficiency of 0.79 (SD 0.23); one-third of hospitals in this category were technically and on the scale efficient. Average technical efficiency of lower-medium hospitals was 0.73 (SD 0.25), with a higher percentage of inefficient hospitals (81.8%), than for small hospitals. Although upper-medium-sized hospitals reported a slightly higher average technical efficiency score of 0.76 (SD 0.19), fewer hospitals in this category reported an efficient score, meaning a higher percentage of inefficiencies (86.4%). Large hospitals were the least efficient when compared to other categories. The average technical efficiency of large hospitals was 0.65 (SD 0.27), only one was technically efficient.

The average scale efficiency score of medium-sized hospitals was higher than for small and large hospitals. Regarding scale-efficiency scores, upper-medium (θ= 0.94) and lower-medium (θ = 0.90) sized hospitals operated at a more optimal scale than small (Θ = 0.82) or large hospitals(Θ= 0.87). Also, 45.5% of lower-medium hospitals operated on the most productive scale size (MPSS), followed by small hospitals (38.5%). However, most of the remaining hospitals in these categories, i.e. lower-medium (45.5%) and small size (61.5%) hospitals were operating on increasing the return to the scale. In contrast, most large hospitals (62.5%) showed decreasing return to the scale, and two of them were on CRS, indicating a need to downsize these hospitals to improve technical efficiency. Similarly, 45.5% of upper-medium-sized hospitals operated on DRS and one-third of this category were operating on MPSS (CRS).

Table 4 shows the results of DEA efficiency scoring in a geographical context. Hospitals in the central region reported the highest average technical efficiency score of 0.83 (SD 0.18) , followed by eastern hospitals with an average score of 0.80 (SD 0.28). Hospitals in western KSA reported the least average score, 0.68 (SD 0.20).

Table 4 Technical efficiency scores and return to scale operations by location

	Technical efficiency	Pure technical efficiency	Scale efficiency	CRS [N (%)]	IRS [N (%)]	DRS [N (%)]
South region hospitals (n= 22)						
Mean	0.75	0.89	0.83	9 (40.9)	9 (40.9)	4 (18.2)
Std. Dev.	0.25	0.18	0.23			
Min	0.11	0.41	0.22			
No. full score	4 (18.2)	13	4			
East region hospitals (n =8)						
Mean	0.80	0.85	0.90	4 (50)	1 (12.5)	3 (37.5)
Std. Dev.	0.28	0.21	0.16			
Min	0.27	0.50	0.54			
No. full score	1 (12.5)	4	1			
North region hospitals (n =17)						
Mean	0.75	0.84	0.90	7 (41.2)	9 (52.9)	1 (5.9)
Std. Dev.	0.28	0.23	0.20			
Min	0.19	0.30	0.19			
No. full score	6 (35.3)	9	6			
Central region hospitals (n =24)						
Mean	0.83	0.89	0.93	10 (41.7)	11 (45.8)	3 (12.5)
Std. Dev.	0.18	0.16	0.10			
Min	0.49	0.50	0.69			
No. full score	8 (33.3)	12	8			
West region hospitals (n =20)						
Mean	0.68	0.85	0.81	4 (20)	10 (50)	6 (30)
Std. Dev.	0.20	0.17	0.17			
Min	0.37	0.42	0.46			
No. full score	3 (15)	9	3			

The number of hospitals in the north (35.3%) and central (33.3%) regions with a full efficiency score was higher, as a proportion of samples, than other regions. Hospitals located in the eastern, western and southern regions had a higher percentage of inefficient hospitals. Both central and southern regions reported a higher pure-technical efficiency score of 0.89. In terms of average scale efficiency scores, central region hospitals (ϴ= 0.93), and hospitals in the north- and east (both ϴ = 0.90) were operating at more optimal scale than those in the west (ϴ = 0.81) and south (ϴ= 0.83). Half of the sample hospitals in the east region were operating on the most productive scale size (MPSS), followed by hospitals in the central and north regions (both 41%). The findings also revealed that 52.9 % of north region hospitals were operating on IRS, while 37.5% of east region hospitals were operating on DRS.

The analysis identified slacks, which were either excess input utilization or shortages of output production. This would permit health regulators to determine inefficiently-used inputs or insufficiently-produced outputs. Table 5 shows the average amount of slack in hospitals deemed inefficient. These results represent the combined scores of slack for all inefficient hospitals, for each input and output. Table 5 also shows the percentage of change (slacks) in the number of inputs or outputs required to eliminate the inefficiencies and achieve target levels.

Table 5 Slacks evaluation for inefficient hospitals

Input slacks	Mean (SD)	Percentage of change
Hospital beds	48.4 (76.6)	-20.4%
Physicians	47.5 (72.6)	-22.4%
Nurses	102.9 (173.1)	-20.8%
Allied Health Personnel	58.38 (98.3)	-20.84%
Output slacks		
Outpatient visits	8866.1 (23712)	12.2%
Discharged patients	3700.6 (8214.2)	14.2%
Surgical operations	282.6 (730.9)	10.7%
Laboratory tests	66105.6 (140332.4)	6.8%
Radiology Investigations	2204.6 (6944.1)	4.1%
Mortality rate	0.006 (0.014)	21.7%

In terms of input, results show that an excess of physicians was the main cause of inefficiencies in public hospitals. A feasible, achievable reduction in the number of physicians was on average 22.38 % of the current values (compared with the amounts given in Table 2). The next most substantial slack was observed in allied health personnel, at 20.84%. Surpluses of hospital beds and nurses were also important causes of inefficiency and should be reduced on average by 20.44% and 20.77%, respectively.

The analysis also showed that significant savings could potentially be made via outputs. To improve technical efficiency, the average number of outpatients and hospitalised inpatients could be increased by 12.15 % and 14.22 % respectively, to meet targets. Surgical operations within these hospitals should be increased by 10.7%. Laboratory and radiological tests should be increased on average by 6.84% and 4.12%, respectively.

Furthermore, the quality of health services in public hospitals would have improved with a decrease in the hospital mortality rate, from 0.0224 to 0.0162. A significant improvement in service quality, reflected in the mortality rate, was needed for hospitals to attain efficient use of resources. Thus, public hospitals should consider the need to deliver health services to a greater volume of patients, through effective utilization of their existing resources.

Discussion

This study evaluated the technical efficiency of public hospitals affiliated to the KSA's MOH, using data envelopment analysis. Analysis showed 75% of sample hospitals could not utilize their intact resources to generate specified outputs. The average technical efficiency score was 0.76, indicating that hospitals could produce their current level of outputs with 76% of inputs currently used, and thereby achieve efficiency. Efficiency scores ranged from 0.11 to 1.00 (Figure 2), revealing considerable variations in efficiency scores among hospitals. Moreover, the average internal (pure technical efficiency) and external technical efficiency (scale efficiency) scores were both 0.87. This indicated that inefficiency was due to administrative failure to overcome external environmental factors, and inability to manage internal operations in the hospitals. Notably, a 2017 study by Helal and Elimam[37], which assessed the efficiency of health services at districts level in KSA using MOH data from 2014, found an average efficiency score of 0.92, and 45% of the districts achieved the technical efficiency score of 1.00. An efficiency analysis of 20 public hospitals, under private sector management in KSA, found that 60% of the study sample had not achieved the efficient score, with an average score of 0.84.[38]

Results of the study presented here suggest that small hospitals were relatively more technically efficient than medium-sized and large hospitals (Table 2). Other efficiency studies have reported similar findings: Gok [26] found that small hospitals achieved higher efficiency scores than medium-sized and large ones. This might be due to the differing locations and missions of small and large hospitals.[26,28] In this study's sample, small hospitals were mainly in peripheral cities and towns, which lacked other sources of public or private healthcare. Service provision in those hospitals might be relatively high compared to the health resources used. Large hospitals (500 or more beds) tended to be in larger cities in urban areas, where many other health providers shared the healthcare of much of the urban population, which might generate a relatively decreased level of production in respect of inputs used.

Regarding the different missions (activities) of each category, large hospitals consumed a high amount of health resources to meet the various requirements of comprehensive care.[26] Since some of these were teaching hospitals, however, teaching activities were not counted in the outcome measurements.[26,34] In such large hospitals, treatment processes might be more complicated, and some of the productions of these hospitals could not be assessed in the hospital outcomes.[39]

It had been argued by Afzali[34] and Hollingsworth[15] that many hospital databases are compromised by insufficient data on a broad range of hospital functions and care, e.g. preventive care, health promotion, staff development activities. Thus, improving hospital's databases through high quality data collection and processing techniques — including data from different health provision levels, capturing valid data that reflects the severity of cases and related health services, quality of care and pattern of activities — is very important.[35,40] Such improvement would facilitate further efficiency research by indicating weaknesses in healthcare production processes and consequently would guide policy-makers in potential reforms of health policy and directives.

This study found 57 hospitals (62.6%) operating on non-optimal scale size; 44% were operating on the IRS, while 18.6% showed DRS (Table 3). This indicated that the efficiency of healthcare in KSA might be improved through downsizing of hospitals on DRS and reallocating these inputs to the hospitals operating in the IRS. Moreover, five out of eight large hospitals (500 or more beds) were operating on DRS, implying that to improve efficiency, they needed to reduce their production capacity. This is supported by other research findings.[41]

This study found that 61.5% of small hospitals had been operating on IRS, none was on DRS, suggesting the increase of capacity (inputs) of this category should be increased by reallocating resources from the larger hospitals, thereby improving efficiency. The efficient scale of public hospitals was in medium-sized establishments (200 to 499 beds). Although half of the hospitals located in the east were operating on the most productive scale size (CRS), three were operating on DRS. Around 53% of the hospitals in the north were operating on

IRS, whereas 30% of western region hospitals, which reported the lowest efficiency scores, were operating on DRS.

Atılgan[42] reported similar, location-specific, differences in efficiency scores for general MOH hospitals in Turkey. This could be due to case mix and/or case severity differences between hospitals, and it might be that hospitals in the west region might be treating more severe cases.[19,] Another explanation could be that hospitals in this region consumed more inputs in anticipation of the annual pilgrimage season, for which government allocates more budget to such hospitals.

Regardless of capacity or location-based performance variations, improving the scale efficiency of hospitals would require long-term effort, reflected in amendments to health policies, strategic plans and the autonomy of hospital-managers.[41] The prevailing ability of patients to access health services should not be compromised while reallocating the resources to the other hospitals until Pareto optimality is achieved.[12]

In this study, slack analysis was conducted to identify surpluses in inputs used and shortages in outputs produced. The use of DEA can identify sources of inefficiency, helping hospital managers and health policy-makers to reach informed decisions.[28] The analysis showed that the number of full-time physicians was the most notable reason for inefficiency, with an average excess of 22.4%, from an input perspective. Other inputs among labour variables that showed a surplus in use were the number of nurses and the number of allied health personnel, in addition to excess number of hospital beds (capital variable). Analysis revealed a shortage of outputs production, e.g. hospitals needed to increase the number of outpatients and hospitalized inpatient services on average by 12.2% and 14.2% respectively, to be efficient. Given the previous findings, health policy-makers might consider redeploying their labour forces from inefficient hospitals to more efficient ones.[28,41] Public hospitals should effectively utilize existing beds to increase efficiency. For example, in this study many large hospitals had been operating on DRS; however, most of the small hospitals were operating on IRS. Healthcare administrators should assess the legal conditions and regulations for the effective use of medical capacity in light of the findings of this slack analysis.

Selecting the input and output variables for this study was challenging, due to our dependence on the availability of data. However, we selected the inputs and outputs that cover all variable dimensions that should be included in the efficiency model and are agreed in the literature.[12] We also included hospital mortality rate as an indicator of the health service quality and outcomes. Six hospitals were removed from the sample because they did not have records of the required inputs and outputs needed for this study. Despite a few limitations, the study site (KSA), and data sources might create strong interest among policy-makers, stakeholders, researchers and academics. This is the first research study of technical efficiency based on official data from KSA, that has considered public hospital capacities and geographical locations. We encourage further research in this area, to provide more specific results with a spotlight on inefficiency causes, given the goals, functions and strategic plans of public hospitals in KSA.

Concluding Remarks

Given the scarcity of resources, growing expenditure on health and demand for health services, more attention should be paid to improving the efficiency of healthcare by better utilization of current resources. In this study, inefficiency existed in most public hospitals, and these could reduce their inputs by 24% without any reduction in service provision. Small hospitals and hospitals in the central region of KSA were relatively more efficient. A high proportion of hospitals were operating at non-optimal scale size, while an efficient scale of operation was observed in medium-sized hospitals. This finding suggests it would be helpful to adjust production capacity by downsizing hospitals operating on DRS and reallocating the resources to hospitals on the IRS, as reflected in the scale analysis.

Any improvement in scale efficiency would require long-term efforts through adjustments to health policies and goals as well as by securing the autonomy of hospital management. This will require collaboration between health administrative, policy planning and daily operations management, to fill the administrative gap and thus overcome external environmental factors and manage internal hospital operations.

The slack analysis described here shows the surplus of physician numbers and a shortage of inpatient and outpatient services to be major causes of inefficiency, implying that health regulators might redeploy their labour forces for effective utilization of medical capacity. A possible reallocation of resource must take place without compromising patients' current access to public-funded health services.

Acknowledgement

We are grateful for the Ministry of Education and the government of Saudi Arabia for unlimited support. The authors would like to thank of the Administration of Statistics and Information and the Administration of Research and Studies in the Ministry of Health for providing access to the hospital's databases. Special gratitude to Mr Nabil A. Othman and Ms Nuwayyir Alshalawi at Administration of Statistics and Information for their contributions through permitting to use the administration's access to the necessary databases to complete the data collection.

Contributors

AA, GK, LN and JK contributed to conceptualizing the research question, study design and settings and literature search. AA contributed to data collection and variable extraction. AA, GK and JK conducted the data analysis, interpretation, and writing the manuscript. AA, GK, LN and JK contributed to writing, reviewing and revising the manuscript. All authors finally reviewed the manuscript critically and approved the final version for submission.

Funding

There is no funding agency in the public, commercial or not-for-profit sectors to report for this submission.

Competing interest

None declared.

Data sharing statement

Data were extracted from the hospital databases at Administration of Statistics and Information in The Ministry of Health. Additional data are available if requested.

Ethics approval

Ethics approval was obtained from the Ethics Committee of Institutional Review Board (IRB) of King Fahad Medical City, the Ministry of Health in Saudi Arabia (IRB log No. 18-166E).

Patient consent for publication

Not required.

References

1. Khoja T, Rawaf S, Qidwai W *et al*. Health care in Gulf Cooperation Council countries: a review of challenges and opportunities. *Cureus* 2017;9(8):e1586. DOI 10.7759/cureus.1586.
2. Ardent Advisory & Accounting. *GCC healthcare sector report. A focus area for governments.* Abu Dhabi, UAE, 2015 Accessed: January 2018: DOI: http://www.ardentadvisory.com/files/GCC-Healthcare-Sector-Report.pdf
3. Ram P. Management of healthcare in the Gulf Cooperation Council (GCC) countries with special reference to Saudi Arabia. *International Journal of Academic Research in Business and Social Sciences* 2014; 4(12). DOI: 10.6007/IJARBSS/v4-i11/1326.
4. Albejaidi F. Healthcare system in Saudi Arabia: an analysis of structure, total quality management and future challenges. *Journal of Alternative Perspectives in the Social Sciences* 2010;2(2):794-818.
5. Al-Homayan A, Shamsudin F, Subramaniam C, Islam R. Analysis of health care system — resources and nursing sector in Saudi Arabia. *Advances in Environmental Biology* 2013;7(9), pp. 2584-2592.
6. MOH portal.com. *2017 Annual Statistical Book* Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/ANNUAL-STATISTICAL-BOOK-1438H.pdf (Accessed Oct. 2018).
7. Almalki M, FitzGerald G, Clark M. Health care system in Saudi Arabia: an overview. *Eastern Mediterranean Health Journal* 2011;17(10).
8. MOH portal.com. *2015 Annual Statistical Book*. Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/StatisticalBook-1436.pdf
9. The World Bank. *2019 Country Data*. Available at: https://data.worldbank.org/country/saudi-arabia (accessed January 2019).
10. Mourshed M, Hediger V, Lambert T. Gulf Cooperation Council healthcare: challenges and opportunities. 2007; *Arab World Competitiveness Report (Part 5)*;55–64, World Economic Forum, Geneva, Switzerland 2007. DOI: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.183.7279&rep=rep1&type=pdf

11. MOH portal.com. *Ministry of Health Strategic Plan 2010–2020*. Available at: https://www.moh.gov.sa/Portal/WhatsNew/Documents/OKIstragi260p.pdf.(Accessed October 2018).

12. Jacobs R, Smith P, Street A. *Measuring efficiency in health care: analytic techniques and health policy.* Cambridge; Cambridge University, p3–39/91-127, 2006.

13. Farrell MJ. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society* 1957;120(3):253–290.

14. Hanson K, Atuyambe L, Kamwanga J *et al*. Towards improving hospital performance in Uganda and Zambia: reflections and opportunities for autonomy. *Health Policy* 2002;61, 73–94.

15. Hollingworth B. Non-parametric and parametric applications measuring efficiency in health care. *Healthcare Management Science* 2003;6:203–218.

16. Kelly E, Stoye G, Vera-Hernández M. Public hospital spending in England: evidence from National Health Service administrative records. *Fiscal Studies* 2016;37(3-4), pp.433–459.

17. Alatawi A, Ahmed S, Niessen L *et al*. Systematic review and meta-analysis of public hospital efficiency studies in Gulf region and selected countries in similar settings. 2018. (Manuscript submitted for publication)

18. Hussey P, de Vries H, Romley J *et al*. A systematic review of health care efficiency measures. *Health Services Research and Educational Trust* 2009; 44(3):784–805. DOI: 10.1111/j.1475-6773.2008.00942.

19. Kiadaliri A, Jafari M, Gerdtham U. Frontier-based techniques in measuring hospital efficiency in Iran: a systematic review and meta-regression analysis. *BMC Health Services Research* 2013;13:312. http://www.biomedcentral.com/1472-6963/13/312

20. Hollingsworth B. The measurement of efficiency and productivity of health care delivery. *Health Economics* 2008;17:1107–28. DOI: 10.1002/hec.1391

21. Varabyova Y, Müller JM. The efficiency of health care production in OECD countries: a systematic review and meta-analysis of cross-country comparisons. *Health Policy* 2016;120(3) 252–263. http://dx.doi.org/10.1016/j.healthpol.2015.12.005

22. Hollingsworth B. Evaluating efficiency of a health care system in the developed world. *Encyclopedia of Health Economics* 2014;1(18) pp.292-299.

23. Cooper W, Seiford L, Tone K. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Springer, New York, p1-85, 2007. DOI: 10.1007/978-0-387-45283-8

24. Charnes A, Cooper W, Rhodes E. Measuring the efficiency of decision-making units. *European Journal of Operational Research* 1978;2(6), 429–444 (1978)

25. Banker R, Charnes A, Cooper W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science* 1984;30(9), 1078–1092

26. Gok MS, Sezen B. Analyzing the ambiguous relationship between efficiency, quality and patient satisfaction in healthcare services: the case of public hospitals in Turkey. *Health Policy* 2013;111(3), pp 290-300. http://dx.doi.org/10.1016/j.healthpol.2013.05.010

27. Chuang CL, Chang PC, Lin RH. An efficiency data envelopment analysis model reinforced by classification and regression tree for hospital performance evaluation. *Journal of Medical Systems* 2010;35(5):1075-83. Doi:10.1007/s10916-010-9598-5.

28. Gok MS, Altindag E. Analysis of the cost and efficiency relationship: experience in the Turkish pay for performance system. *European Journal of Health Economics* 2015;16(5), pp 459–469. DOI 10.1007/s10198-014-0584-6

29. Pelone F, Kringos, DF, Romaniello A *et al*. Primary care efficiency measurement using data envelopment analysis: a systematic review. *Journal of Medical Systems* 2015;, 39(1):156.

30. O'Neill L, Rauner M, Heidenberger K *et al*. A cross-national comparison and taxonomy of DEA-based hospital efficiency studies. *Socio-Economic Planning Sciences* 2008;42:158–189.

31. Mahate A, Hamidi S. Frontier efficiency of hospitals in United Arab Emirates: An application of data envelopment analysis. *Journal of Hospital Administration* 2016;5(1) pp7–16. DOI: 10.1007/s10916-014-0156-4

32. Ramanathan R. Operations assessment of hospitals in the Sultanate of Oman. *International Journal of Operations and Production Management*, 2005;25(1) pp 39-54. DOI: 10.1007/s10916-014-0156-4

33. Emrouznejad A, Thanassoulis E. *Performance Improvement Management Software: PIM-DEAsoft-V3.0 User Guide* May 2011; www.DEAsoftware.co.uk,Performance

Improvement Management Limited, UKISBN: 1-85449-412-2. Available at: https://deazone.com/en/software

34. Afzali HH, Moss JR, Mahmood MA. A conceptual framework for selecting the most appropriate variables for measuring hospital efficiency with a focus on Iranian public hospitals. *Health Services Management Research* 2009;22(2):81–91. DOI: 10.1258/hsmr.2008.008020
35. Sahin I, Ozcan YA. Public sector hospital efficiency for provincial markets in Turkey. *Journal of Medical Systems* 2000;24(6), pp 307–320.
36. Dyson R, Allen R, Camanho A *et al*. Pitfalls and protocols in DEA. European *Journal of Operational Research* 2001;132(2):245–259.
37. Helal S, Elimam H. Measuring the efficiency of health services areas in Kingdom of Saudi Arabia using data envelopment analysis (DEA): a comparative study between the years 2014 and 2006. *International Journal of Economics and Finance* 2017;9(4) pp172–184.
38. Abou El-Seoud M. Measuring efficiency of reformed public hospitals in Saudi Arabia: An application of data envelopment analysis. *International Journal of Economics and Management Sciences* 2013;2(9):44–53.
39. Shahhoseini R, Tofighi S, Jaafaripooyan E *et al*. Efficiency measurement in developing countries: application of data envelopment analysis for Iranian hospitals. *Health Services Management Research* 2010;24(2):75-80. DOI: 10.1258/hsmr.2010.010017
40. Afzali HH, Moss JR, Mahmood AM. Exploring health professionals' perspectives on factors affecting Iranian hospital efficiency and suggestions for improvement. *International Journal of Health Planning and Management* 2011;26: e17–e29. DOI: 10.1002/hpm.1035
41. Kiadaliri A, Haghparast-Bidgoli H, Zarei A. Measuring efficiency of general hospitals in the south of Iran. *World Applied Sciences Journal* 2011;13(6): 1310–1316.
42. Atilgan E. The technical efficiency of hospital inpatient care services: an application for Turkish public hospitals. *Isletme ve Ekonomi Arastirmalari Dergisi/Business and Economics Research Journal* 2016;7(2): 203–214. DOI: 10.20409/berj.2016217537.

Tables

Table 1: Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal)

Table 2: Descriptive statistics of the inputs and outputs of the 91 hospitals

Table 3: Technical efficiency scores, constant, increasing and decreasing returns to the scale

Table 4 Technical efficiency scores and return to scale operations by location

Table 5 Slacks evaluation for inefficient hospitals

Figures

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

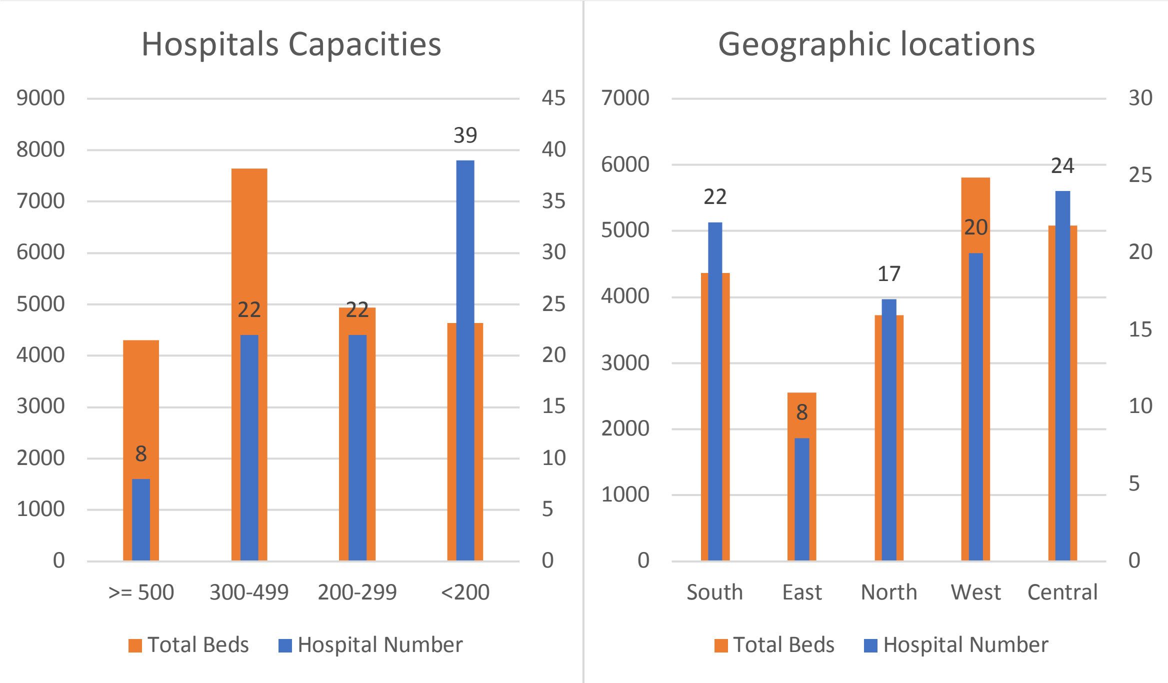

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

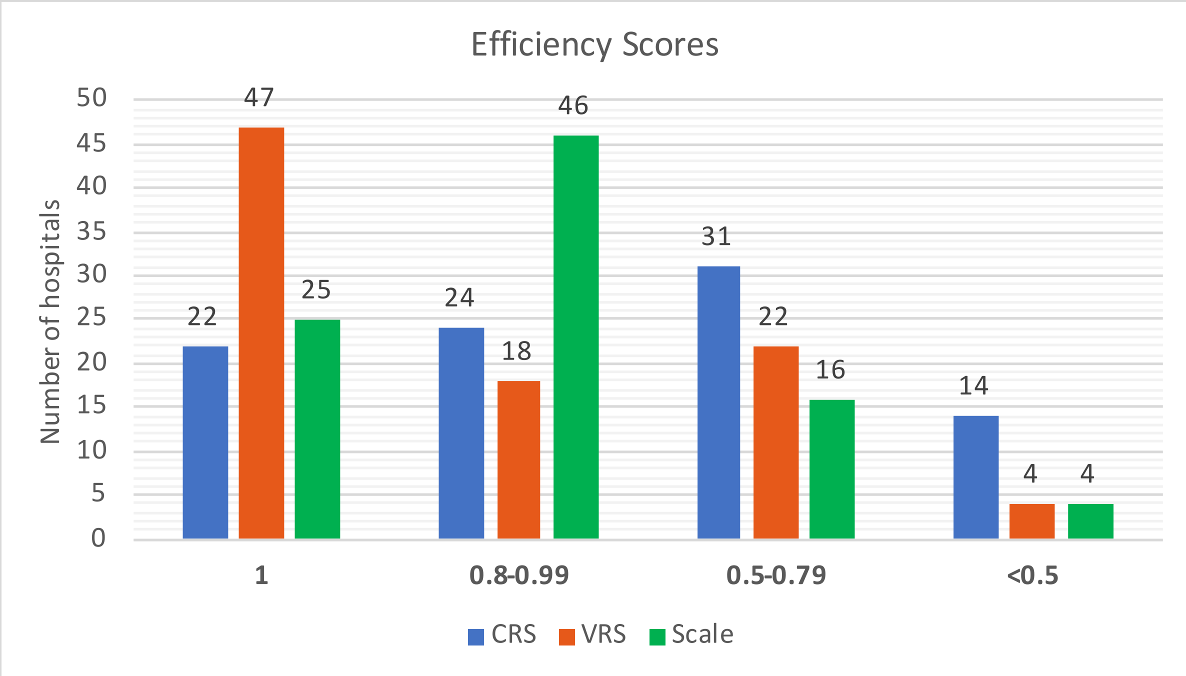

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	0
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2,3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6,7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4,5,6,7
Bias	9	Describe any efforts to address potential sources of bias	*n/a*
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5,6
		(*b*) Describe any methods used to examine subgroups and interactions	7
		(*c*) Explain how missing data were addressed	7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	8
		(*e*) Describe any sensitivity analyses	n/a
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8,9
		(b) Indicate number of participants with missing data for each variable of interest	7
Outcome data	15*	Report numbers of outcome events or summary measures	9,10,11,12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9,10
		(*b*) Report category boundaries when continuous variables were categorized	9,10,11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11,12
Discussion			
Key results	18	Summarise key results with reference to study objectives	12,13,14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14,15
Generalisability	21	Discuss the generalisability (external validity) of the study results	13,14,15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Efficiency evaluation of public hospitals in Saudi Arabia: An application of Data Envelopment Analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2019-031924.R1
Article Type:	Original research
Date Submitted by the Author:	10-Aug-2019
Complete List of Authors:	Alatawi, Ahmed; Liverpool School of Tropical Medicine, Health Economics, department of Clinical Sciences Koronakos, Gregory; University of Pireaus, Department of Informatics Niessen, Louis; Liverpool School of Tropical Medicine, Health Economics; University of Warwick, Dept of Health Sciences Khan, Jahangir; Liverpool School of Tropical Medicine, Health Economics; International Centre for Diarrhoeal Disease Research Bangladesh, Health Systems and Population Studies Division
Primary Subject Heading:	Health economics
Secondary Subject Heading:	Health economics, Health policy, Public health
Keywords:	Technical efficiency, Data Envelopment Analysis, Saudi Arabia, Public hospital, General hospital efficiency

Title

Efficiency Evaluation of Public Hospitals in Saudi Arabia: An Application of Data Envelopment Analysis

Authors: Ahmed Alatawi[*,a,b], Gregory Koronakos [d], Louis Niessen[a,e], Jahangir A. M. Khan[c,f]

Affiliations:
[a] Liverpool School of Tropical Medicine, Department of Clinical Sciences, Liverpool, United Kingdom.
[b] University of Al-Jouf, Pharmacy College, Department of Clinical Pharmacy, Skaka, Saudi Arabia.
[c] Liverpool School of Tropical Medicine, Department of International Public Health, Liverpool, United Kingdom.
[d] University of Piraeus, Department of Informatics, Piraeus, Greece.
[e] University of Warwick, Division of Health Sciences, Coventry, United Kingdom.
[f] Karolinska Institute, Department of Learning, Informatics, Management and Ethics, Stockholm, Sweden.

1. **Ahmed Alatawi***, MSc, Pharm.D. **(Corresponding author)**
   PhD Candidate - Health Economist
   Health Economics Group, Department of Clinical Sciences, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Mobile: +4407491496786
   Fax: +44(0)151 705 3370
   Email: Ahmed.alatawi@lstmed.ac.uk

2. **Gregory Koronakos, PhD**
   Postdoctoral in Operational Research
   University of Piraeus, Department of Informatics.
   Karaoli & Dimitriou 80, 185 34, Piraeus, Greece. Email: gkoron@unipi.gr

3. **Louis Niessen, Professor**
   Chair of Health Economics.
   Health Economics Group, Department of Clinical Sciences, Room 1966-206, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Tel: +44 (0)151 705 3779. Email: louis.niessen@lstmed.ac.uk

4. **Jahangir A. M. Khan, PhD**
   Senior Lecturer in Health Economics
   Health Economics Group, Department of International Public Health, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Tel: +44 (0)151 702 9345. Email: jahangir.khan@lstmed.ac.uk

Word count: 5,694
Keywords: Technical efficiency, Data envelopment analysis, Saudi Arabia, Public hospitals, General hospitals efficiency.

Abstract

Objective: In this study we assess the performance of public hospitals in Saudi Arabia. We detect the sources of inefficiency as well as to provide the optimal levels of the resources that provide the current level of health services. We enrich our analysis by employing locations and capacities of the hospitals.

Design: We employ Data Envelopment Analysis (DEA) to measure the technical efficiency of 91 public hospitals. We apply BCC model under variable returns-to-scale (VRS) and input-orientation. The assessment includes four inputs, and six output variables taken from ministry of health databases for 2017. We conducted the performance assessment via the PIM-DEA 3.2 software.

Setting: Ministry of health-affiliated hospitals in the Kingdom of Saudi Arabia (KSA).

Results: Findings identified 75.8% (69 of 91) of public hospitals as technically inefficient. The average efficiency-score was 0.76, indicating that hospitals could have reduced their inputs by 24% without reduction in health-service provision. Small hospitals, (efficiency-score 0.79), were more efficient than medium-sized and large hospitals. Hospitals in the central-region were more efficient (efficiency-score 0.83), than those located in other geographic-locations. More than half of all hospitals (62.6%) were operating sub-optimally in terms of the scale-efficiency, implying that to improve efficiency, they need to alter their production capacity. Performance analysis identified overuse of physician's numbers and shortage of health-services production, as major causes of inefficiency.

Conclusion: Most hospitals in this study were technically inefficient and operating at sub-optimal scale size and indicate that many hospitals may improve their performance through efficient utilization of health resources to provide the current level of health services. Changes in the production capacity are required, to facilitate optimal use of medical capacity. The inefficient hospitals could benefit from these findings to benchmarking their system and performance in light of the efficient hospital within their capacity and geographic location.

Strengths and limitations of this study:

- The study challenged to find data on economic values, severity of cases and quality of services. We expanded the selection of the variables to cover a broad range of health services and resources in the hospitals.
- The hospital mortality rate was included in output variables as a proxy of the service quality in the studied hospitals.
- We did not apply output-oriented DEA models, alternatively, we adopted input-orientation. Because we aimed to estimate the optimum levels of the resources without deteriorating the health services.
- Further estimation of the optimal levels of resources is required, to examine the allocation of these resources among the hospitals.
- This is the first performance assessment of public hospitals in in Saudi Arabia that uses real data obtained directly from official databases of the Ministry of Health.

Introduction

Increasing demand for healthcare and the expenditure required to provide efficient, equitable and effective healthcare systems, are global concerns. The Kingdom of Saudi Arabia (KSA) has experienced these recently, alongside substantial population growth, increased life expectancy and the proliferation of lifestyle-related disease. These have increased the demand for health services at a time of scant resource.[1,2,3]

Under article 31 of the national constitution, the KSA government guarantees free medical care to all citizens.[4] The government finances the public sector annually, largely from revenue derived from oil and gas production.[5] Table 1 shows the proportion of national budget allocated to the KSA's ministry of health (MOH).[6] Thus, the available resources should be utilized optimally.

The MOH is the primary provider of healthcare services in KSA, administering 60% of all provision. [7] It is the dominant provider of health services in the public sector.[7,8] Other government agencies, including the ministry of defence, the national guard and universities, share the remaining of healthcare provision, as does the private sector.[5] The MOH delivers primary, secondary and tertiary healthcare through 2,361 primary healthcare centres and 282 hospitals, administering 43,080 beds throughout the country.[6] Other MOH functions include strategic planning, formulation of health policy, supervision of all health service delivery programs and the monitoring and management of all other health-related activities.[7] Public (MOH-affiliated) hospitals in KSA can be broadly classified into two groups, general hospitals with different capacities (number of beds) and specialised hospitals. General hospitals provide a wide range of health services, while specialised hospitals deliver health services for a specific health condition or to a particular group of beneficiaries. General hospitals in KSA are located in various geographic locations and serve populations of different demographic characteristics and needs, which may affect the hospital performance, as observed in other studies [4,9].

Table 1: *Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal)*

Year	Government Budget Billion SR	MOH Budget Billion SR	Percentage of MOH to the government budget	No. of Hospitals	No. of Beds
2013	820	54.3	6.63%	268	38970
2014	855	59.9	7.02%	270	40300
2015	860	62.3	7.25%	274	41297
2016	840	58.9	7.01%	274	41835
2017	890	67.7	7.61%	282	43080

Source; Ministry of Health; Statistical yearbook, 2017.

During 2015, KSA government spending on health was 71.3% of the country's total health expenditure, which corresponds to 4.1% of GDP for that year.[10] Healthcare expenditure in KSA increased by 24.7% between 2013 and 2017.[1,2,6] While public spending on health in KSA is remarkably high in comparison to many high-income countries (71.3% for KSA versus 61.2% for high-income countries), the number of hospital beds is considerably lower. [3,10] Just 2.7 hospital beds per 1,000 people are allocated in KSA, whereas the average corresponding figure in other high-income countries is 8.9.[3,10] A previous study suggested that demand for healthcare services in KSA would increase by 145% by 2025 and require twice the number of hospital beds.[11]

Although much has been done to promote the efficient use of resources, this has proven insufficient to meet the rising health expenditure and demand for healthcare in KSA.[12] Providers seem to find it very challenging to deliver adequate provision using current resources.[4] There seems to be an imbalance between health service availability and health spending, so better use of resources is necessary if KSA is to have an efficient and appropriate health system.[12]

Governments worldwide conduct performance assessment of their health sectors, to ensure that public funds are effectively utilized.[13] Efficiency evaluation is carried out under different concepts, such as technical, allocative, cost and overall efficiency.[13] However, the most performance studies are devoted to measuring the technical efficiency. Of these, the technical efficiency approach is most commonly used. This is based on Farrell's theory of 1957, which introduced a measure of technical efficiency based on comparison of the inputs and outputs of set entities, called decision making units (DMUs).[14]

Hospital efficiency is crucial to the efficiency of the health system generally, as hospitals are key consumers of health resources.[15,16] Hanson et al. (2002) found that public hospitals consume around 40% of the total state health budget in many sub-Saharan African countries.[15] Public hospitals used almost 44% of national health spending in the United Kingdom in 2012/13.[17]

In general, there is a scarcity of studies and empirical works on the performance assessment of public hospitals, and that rarity is particularly acute in the context of KSA.[18] Systematic review of public hospital efficiency studies in the Gulf region and similar countries has shown the number of studies to be limited, as efficiency analysis is a novel approach to research in the Gulf, including KSA.[18] The review found only two studies based in KSA context; a study by Helal and Elimam in 2017 [19], which assessed the efficiency of health services at districts level in KSA using MOH data from 2014. Another efficiency analysis conducted in 2013 of 20 public hospitals, under private sector management in KSA, which found that 60% of the study sample had not achieved the efficient score.[20]

Hospital efficiency has hitherto been measured mainly by frontier analysis methods, either through non-parametric data envelopment analysis (DEA) or as parametric stochastic frontier analysis (SFA).[13] These methods compare hospital performance with an estimated efficient frontier comprising the best-performing hospitals.[21,22]

Data envelopment analysis has for many years been the most commonly-used technique for measuring the relative efficiency in healthcare .[16,23] Systematic reviews of efficiency studies have often found that DEA to be the predominant method of public hospital efficiency assessments among studies reviewed.[16,18,23] Hollingworth et al. (2003, 2008) conducted systematic reviews of efficiency analysis internationally and noticed that DEA was used in around the half of studies, a further fifth used DEA in with some form of secondary regressions. [16,23] Another review[22], of efficiency in Iranian hospitals, found DEA was applied in all reviewed studies; three of those studies also used SFA to estimate efficiency scores. A systematic review of health system efficiency studies in OECD countries[24] found DEA applied in 64% of studies.

In this study we conduct a performance assessment of the MOH-administered general hospitals in KSA. We measure the technical efficiency of public hospitals and identify the sources of inefficiency and estimate the optimal levels of the resources. We also provide subscriptions for improvements so as the inefficient hospitals to be rendered efficient. At a post optimality phase, we enrich our analysis by employing information about the geographical location and the capacity (number of beds) of the hospitals. Thus, this performance assessment provides useful information to the decision-makers, which can be employed for policy reforms, to optimise the use of health resources in public hospitals and consequently improve the efficiency of healthcare systems.

Methods

Population and selection of sample

As the application of DEA is based on a homogenous (comparative) sample that use similar inputs to produce similar outputs, we focused on examining the technical efficiency for general hospitals.[13]

Hollingsworth (2008) and Varabyova (2016) argued that sample hospitals should be of same type and provide the same services and health activities.[23,24] Since the inclusion of divergent specialist units in the same sample will confound the results — frontier techniques are susceptible to outliers.[23,24] Specialised hospitals often lack types of secondary service, e.g. surgical operations rarely occur in psychiatric hospitals, and such hospitals, if included, will appear as inefficient while surgery is a considered as one of the outputs.[22,23,25] Specialised hospitals were therefore excluded from this analysis. Similarly, small hospitals (with 50 beds or fewer) provide primary care services while lacking secondary and tertiary health services, and consequently miss a significant number of output variables (e.g. inpatient services, patient discharge, surgical operations, laboratory testing) compared to bigger hospitals. In this study we excluded also the smaller hospitals, to ensure greater homogeneity in performance evaluation across the units.[13,26]

Ultimately, the homogenous sample used in the analysis included 21,528 out of 398,68 (54%) of the total active hospital beds provided by the MOH in KSA. We included in the assessment 97 general hospitals and removed six of them, due to missing data. The data of hospital inputs and outputs for 2017 was collected by the lead author from official statistical, informational and research databases of Administration of Statistics and Information and Administration of Research and Studies, which affiliated of the MOH, following approval from the designated authority. Data collection took place from May to July 2018.

The sample hospitals are in 64 cities, affiliated to 20 administrative districts, located in five geographic regions, namely central, west, east, south and north regions. The general hospitals in the sample are classified into four groups based on their capacity (number of beds): small (fewer than 200 beds), lower-medium (200 to 299 beds), upper-medium (300 to 499 beds) and large (500 or more beds) hospitals, following Gok's[27] categorization. However, these hospitals are affiliated, organized and funded by the MOH, and have not autonomy in term of funding or organising structure by themselves or other agents. Thus, we applied the DEA model for all 91 hospitals. Then, we presented the efficiency scores in each capacity and each geographic location. Figure 1 illustrates number of hospitals and hospital-beds in each category of capacity and location.

Figure 1 to be inserted here

Inputs and outputs

Selection of input and output variables is a crucial step in performance measurement, because the results of any efficiency assessment depend significantly on the variables used in the estimation models.[28] The literature has focused on labour (e.g. health professionals) and capital (e.g. number of beds), as input variables, while some studies included consumable resources.[13,28] The main categories of output used in healthcare-related efficiency studies were healthcare activities (e.g. number of outpatient visits, inpatient services, number of surgeries) and health outcomes (e.g. mortality rate).[13, 22,24]

In our study we selected the hospital outputs that dependent on the selected inputs, which cover a broad range of health services provided and health resources used by public hospitals in KSA. In particular, four inputs and six outputs were chosen based on the availability of the data in KSA context, which were rationally approved in previous theoretical and empirical studies[13,16,23].

The input variables chosen are: (1) number of hospital beds; (2) number of full-time physicians; (3) number of full-time nurses and (4) number of full-time allied health personnel (i.e. pharmacists, midwives, medical technicians, medical radiologists, physiotherapists) employed in the hospital. The output variables used in this study are: (1) outpatient visits (number of patients receiving outpatient treatment within a year); (2) discharged patients (number of patients receiving inpatient treatment within a year); (3) total number of surgical operations during the year; (4) number of radiological investigations conducted in hospital during the year; (5) number of laboratory tests during the year; (6) hospital mortality rate (ratio of inpatient deaths during hospitalization to the total number of inpatients that year). The last output variable is an indicator of health service quality and health outcomes in hospital, as argued by Sahin and Ozcan[29]. Reduction in the mortality rate and increase quantity of life signify an improvement in the health outcomes of the public hospital of investigation. Therefore, mortality rate could be a proxy for a weighted health quality measure in this analysis [30]. The inverse value for the mortality rate (one divided by mortality rate) is included as an output value in the assessment, meaning that hospitals with higher mortality rate would have a smaller ratio as output values.[29] As the model assumes that output and input variables are isotonic, (i.e., increased input reduces efficiency as well as increased output increases efficiency). We had to apply this correction, otherwise, a higher mortality rate would incorrectly contribute to a better hospital outcome [30].

The number of hospitals (DMUs in DEA context) should be at least two times larger than the sum of inputs and outputs.[31] However, Hollingsworth (2014)[32] suggested that the number of units used in efficiency assessment should be at least three times the sum of inputs and outputs. In accordance to the above-mentioned rule of thumb, in this study we include 91 hospitals, more than three times the combined number of input and output variables.

Patient and Public Involvement

No patients were involved in this study, and we used anonymous data from MOH databases.

Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a powerful technique that is based on linear programming. It was developed for measuring the performance of a set of comparable entities, called Decision Making Units (DMUs), which convert multiple inputs into multiple outputs[26,32]. In this method each hospital is compared against the estimated efficient frontier comprising the best-performing hospitals.[21,22]

DEA has been already the most commonly-used technique for measuring the relative efficiency in healthcare .[16,23] In systematic reviews we can observe that DEA is the predominant method of public hospital efficiency assessment.[16,18,23] DEA is widely applicable since does not require any a priori specification of the underlying functional form that relates the inputs with the outputs.[13] In addition, use of DEA is justified by its ability to incorporate multiple inputs and outputs in different units of assessment.[13,32]

Several DEA models have been developed to analyze the efficiency based on Farrell's concept[14]. The most well known and basis for the rest DEA models is the CCR model developed by Charnes, Cooper and Rhodes[33], which assumes that production has constant returns to scale (CRS) and the BCC model developed by Banker, Charnes and Cooper [34], under the assumption of variable returns to scale (VRS).[13,16] The choice of CCR or BCC model depends on the context of the problem under examination i.e. the technology linking the inputs to outputs in the transformation process.[13]

Generally, the CCR model — whereby the efficiency frontier has a constant slope (CRS), which means that any change in the inputs results to a proportional change in the outputs [26]. Constant returns to scale CRS may be adopted when machines are involved in the process, which roughly means that the production can be doubled by doubling the levels of inputs. However, when employees (human factor) partcipate in the production process, then it is naive to expect that they could work at a constant rate. The CCR efficiency assessment by the may be affected if the DMUs are not operating on the optimal scale, since CRS does not distinguish between the scale and pure (managerial) technical efficiency.[35] If the efficiency analysis considers a managerial perspective, a BCC technology assumption will be appropriate to understand if a scale of operations or provider's practice affects productivity.[27,36] Scale efficiency is defined as a ratio of CRS to VRS efficiency scores and provides evidence whether the DMU is operating on the optimal scale size.[16,24] Furthermore, the efficiencies of DMUs can be comprehensively analysed using both CCR and BCC assumption for more realistic changes in production process, and implications in the real world.[13,26] Other systematic reviews[24,25] have reported similar findings where studies used both CCR and BCC assumptions in efficiency measurements.

Rationally, the commonly-used orientations in DEA analysis are input orientation (i.e. minimization of inputs with the given amount of outputs) and output orientation (i.e. inputs are held constant and outputs are proportionally increased).[26] Previous empirical studies [35] have argued that hospitals have relatively little control over their outputs (for example, expanding surgical operations), but more control over the inputs (e.g. medical devices), where they have the social responsibility to provide medical treatment through the public hospitals in general. Thus, most studies adopt input orientation for efficiency assessment of the hospitals.[24,25,37] In a few studies output orientation is adopted in response to the strategic health plans of the countries aiming to expand healthcare provision during a specific period.[38,39] However, in our study we aim to estimate the optimal levels of the resources without deteriorating the levels of the health services that the hospitals provide. In this way, we provide the central authorities with the potential savings that could be made in the health sector.

The efficiency of a hospital is defined as the ratio of the weighted sum of outputs (total virtual output) to the weighted sum of inputs (total virtual input), with the weights being obtained in favour of each evaluated unit by the optimization process. The basic BCC model that provides the BCC efficiency for the hospital $_{jo}$ is given below:

$$\begin{aligned} &max\ e_{j_0} = \frac{\omega Y_{j_0} - \omega_o}{\eta X_{j_0}} \\ &s.t. \\ &\frac{\omega Y_j - \omega_o}{\eta X_j} \leq 1, \quad j = 1,\ldots,n \\ &\eta \geq 0, \omega \geq 0 \end{aligned} \tag{1}$$

Assume n DMUs, each using *m* inputs to produce *s* outputs. We denote by y_{rj} the level of the output *r(r=1,…,s)* produced by unit *j* (*j=1,…,n*) and x_{ij} the level of the input *i* (*i*=1,…, *m*) used by unit *j*. The vector of inputs for DMU *j* is $X_j = (x_{1j},\ldots,x_{mj})^T$ and the vector of outputs is $Y_j = (y_{1j},\ldots,y_{rj})^T$. The model (1) is formulated and solved for each hospital in order to obtain its efficiency score. The variables $\eta=(\eta_1,\ldots,\eta_m)$ and $\omega=(\omega_1,\ldots,\omega_s)$ are the weights associated with the inputs and the outputs respectively. These weights are calculated in a manner that they provide the highest possible efficiency score for the evaluated hospital $_{jo}$.

The BCC model (1) can be transformed to a linear program by applying the Charnes and Cooper (1962) transformation (C-C transformation hereafter)[40]. The transformation is carried out by considering a scalar $t \in \Re^+$ such as $t\eta X_{j_0} = 1$ and multiplying all terms of model (1) with *t>0* so that $v = t\eta$, $u = t\omega$, $u_o = t\omega_o$. The linear equivalent of model (1) is expressed as:

$$
\begin{aligned}
& max\, uY_{j_0} - u_0 \\
& s.t. \\
& vX_{j_0} = 1 \\
& uY_j - u_0 - vX_j \le 0, \quad j = 1,\ldots,n \\
& v \ge 0, u \ge 0
\end{aligned}
\qquad (2)
$$

Once an optimal solution v^*, u^*, $u_o{}^*$ of model (2) is derived, the input oriented CCR-efficiency $e^*_{j_0}$ for the hospital$_{jo}$ under evaluation is obtained directly from the objective function.

The prevailing returns to scale can be identified by the optimal solution of both multiplier and envelopment BCC models. Banker et al (1984) determined the returns to scale (RTS) using the optimal value of the free variable in the multiplier models [34]. Given the point (x_0, y_0) that lies on the efficient frontier, the returns to scale at this point are identified by the following three conditions:

1. Increasing returns to scale (IRS) prevail at (x_0, y_0) if and only if $u_o^* < 0$ for all optimal solutions. Meaning the increase in all production factors (inputs) resulted in more production (outputs).

2. Decreasing returns to scale (DRS) prevail at (x_0, y_0) if and only if $u_o^* > 0$ for all optimal solutions, meaning an equal increase in all production factors led to less production.
3. Constant returns to scale (CRS) prevail at (x_0, y_0) if and only if $u_o^* = 0$ in any optimal solutions, where equal increase in all production factors led to the same amount of increase in production.

Improvement management software (PIM-DEA version 3.2) was used for DEA analysis.[41]

Results

Descriptive statistics, concerning the inputs and outputs of 91 general hospitals during 2017, are presented in Table 2. The average hospital size is 236.57 beds, with a range of 100 to 711 beds. Full-time physicians ranged from 38 to 894, with a mean of 212. The number of nurses is on average 495 but ranged from 74 to 1,930. Full-time allied health personnel ranged from 37 to 1,149, with an average of 280.

Table 2: *Descriptive statistics of the inputs and outputs of the 91 hospitals*

	Mean	Standard Deviation	Min	Max
Inputs				
Hospital beds	236.6	137.6	100	711
Physicians	212.3	168.7	38	894
Nurses	495.2	403.6	74	1,930
Allied Health Personnel	280.1	219.1	37	1,149
Outputs				
Outpatient visits	72,986.5	72,475.3	1,785	466,608
Discharged patients	26,016.4	55,856.4	19	503,216
Surgical operations	2,638.4	2,151.2	172	9,464
Laboratory tests	965,840.8	1,095,415.6	794	5,512,774
Radiology Investigations	53,531.4	46,788.7	107	221,980
Hospital mortality rate	0.0224	0.0212	0.0003	0.125

Concerning the outputs, the average number of patient visits to outpatient departments is 72,986 and ranged from 1,785 to 466,608 visits. Discharged patients receiving inpatient services during 2017 averaged 26,016, ranging from 19 to 503,216. Surgical operations ranged from 172 to 9,464 with a mean of 2,638 surgeries per hospital. Means for laboratory and radiology tests are 965840 and 53531 respectively, during 2017. Average mortality rate is 2.24%.

Table 3 presents the results of DEA models, summary statistics of average technical (CRS and VRS) efficiency, and scale (SE) efficiency scores, as well as concerning the return to scale

Table 3: *Technical efficiency scores and returns to the scale of the public hospitals in KSA*

	CRS technical efficiency	VRS technical efficiency	Scale efficiency	CRS [N (%)]	IRS [N (%)]	DRS [N (%)]
All hospitals (n=91)						
Mean	0.76	0.87	0.87	34 (37.4)	40 (44)	17 (18.6)
Std. Dev.	0.23	0.18	0.18			
Min	0.11	0.30	0.19			
No. full score	22 (24.2%)	47	25			
Large hospitals: >=500 beds (n= 8)						
Mean	0.65	0.75	0.87	2 (25)	1 (12.5)	5 (62.5)
Std. Dev.	0.27	0.30	0.13			
Min	0.28	0.30	0.59			
No. full score	1 (12.5)	4	1			
Upper-medium hospitals: 300-499 beds (n= 22)						
Mean	0.76	0.80	0.94	7 (31.8)	5 (22.7)	10 (45.5)
Std. Dev.	0.19	0.19	0.07			
Min	0.39	0.41	0.76			
No. full score	3 (13.6)	7	3			
Lower-medium hospitals: 200-299 beds (n= 22)						
Mean	0.73	0.79	0.90	10 (45.5)	10 (45.5)	2 (9.1)
Std. Dev.	0.25	0.19	0.18			
Min	0.11	0.50	0.22			
No. full score	4 (18.2)	4	4			
Small hospitals: <200 beds (n= 39)						
Mean	0.79	0.96	0.82	15 (38.5)	24 (61.5)	0 (0)
Std. Dev.	0.23	0.09	0.22			
Min	0.19	0.67	0.19			
No. full score	13 (33.3)	31	13			

The average CRS technical efficiency score for MOH general hospitals is 0.76, with a standard deviation (SD) of 0.23, which indicates that these hospitals could reduce use of all their inputs on average by 24% without any reduction in the number of services provided. Also, the VRS technical score on average is 0.87 (SD 0.18). The distribution of technical, pure technical and scale efficiency scores is given in Figure 2.

Figure 2 to be inserted here

The lowest technical efficiency score reported is 0.11, but 22 hospitals out of 91 (24.2%) are both technically and scale efficient, which indicates that these hospitals utilize optimally their inputs. Among the inefficient hospitals 55 hospitals (60.4%) achieved efficiency scores of at least 0.50 efficiency level (Figure 2) and 14 hospitals (15.4%) reported efficiency scores below 0.50. Average scale efficiency scores are 0.87, with (SD 0.18). Although 47 hospitals (52%) reported an efficient score on VRS (pure efficiency), only 25 (27%) hospitals are efficient on the scale.

Concerning the returns to scale , we have found that 34 hospitals (37.4%) operate under constant returns to scale (CRS); while 40 hospitals (44%) operate under increasing returns to scale (IRS), and 17 hospitals (18.6%) decreasing returns to scale, However, hospitals that were operating on either IRS or DRS needed to alter their capacity to operate on the optimal scale size i.e., at the constant return to the scale, which would be required to achieve technical efficiency.

We present in table 3 the efficiency scores of the 91 hospitals for each capacity (size category). From the capacity perspective, small hospitals had higher levels of technical (CRS and VRS) efficiencies than medium-sized (both lower- and upper-medium) and large hospitals. Table 3 shows that small hospitals have on average technical efficiency of 0.79 (SD 0.23); one-third of hospitals in this category are technically and the scale efficient. Average technical efficiency of lower-medium hospitals is 0.73 (SD 0.25), with a higher percentage of inefficient hospitals (81.8%), than for small hospitals. Although upper-medium-sized hospitals reported a slightly higher average technical efficiency score of 0.76 (SD 0.19), fewer hospitals in this category reported an efficient score, meaning a higher percentage of inefficiencies (86.4%). Large hospitals were the least efficient when compared to other categories. The average technical efficiency of large hospitals was 0.65 (SD 0.27), only one was technically efficient.

Regarding scale-efficiency scores, upper-medium (0.94) and lower-medium (0.90) sized hospitals operate at a more optimal scale than small (0.82) or large hospitals (0.87). Also, 45.5% of lower-medium hospitals operate on the CRS, followed by small hospitals (38.5%). However, most of the remaining hospitals in these categories, i.e. lower-medium (45.5%) and small size (61.5%) hospitals are operating on IRS. In contrast, most large hospitals (62.5%) showed DRS, and two of them were on CRS, indicating a need to downsize these hospitals to improve technical efficiency. Similarly, 45.5% of upper-medium-sized hospitals operate on DRS and one-third of this category are operating (CRS).

Table 4 shows the average efficiency scores in five geographical regions, however, based on the analysis of all 91 hospitals together. Hospitals in the central region reported the highest average technical efficiency score of 0.83 (SD 0.18), followed by eastern hospitals with an average score of 0.80 (SD 0.28). Hospitals in western KSA reported the least average score, 0.68 (SD 0.20).

Table 4 Technical efficiency scores and returns to the scale of the hospitals categorized by location

	CRS technical efficiency	VRS technical efficiency	Scale efficiency	CRS [N (%)]	IRS [N (%)]	DRS [N (%)]
South region hospitals (n= 22)						
Mean	0.75	0.89	0.83	9 (40.9)	9 (40.9)	4 (18.2)
Std. Dev.	0.25	0.18	0.23			
Min	0.11	0.41	0.22			
No. full score	4 (18.2)	13	4			
East region hospitals (n =8)						
Mean	0.80	0.85	0.90	4 (50)	1 (12.5)	3 (37.5)
Std. Dev.	0.28	0.21	0.16			
Min	0.27	0.50	0.54			
No. full score	1 (12.5)	4	1			
North region hospitals (n =17)						
Mean	0.75	0.84	0.90	7 (41.2)	9 (52.9)	1 (5.9)
Std. Dev.	0.28	0.23	0.20			
Min	0.19	0.30	0.19			
No. full score	6 (35.3)	9	6			
Central region hospitals (n =24)						
Mean	0.83	0.89	0.93	10 (41.7)	11 (45.8)	3 (12.5)
Std. Dev.	0.18	0.16	0.10			
Min	0.49	0.50	0.69			
No. full score	8 (33.3)	12	8			
West region hospitals (n =20)						
Mean	0.68	0.85	0.81	4 (20)	10 (50)	6 (30)
Std. Dev.	0.20	0.17	0.17			
Min	0.37	0.42	0.46			
No. full score	3 (15)	9	3			

The percentage of efficient hospitals in the north (35.3%) and the central (33.3%) regions are higher than the other regions. the eastern, western and southern regions have a higher percentage of inefficient hospitals. Both central and southern regions reported relatively higher VRS efficiency score of 0.89. In terms of average scale efficiency scores, central region hospitals (0.93), and hospitals in the north- and east (both 0.90) were operating at more optimal scale than those in the west (0.81) and south (0.83). Half of the sample hospitals in the east region operate on CRS, followed by hospitals in the central and north regions (both 41%). The findings also revealed that 52.9 % of north region hospitals were operating on IRS, while 37.5% of east region hospitals were operating on DRS.

The performance analysis identified the slacks, which showed either excess input utilization or shortages of output production. Table 5 shows the average amount of slack in hospitals deemed inefficient. These results represent the combined scores of slack for all inefficient hospitals, for each input and output. Table 5 also shows the percentage of change (slacks) in the number of inputs or outputs required to eliminate the inefficiencies and achieve target levels.

Table 5 Slacks evaluation for inefficient hospitals

Input slacks	Mean (SD)	Percentage of change
Hospital beds	48.4 (76.6)	-20.4%
Physicians	47.5 (72.6)	-22.4%
Nurses	102.9 (173.1)	-20.8%
Allied Health Personnel	58.38 (98.3)	-20.84%
Output slacks		
Outpatient visits	8866.1 (23712)	12.2%
Discharged patients	3700.6 (8214.2)	14.2%
Surgical operations	282.6 (730.9)	10.7%
Laboratory tests	66105.6 (140332.4)	6.8%
Radiology Investigations	2204.6 (6944.1)	4.1%
Mortality rate	0.006 (0.014)	21.7%

In terms of input, results show that an excess of physicians was the main cause of inefficiencies in public hospitals. A feasible, achievable reduction in the number of physicians was on average 22.38 % of the current values (compared with the amounts given in Table 2). The next most substantial slack was observed in allied health personnel, at 20.84%. Surpluses of hospital beds and nurses were also important causes of inefficiency and should be reduced on average by 20.44% and 20.77%, respectively. In addition to the input reduction, the average number of services should be increased to meet targets. Furthermore, the quality of health services in public hospitals would have improved with a decrease in the hospital mortality rate.

Discussion

This study evaluated the technical efficiency of public hospitals affiliated to the KSA's MOH, using data envelopment analysis. Analysis showed 75% of sample hospitals could not utilize their intact resources to generate specified outputs. The average CRS technical efficiency score was 0.76, indicating that hospitals could produce their current level of outputs with 76% of inputs currently used, and thereby achieve efficiency. Efficiency scores ranged from 0.11 to 1.00 (Figure 2), revealing considerable variations in efficiency scores among hospitals. Moreover, the average VRS technical efficiency and scale efficiency scores were both 0.87. This indicated that inefficiency was due to administrative failure to overcome external environmental factors, and inability to manage internal operations in the hospitals. Notably, Helal and Elimam [19] in 2017, assessed the efficiency of health services at districts level in KSA based on MOH data 2014, found an average efficiency score of 0.92, and 45% of the districts achieved the technical efficiency score. An efficiency analysis of 20 public hospitals, under private sector management in KSA, found that 60% of the study sample had not achieved the efficient score, with an average score of 0.84.[20]

Results of the study presented here suggest that small hospitals were relatively more technically efficient than medium-sized and large hospitals (Table 2). Other efficiency studies have reported similar findings: Gok [27] found that small hospitals achieved higher efficiency scores than medium-sized and large ones. This might be due to the differing locations and missions of small and large hospitals.[27,36] In this study's sample, small hospitals were mainly in peripheral cities and towns in KSA, which lacked other sources of public or private healthcare. Service provision in those hospitals might be relatively high compared to the health resources used. Large hospitals (500 or more beds) tended to be in larger cities in urban areas, where many other health providers shared the healthcare of much of the urban population, which might generate a relatively decreased level of health services production in respect of inputs used.

Regarding the different missions, large hospitals consumed a high amount of health resources to meet the various requirements of comprehensive care.[27] Since some of these were teaching hospitals, however, teaching activities were not counted in the outcome measurements.[27,28] In such large hospitals, treatment processes might be more complicated, and some of the productions of these hospitals could not be assessed in the hospital outcomes.[42]

This study found 57 hospitals (62.6%) operating on non-optimal scale size; 44% were operating on the IRS, while 18.6% showed DRS (Table 3). This indicated that the efficiency of healthcare in KSA might be improved through downsizing of hospitals on DRS and reallocating these inputs to the hospitals operating in the IRS. Moreover, five out of eight large hospitals (500 or more beds) were operating on DRS, implying that to improve efficiency, they needed to reduce their production capacity. This is supported by other research findings.[43]

This study found that 61.5% of small hospitals had been operating on IRS, none was on DRS. It can thus be argued, like Kiadaliri and colleagues (2011), that the increase of capacity (inputs) of this category should be increased by reallocating resources from the larger hospitals for improving efficiency [43]. The efficient scale of public hospitals was in medium-sized establishments (200 to 499 beds). Although half of the hospitals located in the east were operating on the most productive scale size (CRS), three were operating on DRS. Around 53% of the hospitals in the north were operating on IRS, whereas 30% of western region hospitals, which reported the lowest efficiency scores, were operating on DRS.

Our analysis found that hospitals located in the west region were relatively less efficient than hospitals located in other regions. The central region hospitals appeared to be the efficient. Atılgan[44] reported in the same line as our findings, i.e. location-specific differences in efficiency scores for general MOH hospitals in Turkey. Atilgan argued that this could be due to case mix and/or case severity differences between hospitals. We can similarly argue that hospitals in the west region might be treating more severe cases than hospitals in other regions in KSA, which might have led to different levels of efficiency scores in hospitals across regions.[22] Another explanation could be that hospitals in this region consumed more inputs in anticipation of the annual pilgrimage season, for which government of KSA allocates more resources to such hospitals.

Regardless of the capacity or location-based performance variations, improving the scale efficiency of hospitals would require long-term effort, reflected in amendments to health policies, strategic plans and the autonomy of hospital-managers.[43] The prevailing ability of patients to access health services should not be compromised while reallocating the resources to the other hospitals until Pareto optimality is achieved.[13]

The use of DEA can identify sources of inefficiency, helping hospital managers and health policy-makers to reach informed decisions.[36] The analysis showed that the number of full-time physicians was the most notable reason for inefficiency, with an average excess of 22.4%, from an input perspective. Other inputs among labour variables that showed a surplus in use were the number of nurses and the number of allied health personnel, in addition to excess number of hospital beds (capital variable). Analysis revealed a shortage of outputs production, e.g. hospitals needed to increase the number of outpatients and hospitalized inpatient services on average by 12.2% and 14.2% respectively, to be efficient.

Given the previous findings, health policy-makers might consider redeploying their labour forces from inefficient hospitals to more efficient ones.[36,43] Public hospitals should effectively utilize existing beds to increase efficiency. For example, in this study many large hospitals had been operating on DRS; however, most of the small hospitals were operating on IRS. Healthcare administrators should assess the legal conditions and regulations for the effective use of medical capacity in light of the findings of this slack analysis.

It had been argued by Afzali[28] and Hollingsworth[16] that many hospital databases are compromised by insufficient data on a broad range of hospital functions and care, e.g. preventive care, health promotion, staff development activities. Thus, improving hospital's databases through high quality data collection and processing techniques — including data from different health provision levels, capturing valid data that reflects the severity of cases and related health services, quality of care and pattern of activities — is very important.[29,44] Such improvement would facilitate further efficiency research by indicating weaknesses in healthcare production processes and consequently would guide policy-makers in potential reforms of health policy and directives.

In recent years, KSA has been facing the global trends of rising healthcare costs in addition to high growth rate of population and high prevalence of chronic diseases. The government thus realized that the existing healthcare financing system with oil revenue is unsustainable[45]. It thus can be argued that optimum use of existing health resources, which is a fundamental requirement for achieving universal health coverage as advised by the World Health organization[46] can appropriately be applied for KSA. An application of these findings are useful for high income, and Gulf countries in particular, which have the same health financing systems and comparable demand for health services.[2,3,18] Our findings from this current analysis of KSA public hospitals indicated that there is large scope for improving efficiency in utilizing healthcare resources. We recommend the policy-makers to consider the appropriate use of resources within hospitals as well as reallocate resources across hospitals, given the findings of this research. Thus, to meet the efficient use of health resources to ensure the maximum value for money, which is expected to contribute significantly towards achieving universal health coverage in KSA.

The study faced the challenges of finding data on economic values of the inputs, also severity of cases and quality of services of the outputs. We, however, could use the mortality rate as the proxy for quality of services. The performance assessment is devoted on how to utilize optimally the resources of the health sector in order to provide the given levels of health services. Thus, we rationally adopted input orientation in the assessment. However, DEA methodology also permits the assumption of output orientation. We did not apply output-oriented DEA models because outputs of different type than the ones used in the current study would need to be available.

In this study we provide the optimal levels of resources that render efficient each hospital given the health services levels that each one of them provides. Further to estimating the optimal levels of resources, a different yet important assessment is to examine the allocation of these resources among the hospitals. This extension is left for future research. Despite a few limitations, the study site (KSA), and data sources might create strong interest among policy-makers, stakeholders, researchers and academics. This is the first research study of technical efficiency based on official data from KSA, that has considered public hospital capacities and geographical locations.

Concluding Remarks

Given the scarcity of resources, growing expenditure on health and demand for health services, more attention should be paid to improving the efficiency of healthcare by better utilization of current resources. In this study, inefficiency existed in most public hospitals, and these could reduce their inputs by 24% without any reduction in service provision. Small hospitals and hospitals in the central region of KSA were relatively more efficient. A high proportion of hospitals were operating at non-optimal scale size, while an efficient scale of operation was observed in medium-sized hospitals.

The finding suggests that it would be helpful to adjust production capacity by downsizing hospitals operating on DRS and reallocating the resources to hospitals on the IRS, as reflected in the scale analysis. The application of these findings will require collaboration between health administrative, policy planning and daily operations management, to fill the administrative gap and thus overcome external environmental factors and manage internal hospital operations.

Performance analysis shows the surplus of the health workers and a shortage of health services to be major causes of inefficiency, implying that health regulators might redeploy their labour forces for effective utilization of medical capacity. A possible reallocation of resource must take place without compromising patients' current access to public-funded health services. We encourage further research in technical and allocative efficiency, to provide more specific results with a spotlight on inefficiency causes, given the goals, functions and strategic plans of public hospitals in KSA.

Acknowledgement

We are grateful for the Ministry of Education and the government of Saudi Arabia for unlimited support. The authors would like to thank of the Administration of Statistics and Information and the Administration of Research and Studies in the Ministry of Health for providing access to the hospital's databases. Special gratitude to Mr Nabil A. Othman and Ms Nuwayyir Alshalawi at Administration of Statistics and Information for their contributions through permitting to use the administration's access to the necessary databases to complete the data collection.

Contributors

AA, GK, LN and JK contributed to conceptualizing the research question, study design and settings and literature search. AA contributed to data collection and variable extraction. AA, GK and JK conducted the data analysis, interpretation, and writing the manuscript. AA, GK, LN and JK contributed to writing, reviewing and revising the manuscript. All authors finally reviewed the manuscript critically and approved the final version for submission.

Funding

There is no funding agency in the public, commercial or not-for-profit sectors to report for this submission.

Competing interest

None declared.

Data sharing statement

Data were extracted from the hospital databases at Administration of Statistics and Information in The Ministry of Health. Additional data are available if requested.

Ethics approval

Ethics approval was obtained from the Ethics Committee of Institutional Review Board (IRB) of King Fahad Medical City, the Ministry of Health in Saudi Arabia (IRB log No. 18-166E).

Patient consent for publication

Not required.

References

1. Khoja T, Rawaf S, Qidwai W *et al*. Health care in Gulf Cooperation Council countries: a review of challenges and opportunities. *Cureus* 2017;9(8):e1586. DOI 10.7759/cureus.1586.
2. Ardent Advisory & Accounting. *GCC healthcare sector report. A focus area for governments.* Abu Dhabi, UAE, 2015 Accessed: January 2018: DOI: http://www.ardentadvisory.com/files/GCC-Healthcare-Sector-Report.pdf

3. Ram P. Management of healthcare in the Gulf Cooperation Council (GCC) countries with special reference to Saudi Arabia. *International Journal of Academic Research in Business and Social Sciences* 2014; 4(12). DOI: 10.6007/IJARBSS/v4-i11/1326.
4. Albejaidi F. Healthcare system in Saudi Arabia: an analysis of structure, total quality management and future challenges. *Journal of Alternative Perspectives in the Social Sciences* 2010;2(2):794-818.
5. Al-Homayan A, Shamsudin F, Subramaniam C, Islam R. Analysis of health care system — resources and nursing sector in Saudi Arabia. *Advances in Environmental Biology* 2013;7(9), pp. 2584-2592.
6. MOH portal.com. *2017 Annual Statistical Book* Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/ANNUAL-STATISTICAL-BOOK-1438H.pdf (Accessed Oct. 2018).
7. Almalki M, FitzGerald G, Clark M. Health care system in Saudi Arabia: an overview. *Eastern Mediterranean Health Journal* 2011;17(10).
8. MOH portal.com. *2015 Annual Statistical Book*. Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/StatisticalBook-1436.pdf.
9. Atilgan E. The technical efficiency of hospital inpatient care services: an application for Turkish public hospitals. *Isletme ve Ekonomi Arastirmalari Dergisi/Business and Economics Research Journal* 2016;7(2): 203–214. DOI: 10.20409/berj.2016217537.
10. The World Bank. *2019 Country Data*. Available at: https://data.worldbank.org/country/saudi-arabia (accessed January 2019).
11. Mourshed M, Hediger V, Lambert T. Gulf Cooperation Council healthcare: challenges and opportunities. 2007; *Arab World Competitiveness Report (Part 5)*;55–64, World Economic Forum, Geneva, Switzerland 2007. DOI: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.183.7279&rep=rep1&type=pdf
12. MOH portal.com. *Ministry of Health Strategic Plan 2010–2020*. Available at: https://www.moh.gov.sa/Portal/WhatsNew/Documents/OKIstragi260p.pdf.(Accessed October 2018).
13. Jacobs R, Smith P, Street A. *Measuring efficiency in health care: analytic techniques and health policy.* Cambridge; Cambridge University, p3–39/91-127, 2006.

14. Farrell MJ. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society* 1957;120(3):253–290.
15. Hanson K, Atuyambe L, Kamwanga J *et al*. Towards improving hospital performance in Uganda and Zambia: reflections and opportunities for autonomy. *Health Policy* 2002;61, 73–94.
16. Hollingworth B. Non-parametric and parametric applications measuring efficiency in health care. *Healthcare Management Science* 2003;6:203–218.
17. Kelly E, Stoye G, Vera-Hernández M. Public hospital spending in England: evidence from National Health Service administrative records. *Fiscal Studies* 2016;37(3-4), pp.433–459.
18. Alatawi A, Ahmed S, Niessen L *and Khan J*. Systematic review and meta-analysis of public hospital efficiency studies in Gulf region and selected countries in similar settings. Cost Effectiveness and Resource Allocation 2019;17(17). doi.org/10.1186/s12962-019-0185-4
19. Helal S, Elimam H. Measuring the efficiency of health services areas in Kingdom of Saudi Arabia using data envelopment analysis (DEA): a comparative study between the years 2014 and 2006. *International Journal of Economics and Finance* 2017;9(4) pp172–184.
20. Abou El-Seoud M. Measuring efficiency of reformed public hospitals in Saudi Arabia: An application of data envelopment analysis. *International Journal of Economics and Management Sciences* 2013;2(9):44–53.
21. Hussey P, de Vries H, Romley J *et al*. A systematic review of health care efficiency measures. *Health Services Research and Educational Trust* 2009; 44(3):784–805. DOI: 10.1111/j.1475-6773.2008.00942.
22. Kiadaliri A, Jafari M, Gerdtham U. Frontier-based techniques in measuring hospital efficiency in Iran: a systematic review and meta-regression analysis. *BMC Health Services Research* 2013;13:312. http://www.biomedcentral.com/1472-6963/13/312
23. Hollingsworth B. The measurement of efficiency and productivity of health care delivery. *Health Economics* 2008;17:1107–28. DOI: 10.1002/hec.1391
24. Varabyova Y, Müller JM. The efficiency of health care production in OECD countries: a systematic review and meta-analysis of cross-country comparisons. *Health Policy* 2016;120(3) 252–263. http://dx.doi.org/10.1016/j.healthpol.2015.12.005

25. Pelone F, Kringos, DF, Romaniello A *et al*. Primary care efficiency measurement using data envelopment analysis: a systematic review. *Journal of Medical Systems* 2015;, 39(1):156.

26. Cooper W, Seiford L, Tone K. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Springer, New York, p1-85, 2007. DOI: 10.1007/978-0-387-45283-8

27. Gok MS, Sezen B. Analyzing the ambiguous relationship between efficiency, quality and patient satisfaction in healthcare services: the case of public hospitals in Turkey. *Health Policy* 2013;111(3), pp 290-300. http://dx.doi.org/10.1016/j.healthpol.2013.05.010

28. Afzali HH, Moss JR, Mahmood MA. A conceptual framework for selecting the most appropriate variables for measuring hospital efficiency with a focus on Iranian public hospitals. *Health Services Management Research* 2009;22(2):81–91. DOI: 10.1258/hsmr.2008.008020

29. Sahin I, Ozcan YA. Public sector hospital efficiency for provincial markets in Turkey. *Journal of Medical Systems* 2000;24(6), pp 307–320.

30. Ahmed S, Hasan MZ, MacLennan M, et al. Measuring the efficiency of health systems in Asia: a data envelopment analysis. BMJ Open 2019;9: e022155. doi:10.1136/bmjopen-2018-022155

31. Dyson R, Allen R, Camanho A *et al*. Pitfalls and protocols in DEA. European *Journal of Operational Research* 2001;132(2):245–259.

32. Hollingsworth B. Evaluating efficiency of a health care system in the developed world. *Encyclopedia of Health Economics* 2014;1(18) pp.292-299.

33. Charnes A, Cooper W, Rhodes E. Measuring the efficiency of decision-making units. *European Journal of Operational Research* 1978;2(6), 429–444 (1978)

34. Banker R, Charnes A, Cooper W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science* 1984;30(9), 1078–1092

35. Chuang CL, Chang PC, Lin RH. An efficiency data envelopment analysis model reinforced by classification and regression tree for hospital performance evaluation. *Journal of Medical Systems* 2010;35(5):1075-83. Doi:10.1007/s10916-010-9598-5.
36. Gok MS, Altindag E. Analysis of the cost and efficiency relationship: experience in the Turkish pay for performance system. *European Journal of Health Economics* 2015;16(5), pp 459–469. DOI 10.1007/s10198-014-0584-6
37. O'Neill L, Rauner M, Heidenberger K *et al*. A cross-national comparison and taxonomy of DEA-based hospital efficiency studies. *Socio-Economic Planning Sciences* 2008;42:158–189.
38. Mahate A, Hamidi S. Frontier efficiency of hospitals in United Arab Emirates: An application of data envelopment analysis. *Journal of Hospital Administration* 2016;5(1) pp7–16. DOI: 10.1007/s10916-014-0156-4
39. Ramanathan R. Operations assessment of hospitals in the Sultanate of Oman. *International Journal of Operations and Production Management*, 2005;25(1) pp 39-54. DOI: 10.1007/s10916-014-0156-4
40. Charnes, A. and Cooper, W.W. Programming with Fractional Functions. Naval Research Logistic Quarterly (1962;(9): 181-186. DOI: org/10.1002/nav.3800090303
41. Emrouznejad A, Thanassoulis E. *Performance Improvement Management Software: PIM-DEAsoft-V3.0 User Guide* May 2011; www.DEAsoftware.co.uk,Performance Improvement Management Limited, UKISBN: 1-85449-412-2. Available at: https://deazone.com/en/software
42. Shahhoseini R, Tofighi S, Jaafaripooyan E *et al*. Efficiency measurement in developing countries: application of data envelopment analysis for Iranian hospitals. *Health Services Management Research* 2010;24(2):75-80. DOI: 10.1258/hsmr.2010.010017
43. Kiadaliri A, Haghparast-Bidgoli H, Zarei A. Measuring efficiency of general hospitals in the south of Iran. *World Applied Sciences Journal* 2011;13(6): 1310–1316.
44. Afzali HH, Moss JR, Mahmood AM. Exploring health professionals' perspectives on factors affecting Iranian hospital efficiency and suggestions for improvement. *International Journal of Health Planning and Management* 2011;26: e17–e29. DOI: 10.1002/hpm.1035

45. Al-Salem AA. Renovation of financing healthcare services in Kingdom of Saudi Arabia, by implementing National Health Insurance (NHI). *European Journal of Pharmaceutical and Medical Research*, 2018,5(9), 439-448.

46. World Health Organization. 2010. Health systems financing: the path to universal coverage, World Health Report 2010, Geneva.

Tables

Table 1: Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal)

Table 2: Descriptive statistics of the inputs and outputs of the 91 hospitals

Table 3: Technical efficiency scores and return to the scale of the public hospitals in KSA

Table 4 Technical efficiency scores and returns to the scale of the hospitals categorized by location

Table 5 Slacks evaluation for inefficient hospitals

Figures

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

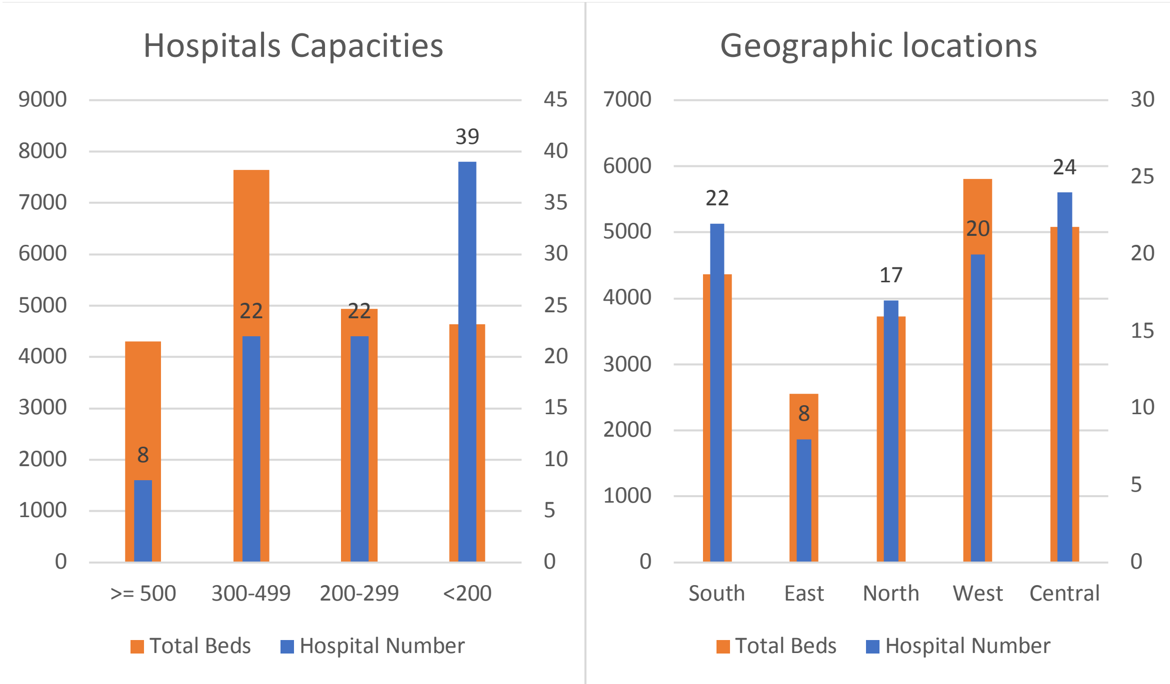

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

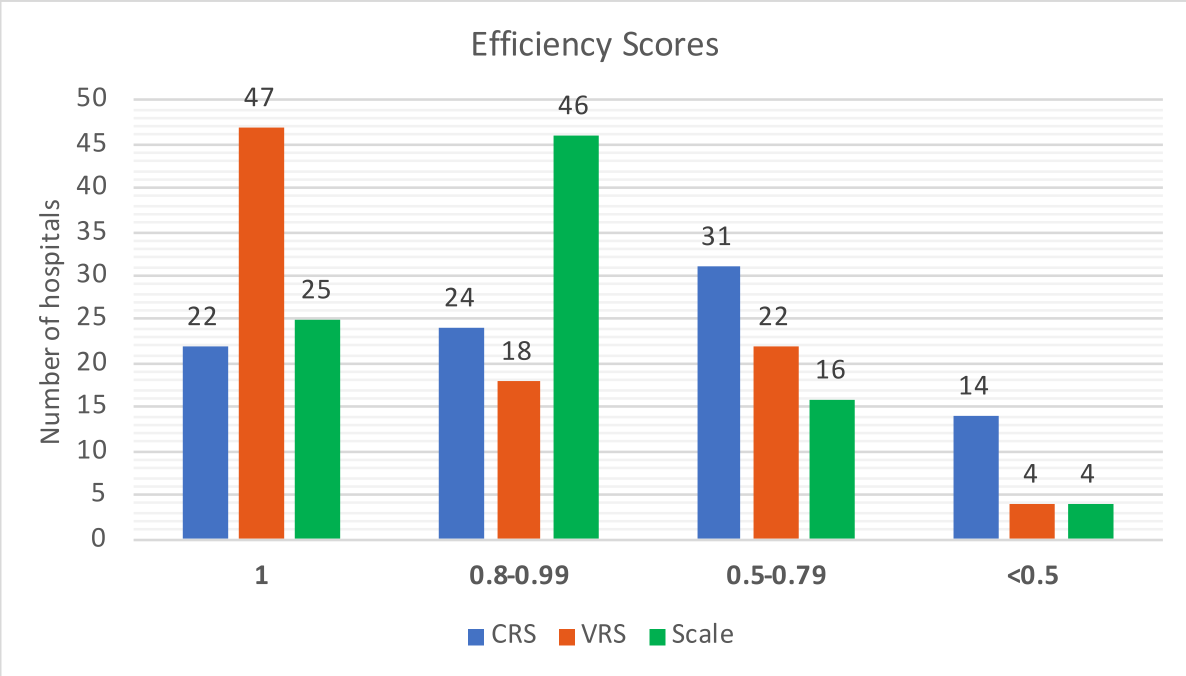

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	0
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2,3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6,7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4,5,6,7
Bias	9	Describe any efforts to address potential sources of bias	*n/a*
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5,6
		(*b*) Describe any methods used to examine subgroups and interactions	7
		(*c*) Explain how missing data were addressed	7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	8
		(*e*) Describe any sensitivity analyses	n/a
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8,9
		(b) Indicate number of participants with missing data for each variable of interest	7
Outcome data	15*	Report numbers of outcome events or summary measures	9,10,11,12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9,10
		(*b*) Report category boundaries when continuous variables were categorized	9,10,11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11,12
Discussion			
Key results	18	Summarise key results with reference to study objectives	12,13,14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14,15
Generalisability	21	Discuss the generalisability (external validity) of the study results	13,14,15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Efficiency evaluation of public hospitals in Saudi Arabia: An application of Data Envelopment Analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2019-031924.R2
Article Type:	Original research
Date Submitted by the Author:	07-Oct-2019
Complete List of Authors:	Alatawi, Ahmed; Liverpool School of Tropical Medicine, Health Economics, department of Clinical Sciences; Al-Jouf University College of Pharmacy, Clinical Pharmacy Niessen, Louis; Liverpool School of Tropical Medicine, Health Economics; University of Warwick, Dept of Health Sciences Khan, Jahangir; Liverpool School of Tropical Medicine, Health Economics; International Centre for Diarrhoeal Disease Research Bangladesh, Health Systems and Population Studies Division
Primary Subject Heading:	Health economics
Secondary Subject Heading:	Health economics, Health policy, Public health, Health services research
Keywords:	Technical efficiency, Data Envelopment Analysis, Saudi Arabia, Public hospital, General hospital efficiency

Title

Efficiency Evaluation of Public Hospitals in Saudi Arabia: An Application of Data Envelopment Analysis

Authors: Ahmed Alatawi[*,a,b], Louis Niessen[c,d], Jahangir A. M. Khan[c,e]

Affiliations:

[a] Liverpool School of Tropical Medicine, Department of Clinical Sciences, Liverpool, United Kingdom.

[b] University of Al-Jouf, Pharmacy College, Department of Clinical Pharmacy, Skaka, Saudi Arabia.

[c] Liverpool School of Tropical Medicine, Department of International Public Health, Liverpool, United Kingdom.

[d] University of Warwick, Division of Health Sciences, Coventry, United Kingdom.

[e] Karolinska Institute, Department of Learning, Informatics, Management and Ethics, Stockholm, Sweden.

1. **Ahmed Alatawi***, MSc, Pharm.D. **(Corresponding author)**
   PhD Candidate - Health Economist
   Health Economics Group, Department of Clinical Sciences, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Mobile: +4407491496786
   Fax: +44(0)151 705 3370
   Email: Ahmed.alatawi@lstmed.ac.uk

2. **Louis Niessen, Professor**
   Chair of Health Economics.
   Health Economics Group, Department of Clinical Sciences, Room 1966-206, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Tel: +44 (0)151 705 3779. Email: louis.niessen@lstmed.ac.uk

3. **Jahangir A. M. Khan, PhD**
   Senior Lecturer in Health Economics
   Health Economics Group, Department of International Public Health, Room 1966-215, Liverpool School of Tropical Medicine, LSTM, Pembroke Place, Liverpool, L3 5QA, United Kingdom.
   Tel: +44 (0)151 702 9345. Email: jahangir.khan@lstmed.ac.uk

Word count: 5,664

Keywords: Technical efficiency, Data envelopment analysis, Saudi Arabia, Public hospitals, General hospitals efficiency.

Abstract

Objective: In this study we assess the performance of public hospitals in Saudi Arabia. We detect the sources of inefficiency and estimate the optimal levels of the resources that provide the current level of health services. We enrich our analysis by employing locations and capacities of the hospitals.

Design: We employ Data Envelopment Analysis (DEA) to measure the technical efficiency of 91 public hospitals. We apply the input-oriented CCR and BCC models under constant and variable returns-to-scale (CRS and VRS). The assessment includes four inputs, and six output variables taken from ministry of health databases for 2017. We conducted the assessment via PIM-DEA 3.2 software.

Setting: Ministry of health-affiliated hospitals in the Kingdom of Saudi Arabia (KSA).

Results: Findings identified 75.8% (69 of 91) of public hospitals as technically inefficient. The average efficiency-score was 0.76, indicating that hospitals could have reduced their inputs by 24% without reduction in health-service provision. Small hospitals, (efficiency-score 0.79), were more efficient than medium-sized and large hospitals. Hospitals in the central-region were more efficient (efficiency-score 0.83), than those located in other geographic-locations. More than half of the hospitals (62.6%) were operating sub-optimally in terms of the scale-efficiency, implying that to improve efficiency, they need to alter their production capacity. Performance analysis identified overuse of physician's numbers and shortage of health-services production, as major causes of inefficiency.

Conclusion: Most hospitals were technically inefficient and operating at sub-optimal scale size and indicate that many hospitals may improve their performance through efficient utilization of health resources to provide the current level of health services. Changes in the production capacity are required, to facilitate optimal use of medical capacity. The inefficient hospitals could benefit from these findings to benchmarking their system and performance in light of the efficient hospital within their capacity and geographic location.

Strengths and limitations of this study:

- The study challenged to find data on economic values, severity of cases and quality of services. We expanded the selection of the variables to cover a broad range of health services and resources in the hospitals.
- The hospital mortality rate was included in output variables as a proxy of the service quality in the studied hospitals.
- We did not apply output-oriented DEA models, alternatively, we adopted input-orientation, since we aimed to estimate the optimum levels of the resources without deteriorating the health services.
- Further estimation of the optimal levels of resources is required, to examine the allocation of these resources among the hospitals.
- This is the first performance assessment of public hospitals in Saudi Arabia that uses real data obtained directly from official databases of the Ministry of Health.

Introduction

Increasing demand for healthcare and the expenditure required to provide efficient, equitable and effective healthcare systems, are global concerns. The Kingdom of Saudi Arabia (KSA) has experienced these recently, alongside substantial population growth, increased life expectancy and the proliferation of lifestyle-related disease. These have increased the demand for health services at a time of scant resource.[1,2,3]

During 2015, KSA government spending on health was 71.3% of the country's total health expenditure, which corresponds to 4.1% of GDP for that year.[4] Healthcare expenditure in KSA increased by 24.7% between 2013 and 2017 (Table 1).[1,2,5] While public spending on health in KSA is remarkably high in comparison to many high-income countries (71.3% for KSA versus 61.2% for high-income countries), the number of hospital beds is considerably lower. [3,4] In other words, the cost of each hospital-bed in the KSA is remarkably higher than those in other high-income countries.

Although much has been done to promote the efficient use of resources, this has proven insufficient to meet the rising health expenditure and demand for healthcare in KSA.[6,7] Providers seem to find it very challenging to deliver adequate provision using current resources.[8] There seems to be an imbalance between health service availability and health spending, so better use of resources is necessary if KSA is to have an efficient and appropriate health system.[7] It is thus important to investigate how existing resources can be used more efficiently for meeting the demand for healthcare in the country.

Governments worldwide conduct performance assessments of their health sectors, to ensure that public funds are effectively utilized.[9] Efficiency evaluation is carried out under different concepts, such as technical, allocative, cost and overall efficiency.[9] Of these, the technical efficiency approach is most commonly used. This is based on Farrell's theory of 1957, which introduced a measure of technical efficiency based on comparison of the inputs and outputs of set entities, called decision making units (DMUs).[10]

Hospital efficiency is crucial to the efficiency of the health system generally, as hospitals are key consumers of health resources.[11,12] Hanson et al. (2002) found that public hospitals consume around 40% of the total health budget in many sub-Saharan African countries.[11] Public hospitals used almost 44% of the health spending in the United Kingdom in 2012/13.[13]

In general, there is a scarcity of studies and empirical works on the performance assessment of public hospitals, and this rarity is particularly acute in the context of KSA.[14] Systematic review of public hospital efficiency studies in the Gulf region and similar countries has shown the number of studies to be limited, as efficiency analysis is a novel approach to research in the Gulf, including KSA.[14] The review found only two studies based in KSA context; a study by Helal and Elimam in 2017 [15], which assessed the efficiency of health services at districts level in KSA. Another efficiency analysis conducted in 2013 of 20 public hospitals, under private sector management, which found that 60% of the study sample had not achieved the efficient score.[16]

Hospital efficiency has hitherto been measured mainly by frontier analysis methods, either through non-parametric data envelopment analysis (DEA) or as parametric stochastic frontier analysis (SFA).[9] These methods compare hospital performance with an estimated efficient frontier comprising the best-performing hospitals.[17,18]

Data envelopment analysis has for many years been the most commonly-used technique for measuring the relative efficiency in healthcare .[12,19] Systematic reviews of efficiency studies have often identified that DEA to be the predominant method of public hospital efficiency assessments among studies reviewed.[12,14,19] Hollingworth et al. (2003, 2008) conducted systematic reviews of efficiency analysis internationally and noticed that DEA was used in around the half of studies, a further fifth used DEA in with some form of secondary regressions. [12,19] Another review[18], of efficiency in Iranian hospitals, found DEA was applied in all reviewed studies; three of those studies also used SFA to estimate efficiency scores. A systematic review of health system efficiency studies in OECD countries[20] found that DEA was applied in 64% of them.

In this study we conduct a performance assessment of the MOH-administered general hospitals in KSA. We measure the technical efficiency of public hospitals and identify the sources of inefficiency and estimate the optimal levels of the resources. We also provide subscriptions for improvements so as the inefficient hospitals to be rendered efficient. At a post optimality phase, we enrich our analysis by employing information about the geographical location and the capacity (number of beds) of the hospitals. Thus, this performance assessment provides useful information to the decision-makers, which can be employed for policy reforms, to optimise the use of health resources in public hospitals and consequently improve the efficiency of healthcare systems.

Public health system in KSA

Under article 31 of the national constitution, the KSA government guarantees free medical care to all citizens.[8] The government finances the public sector annually, largely from revenue derived from oil and gas production.[21] Table 1 shows the proportion of national budget allocated to the KSA's ministry of health (MOH).[5] Thus, the available resources should be utilized optimally.

The MOH is the primary provider of healthcare services in KSA, administering 60% of all provision. [22] It is the dominant provider of health services in the public sector.[22,23] Other government agencies, including the ministry of defence, the national guard and universities, share the remaining of healthcare provision, as does the private sector.[21] The MOH delivers primary, secondary and tertiary healthcare through 2,361 primary healthcare centres and 282 hospitals, administering 43,080 beds throughout the country.[5] Other MOH functions include strategic planning, formulation of health policy, supervision of all health service delivery programs and the monitoring and management of all other health-related activities.[22] Public (MOH-affiliated) hospitals in KSA can be broadly classified into two groups, general hospitals with different capacities (number of beds) and specialised hospitals. General hospitals provide a wide range of health services, while specialised hospitals deliver health services for a specific health condition or to a particular group of beneficiaries. General hospitals in KSA are located in various geographic locations and serve populations of different demographic characteristics and needs, which may affect the hospital performance, as observed in other studies.[8,24]

Table 1: *Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal)*

Year	Government Budget Billion SR	MOH Budget Billion SR	Percentage of MOH to the government budget	No. of Hospitals	No. of Beds
2013	820	54.3	6.63%	268	38970
2014	855	59.9	7.02%	270	40300
2015	860	62.3	7.25%	274	41297
2016	840	58.9	7.01%	274	41835
2017	890	67.7	7.61%	282	43080

Source; Ministry of Health; Statistical yearbook, 2017.

Methods

Population and selection of sample

As the application of DEA is based on a homogenous (comparative) sample that use similar inputs to produce similar outputs, we focused on examining the technical efficiency for general hospitals.[9]

Hollingsworth (2008) and Varabyova (2016) argued that the hospitals under evaluation should be of same type and provide the same services and health activities.[19,20] Since the inclusion of divergent specialist units in the same sample will confound the results — frontier techniques are susceptible to outliers.[19,20] Specialised hospitals often lack types of secondary service, e.g. surgical operations rarely occur in psychiatric hospitals, and such hospitals, if included, will appear as inefficient while surgery is a considered as one of the outputs.[18,19,25] Specialised hospitals were therefore excluded from this analysis. Similarly, small hospitals (with 50 beds or fewer) provide primary care services while lacking secondary and tertiary health services, and consequently miss a significant number of output variables (e.g. inpatient services, patient discharge, surgical operations, laboratory testing) compared to bigger hospitals. In this study we excluded also the smaller hospitals, to ensure greater homogeneity in performance evaluation across the units.[9,26]

Ultimately, the homogenous sample used in the analysis included 21,528 out of 398,68 (54%) of the total active hospital beds provided by the MOH in KSA. We included in the assessment 97 general hospitals and removed six of them, due to missing data. The data of hospital inputs and outputs for 2017 was collected by the lead author from official statistical, informational and research databases of Administration of Statistics and Information and Administration of Research and Studies, which affiliated of the MOH, following approval from the designated authority. Data collection took place from May to July 2018.

The sample hospitals are in 64 cities, affiliated to 20 administrative districts, located in five geographic regions, namely central, west, east, south and north regions. The general hospitals in the sample are classified into four groups based on their capacity (number of beds): small (fewer than 200 beds), lower-medium (200 to 299 beds), upper-medium (300 to 499 beds) and large (500 or more beds) hospitals, following Gok's[27] categorization. However, these hospitals are affiliated, organized and funded by the MOH, and have not autonomy in term of funding or organising structure by themselves or other agents. Thus, we applied the DEA model for all 91 hospitals. Then, we presented the efficiency scores in each capacity and each geographic location. Figure 1 illustrates number of hospitals and hospital-beds in each category of capacity and location.

Figure 1 to be inserted here

Inputs and outputs

The selection of input and output variables is a crucial step in performance measurement, because the results of any efficiency assessment depend significantly on the variables used in the estimation models.[28] The literature has focused on labour (e.g. health professionals) and capital (e.g. number of beds), as input variables, while some studies included consumable resources.[9,28] The main categories of output used in healthcare-related efficiency studies were healthcare activities (e.g. number of outpatient visits, inpatient services, number of surgeries) and health outcomes (e.g. mortality rate).[9,18,20]

In our study we selected the hospital outputs that dependent on the selected inputs, which cover a broad range of health services provided and health resources used by public hospitals in KSA. In particular, four inputs and six outputs were chosen based on the availability of the data in KSA context, which were rationally approved in previous theoretical and empirical studies. [9,12,19]

The input variables chosen are: (1) number of hospital beds; (2) number of full-time physicians; (3) number of full-time nurses and (4) number of full-time allied health personnel (i.e. pharmacists, midwives, medical technicians, medical radiologists, physiotherapists) employed in the hospital. The output variables used in this study are: (1) outpatient visits (number of patients receiving outpatient treatment within a year); (2) discharged patients (number of patients receiving inpatient treatment within a year); (3) total number of surgical operations during the year; (4) number of radiological investigations conducted in hospital during the year; (5) number of laboratory tests during the year; (6) hospital mortality rate (ratio of inpatient deaths during hospitalization to the total number of inpatients that year). The last output variable is an indicator of health service quality and health outcomes in hospital, as argued by Sahin and Ozcan.[29] Reduction in the mortality rate and increase quantity of life signify an improvement in the health outcomes of the public hospital of investigation. Therefore, mortality rate could be a proxy for a weighted health quality measure in our assessment.[30] The inverse value for the mortality rate (one divided by mortality rate) is included as an output value in the assessment, meaning that hospitals with higher mortality rate would have a smaller ratio as output values.[29] As the model assumes that output and input variables are isotonic, (i.e., increased input reduces efficiency as well as increased output increases efficiency). We had to apply this correction, otherwise, a higher mortality rate would incorrectly contribute to a better hospital outcome.[30]

The number of hospitals (DMUs in DEA context) should be at least two times larger than the sum of inputs and outputs.[31] However, Hollingsworth (2014)[32] suggested that the number of units used in efficiency assessment should be at least three times the sum of inputs and outputs. In accordance to the above-mentioned rule of thumb, in this study we include 91 hospitals, more than three times the combined number of input and output variables.

Patient and Public Involvement

No patients were involved in this study, and we used anonymous data from MOH databases.

Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a powerful technique that is based on linear programming. It was developed for measuring the performance of a set of comparable entities, called Decision Making Units (DMUs), which convert multiple inputs into multiple outputs.[26,32] In this method each hospital is compared against the estimated efficient frontier comprising the best-performing hospitals.[17,18]

DEA has been already the most commonly-used technique for measuring the relative efficiency in healthcare.[12,19] In systematic reviews we can observe that DEA is the predominant method of public hospital efficiency assessment.[12,14,19] DEA is widely applicable since does not require any a priori specification of the underlying functional form that relates the inputs with the outputs.[9] In addition, use of DEA is justified by its ability to incorporate multiple inputs and outputs in different units of assessment.[9,32]

Several DEA models have been developed to analyze the efficiency based on Farrell's concept.[10] The most well known and basis for the rest DEA models is the CCR model developed by Charnes, Cooper and Rhodes,[33] which assumes that production has constant returns to scale (CRS) and the BCC model developed by Banker, Charnes and Cooper, [34] under the assumption of variable returns to scale (VRS).[9,12] The choice of CCR or BCC model depends on the context of the problem under examination, i.e. the technology linking the inputs to outputs in the transformation process.[9]

Generally, the CCR model — whereby the efficiency frontier has a constant slope (CRS), which means that any change in the inputs results to a proportional change in the outputs.[26] Constant returns to scale CRS may be adopted when machines are involved in the process, which roughly means that the production can be doubled by doubling the levels of inputs. However, when employees (human factor) partcipate in the production process, then it is naive to expect that they could work at a constant rate. The CCR efficiency assessment by the may be affected if the DMUs are not operating on the optimal scale, since CRS does not distinguish between the scale and pure (managerial) technical efficiency.[35] If the efficiency analysis considers a managerial perspective, a BCC technology assumption will be appropriate to understand if a scale of operations or provider's practice affects productivity.[27,36] Scale efficiency is defined as a ratio of CRS to VRS efficiency scores and provides evidence whether the DMU is operating on the optimal scale size.[12,20] Furthermore, the efficiencies of DMUs can be comprehensively analysed using both CRS and VRS assumption for more realistic changes in production process, and implications in the real world.[9,26] Other systematic reviews [20,25] have reported similar findings where studies used both CRS and VRS assumptions in efficiency measurements.

Rationally, the commonly-used orientations in DEA analysis are input orientation (i.e. minimization of inputs with the given amount of outputs) and output orientation (i.e. inputs are held constant and outputs are proportionally increased).[26] Previous empirical studies [35] have argued that hospitals have relatively little control over their outputs (for example, expanding surgical operations), but more control over the inputs (e.g. medical devices), where they have the social responsibility to provide medical treatment through the public hospitals in general. Thus, most studies adopt input orientation for efficiency assessment of the hospitals.[20,25,37] In a few studies output orientation is adopted in response to the strategic health plans of the countries aiming to expand healthcare provision during a specific period.[38,39] However, in our study we aim to estimate the optimal levels of the resources without deteriorating the levels of the health services that the hospitals provide. In this way, we provide the central authorities with the potential savings that could be made in the health sector.

The efficiency of a hospital is defined as the ratio of the weighted sum of outputs (total virtual output) to the weighted sum of inputs (total virtual input), with the weights being obtained in favour of each evaluated unit by the optimization process. Assume *n* DMUs, each using *m* inputs to produce *s* outputs. We denote the vector of inputs for DMU *j* is $X_j = (x_{1j},...,x_{mj})^T$ and the vector of outputs is $Y_j = (y_{1j},...,y_{rj})^T$. The model (1) is formulated and solved for each hospital in order to obtain its efficiency score. The variables $\eta=(\eta_1,...,\eta_m)$ and $\omega=(\omega_1,...,\omega_s)$ are the weights associated with the inputs and the outputs respectively. These weights are calculated in a manner that they provide the highest possible efficiency score for each hospital $_{jo}$ under evaluation.

The input-oriented BCC model that provides the efficiency for the hospital $_{jo}$ under VRS assumption is given below:

$$\max e_{j_0} = \frac{\omega Y_{j_0} - \omega_o}{\eta X_{j_0}}$$
$$s.t.$$
$$\frac{\omega Y_j - \omega_o}{\eta X_j} \leq 1, \quad j = 1, \ldots, n \qquad (1)$$
$$\eta \geq 0, \omega \geq 0$$

Notice that by excluding the free of sign variable ω_o from model (1), the CCR model is obtained. The fractional model (1) can be transformed to a linear program by applying the Charnes and Cooper (1962) transformation (C-C transformation hereafter).[40] The transformation is carried out by considering a scalar $t \in \Re^+$ such as $t\eta X_{j_0} = 1$ and multiplying all terms of model (1) with $t>0$ so that $v = t\eta$, $u = t\omega$, $u_o = t\omega_o$. The linear equivalent of model (1) is formulated as:

$$\max uY_{j_0} - u_0$$
$$s.t.$$
$$vX_{j_0} = 1 \qquad (2)$$
$$uY_j - u_0 - vX_j \leq 0, \quad j = 1, \ldots, n$$
$$v \geq 0, u \geq 0$$

Once an optimal solution v^*, u^*, u_o^* of model (2) is derived, the input-oriented BCC-efficiency $e^*_{j_0}$ for the hospital$_{jo}$ under evaluation is obtained directly from the objective function.

Banker et al (1984) determined the returns to scale (RTS) using the optimal value of the free variable u_o in the multiplier model (2).[34] Given the point (x_0, y_0) that lies on the efficient frontier, the returns to scale at this point are identified by the following three conditions:

1. Increasing returns to scale (IRS) prevail at (x_0, y_0) if and only if $u_o^* < 0$ for all optimal solutions. Meaning the increase in all production factors (inputs) resulted in more production (outputs).
2. Decreasing returns to scale (DRS) prevail at (x_0, y_0) if and only if $u_o^* > 0$ for all optimal solutions, meaning an equal increase in all production factors led to less production.

3. Constant returns to scale (CRS) prevail at (x_0, y_0) if and only if $u_o^* = 0$ in any optimal solutions, where equal increase in all production factors led to the same amount of increase in production.

Improvement management software (PIM-DEA version 3.2) was used for DEA analysis.[41]

Results

Descriptive statistics, concerning the inputs and outputs of 91 general hospitals during 2017, are presented in Table 2. The average hospital size is 236.57 beds, with a range of 100 to 711 beds. Full-time physicians ranged from 38 to 894, with a mean of 212. The number of nurses is on average 495 but ranged from 74 to 1,930. Full-time allied health personnel ranged from 37 to 1,149, with an average of 280.

Table 2: *Descriptive statistics of the inputs and outputs of the 91 hospitals*

	Mean	**Standard Deviation**	**Min**	**Max**
Inputs				
Hospital beds	236.6	137.6	100	711
Physicians	212.3	168.7	38	894
Nurses	495.2	403.6	74	1,930
Allied Health Personnel	280.1	219.1	37	1,149
Outputs				
Outpatient visits	72,986.5	72,475.3	1,785	466,608
Discharged patients	26,016.4	55,856.4	19	503,216
Surgical operations	2,638.4	2,151.2	172	9,464
Laboratory tests	965,840.8	1,095,415.6	794	5,512,774
Radiology Investigations	53,531.4	46,788.7	107	221,980
Hospital mortality rate	0.0224	0.0212	0.0003	0.125

Concerning the outputs, the average number of patient visits to outpatient departments is 72,986 and ranged from 1,785 to 466,608 visits. Discharged patients receiving inpatient services during 2017 averaged 26,016, ranging from 19 to 503,216. Surgical operations ranged from 172 to 9,464 with a mean of 2,638 surgeries per hospital. Means for laboratory and radiology tests are 965840 and 53531 respectively, during 2017. Average mortality rate is 2.24%.

Table 3 presents the results of DEA models, summary statistics of average technical (CRS and VRS) efficiency, and scale (SE) efficiency scores, as well as concerning the return to scale.

Table 3: *Technical efficiency scores and returns to the scale of the public hospitals in KSA*

	CRS technical efficiency	VRS technical efficiency	Scale efficiency	CRS [N (%)]	IRS [N (%)]	DRS [N (%)]
All hospitals (n=91)						
Mean	0.76	0.87	0.87	34 (37.4)	40 (44)	17 (18.6)
Std. Dev.	0.23	0.18	0.18			
Min	0.11	0.30	0.19			
No. full score	22 (24.2%)	47	25			
Large hospitals: >=500 beds (n= 8)						
Mean	0.65	0.75	0.87	2 (25)	1 (12.5)	5 (62.5)
Std. Dev.	0.27	0.30	0.13			
Min	0.28	0.30	0.59			
No. full score	1 (12.5)	4	1			
Upper-medium hospitals: 300-499 beds (n= 22)						
Mean	0.76	0.80	0.94	7 (31.8)	5 (22.7)	10 (45.5)
Std. Dev.	0.19	0.19	0.07			
Min	0.39	0.41	0.76			
No. full score	3 (13.6)	7	3			
Lower-medium hospitals: 200-299 beds (n= 22)						
Mean	0.73	0.79	0.90	10 (45.5)	10 (45.5)	2 (9.1)
Std. Dev.	0.25	0.19	0.18			
Min	0.11	0.50	0.22			
No. full score	4 (18.2)	4	4			
Small hospitals: <200 beds (n= 39)						
Mean	0.79	0.96	0.82	15 (38.5)	24 (61.5)	0 (0)
Std. Dev.	0.23	0.09	0.22			
Min	0.19	0.67	0.19			
No. full score	13 (33.3)	31	13			

The average CRS technical efficiency score for MOH general hospitals is 0.76, with a standard deviation (SD) of 0.23, which indicates that these hospitals could reduce use of all their inputs on average by 24% without any reduction in the number of services provided. Also, the VRS technical score on average is 0.87 (SD 0.18). The distribution of technical, pure technical and scale efficiency scores is given in Figure 2.

Figure 2 to be inserted here

The lowest technical efficiency score reported is 0.11, but 22 hospitals out of 91 (24.2%) are both technically and scale efficient, which indicates that these hospitals utilize optimally their inputs. Among the inefficient hospitals 55 hospitals (60.4%) achieved efficiency scores of at least 0.50 efficiency level (Figure 2) and 14 hospitals (15.4%) reported efficiency scores below 0.50. Average scale efficiency scores are 0.87, with (SD 0.18). Although 47 hospitals (52%) reported an efficient score on VRS (pure efficiency), only 25 (27%) hospitals are efficient on the scale.

Concerning the returns to scale , we have found that 34 hospitals (37.4%) operate under constant returns to scale (CRS); while 40 hospitals (44%) operate under increasing returns to scale (IRS), and 17 hospitals (18.6%) decreasing returns to scale, However, hospitals that were operating on either IRS or DRS needed to alter their capacity to operate on the optimal scale size i.e., at the constant return to the scale, which would be required to achieve technical efficiency.

We present in table 3 the efficiency scores of the 91 hospitals for each capacity (size category). From the capacity perspective, small hospitals had higher levels of technical (CRS and VRS) efficiencies than medium-sized (both lower- and upper-medium) and large hospitals. Table 3 shows that small hospitals have on average technical efficiency of 0.79 (SD 0.23); one-third of the hospitals in this category are technically and the scale efficient. Average technical efficiency of lower-medium hospitals is 0.73 (SD 0.25), with a higher percentage of inefficient hospitals (81.8%), than for small hospitals. Although upper-medium-sized hospitals reported a slightly higher average technical efficiency score of 0.76 (SD 0.19), fewer hospitals in this category reported an efficient score, meaning a higher percentage of inefficiencies (86.4%). Large hospitals were the least efficient when compared to other categories. The average technical efficiency of large hospitals was 0.65 (SD 0.27), only one was technically efficient.

Regarding scale-efficiency scores, upper-medium (0.94) and lower-medium (0.90) sized hospitals operate at a more optimal scale than small (0.82) or large hospitals (0.87). Also, 45.5% of lower-medium hospitals operate on the CRS, followed by small hospitals (38.5%). However, most of the remaining hospitals in these categories, i.e. lower-medium (45.5%) and small size (61.5%) hospitals are operating on IRS. In contrast, most large hospitals (62.5%) showed DRS, and two of them were on CRS, indicating a need to downsize these hospitals to improve technical efficiency. Similarly, 45.5% of upper-medium-sized hospitals operate on DRS and one-third of this category are operating (CRS).

Table 4 shows the average efficiency scores in five geographical regions, however, based on the analysis of all 91 hospitals together. Hospitals in the central region reported the highest average technical efficiency score of 0.83 (SD 0.18), followed by eastern hospitals with an average score of 0.80 (SD 0.28). Hospitals in western KSA reported the least average score, 0.68 (SD 0.20).

Table 4 Technical efficiency scores and returns to the scale of the hospitals categorized by location

	CRS technical efficiency	**VRS technical efficiency**	**Scale efficiency**	**CRS [N (%)]**	**IRS [N (%)]**	**DRS [N (%)]**
South region hospitals (n= 22)						
Mean	0.75	0.89	0.83	9 (40.9)	9 (40.9)	4 (18.2)
Std. Dev.	0.25	0.18	0.23			
Min	0.11	0.41	0.22			
No. full score	4 (18.2)	13	4			
East region hospitals (n =8)						
Mean	0.80	0.85	0.90	4 (50)	1 (12.5)	3 (37.5)
Std. Dev.	0.28	0.21	0.16			
Min	0.27	0.50	0.54			
No. full score	1 (12.5)	4	1			
North region hospitals (n =17)						
Mean	0.75	0.84	0.90	7 (41.2)	9 (52.9)	1 (5.9)
Std. Dev.	0.28	0.23	0.20			
Min	0.19	0.30	0.19			
No. full score	6 (35.3)	9	6			
Central region hospitals (n =24)						
Mean	0.83	0.89	0.93	10 (41.7)	11 (45.8)	3 (12.5)
Std. Dev.	0.18	0.16	0.10			
Min	0.49	0.50	0.69			
No. full score	8 (33.3)	12	8			
West region hospitals (n =20)						
Mean	0.68	0.85	0.81	4 (20)	10 (50)	6 (30)
Std. Dev.	0.20	0.17	0.17			
Min	0.37	0.42	0.46			
No. full score	3 (15)	9	3			

The percentage of efficient hospitals in the north (35.3%) and the central (33.3%) regions are higher than the other regions. the eastern, western and southern regions have a higher percentage of inefficient hospitals. Both central and southern regions reported relatively higher VRS efficiency score of 0.89. In terms of average scale efficiency scores, central region hospitals (0.93), and hospitals in the north- and east (both 0.90) were operating at more optimal scale than those in the west (0.81) and south (0.83). Half of the sample hospitals in the east region operate on CRS, followed by hospitals in the central and north regions (both 41%). The findings also revealed that 52.9 % of north region hospitals were operating on IRS, while 37.5% of east region hospitals were operating on DRS.

The performance analysis identified the slacks, which showed either excess input utilization or shortages of output production. Table 5 shows the average amount of slack in hospitals deemed inefficient. These results represent the combined scores of slack for all inefficient hospitals, for each input and output. Table 5 also shows the percentage of change (slacks) in the number of inputs or outputs required to eliminate the inefficiencies and achieve target levels.

Table 5 Slacks evaluation for inefficient hospitals

Input slacks	Mean (SD)	Percentage of change
Hospital beds	48.4 (76.6)	-20.4%
Physicians	47.5 (72.6)	-22.4%
Nurses	102.9 (173.1)	-20.8%
Allied Health Personnel	58.38 (98.3)	-20.84%
Output slacks		
Outpatient visits	8866.1 (23712)	12.2%
Discharged patients	3700.6 (8214.2)	14.2%
Surgical operations	282.6 (730.9)	10.7%
Laboratory tests	66105.6 (140332.4)	6.8%
Radiology Investigations	2204.6 (6944.1)	4.1%
Mortality rate	0.006 (0.014)	21.7%

In terms of inputs, results show that an excess of physicians was the main cause of inefficiencies in public hospitals. A feasible, achievable reduction in the number of physicians was on average 22.38 % of the current values (compared with the amounts given in Table 2). The next most substantial slack was observed in allied health personnel, at 20.84%. Surpluses of hospital beds and nurses were also important causes of inefficiency and should be reduced on average by 20.44% and 20.77%, respectively. In addition to the input reduction, the average number of services should be increased to meet targets. Furthermore, the quality of health services in public hospitals would have improved with a decrease in the hospital mortality rate.

Discussion

This study evaluated the technical efficiency of public hospitals affiliated to the KSA's MOH, using data envelopment analysis. Analysis showed 75% of sample hospitals could not utilize their intact resources to generate specified outputs. The average CRS technical efficiency score was 0.76, indicating that hospitals could produce their current level of outputs with 76% of inputs currently used, and thereby achieve efficiency. Efficiency scores ranged from 0.11 to 1.00 (Figure 2), revealing considerable variations in efficiency scores among hospitals. Moreover, the average VRS technical efficiency and scale efficiency scores were both 0.87. This indicated that inefficiency might be due to administrative gaps to overcome external environmental factors, and limitations in managing internal operations in the hospitals. Notably, Helal and Elimam [15] in 2017, assessed the efficiency of health services at districts level in KSA based on MOH data 2014, found an average efficiency score of 0.92, and 45% of the districts achieved the technical efficiency score. An efficiency analysis of 20 public hospitals, under private sector management in KSA, found that 60% of the study sample had not achieved the efficient score, with an average score of 0.84.[16]

Results of the study presented here suggest that small hospitals were relatively more technically efficient than medium-sized and large hospitals (Table 2). Other efficiency studies have reported similar findings: Gok [27] found that small hospitals achieved higher efficiency scores than medium-sized and large ones. This might be due to the differing locations and missions of small and large hospitals.[27,36] In this study's sample, small hospitals were mainly in peripheral cities and towns in KSA, which lacked other sources of public or private healthcare. Service provision in those hospitals might be relatively high compared to the health resources used. Large hospitals (500 or more beds) tended to be in larger cities in urban areas, where many other health providers shared the healthcare of much of the urban population, which might generate a relatively decreased level of health services production in respect of inputs used.

Regarding the different missions, large hospitals consumed a high amount of health resources to meet the various requirements of comprehensive care.[27] Since some of these were teaching hospitals, however, teaching activities were not counted in the outcome measurements.[27,28] In such large hospitals, treatment processes might be more complicated, and some of the productions of these hospitals could not be assessed in the hospital outcomes.[42]

This study found 57 hospitals (62.6%) operating on non-optimal scale size; 44% were operating on the IRS, while 18.6% showed DRS (Table 3). This indicated that the efficiency of healthcare in KSA might be improved through downsizing of hospitals on DRS and reallocating these inputs to the hospitals operating in the IRS. Moreover, five out of eight large hospitals (500 or more beds) were operating on DRS, implying that to improve efficiency, they needed to reduce their production capacity. This is supported by other research findings.[43]

This study found that 61.5% of small hospitals had been operating on IRS, none was on DRS. It can thus be argued, like Kiadaliri and colleagues (2011), that the increase of capacity (inputs) of this category should be increased by reallocating resources from the larger hospitals for improving efficiency.[43] The efficient scale of public hospitals was in medium-sized establishments (200 to 499 beds). Although half of the hospitals located in the east were operating on the most productive scale size (CRS), three were operating on DRS. Around 53% of the hospitals in the north were operating on IRS, whereas 30% of western region hospitals, which reported the lowest efficiency scores, were operating on DRS.

Our analysis found that hospitals located in the west region were relatively less efficient than hospitals located in other regions. The central region hospitals appeared to be the efficient. Atılgan[44] reported in the same line as our findings, i.e. location-specific differences in efficiency scores for general MOH hospitals in Turkey. Atılgan argued that this could be due to case mix and/or case severity differences between hospitals. We observed that five out of eight large hospitals in our sample are located in the west region. We can argue that hospitals in the west region might be treating more severe cases than hospitals in other regions in KSA, which might have led to different levels of efficiency scores in hospitals across regions.[18] Another explanation could be that hospitals in this region consumed more inputs in anticipation of the annual pilgrimage season, for which government of KSA allocates more resources to such hospitals.

Regardless of the capacity or location-based performance variations, improving the scale efficiency of hospitals would require long-term effort, reflected in amendments to health policies, strategic plans and the autonomy of hospital-managers.[43] The prevailing ability of patients to access health services should not be compromised while reallocating the resources to the other hospitals until Pareto optimality is achieved.[9]

The use of DEA can identify sources of inefficiency, helping hospital managers and health policy-makers to reach informed decisions.[36] The analysis showed that the number of full-time physicians was slightly larger notable reason for inefficiency than the other factors, with an average excess of 22.4%, from an input perspective. Other inputs among labour variables that showed a surplus in use were the number of nurses and the number of allied health personnel, in addition to excess number of hospital beds (capital variable). Analysis revealed a shortage of outputs production, e.g. hospitals needed to increase the number of outpatients and hospitalized inpatient services on average by 12.2% and 14.2% respectively, to be efficient.

Given our findings, health policy-makers may consider redeploying their labour forces from inefficient hospitals to more efficient ones.[36,43] Public hospitals can consider taking measures for utilizing existing beds effectively to increase efficiency. For example, in this study many large hospitals had been operating on DRS; however, most of the small hospitals were operating on IRS. Healthcare administrators should assess the legal conditions and regulations for the effective use of medical capacity in light of the findings of this slack analysis.

It had been argued by Afzali[28] and Hollingsworth[12] that many hospital databases are compromised by insufficient data on a broad range of hospital functions and care, e.g. preventive care, health promotion, staff development activities. Thus, improving hospital's databases through high quality data collection and processing techniques — including data from different health provision levels, capturing valid data that reflects the severity of cases and related health services, quality of care and pattern of activities — is very important.[29,44] Such improvement would facilitate further efficiency research by indicating weaknesses in healthcare production processes and consequently would guide policy-makers in potential reforms of health policy and directives.

In recent years, KSA has been facing the global trends of rising healthcare costs in addition to high growth rate of population and high prevalence of chronic diseases. The government thus realized that the existing healthcare financing system with oil revenue is unsustainable.[45] It thus can be argued that optimum use of existing health resources, which is a fundamental requirement for achieving universal health coverage as advised by the World Health organization[46] can appropriately be applied for KSA. An application of these findings are useful for high income, and Gulf countries in particular, which have the same health financing systems and comparable demand for health services.[2,3,14] Our findings from this current analysis of KSA public hospitals indicated that there is large scope for improving efficiency in utilizing healthcare resources. We recommend the policy-makers to consider the appropriate use of resources within hospitals as well as reallocate resources across hospitals, given the findings of this research. Thus, to meet the efficient use of health resources to ensure the maximum value for money, which is expected to contribute significantly towards achieving universal health coverage in KSA.

The study faced the challenges of finding data on economic values of the inputs, also severity of cases and quality of services of the outputs. We, however, could use the mortality rate as the proxy for quality of services. The performance assessment is devoted on how to utilize optimally the resources of the health sector in order to provide the given levels of health services. Thus, we rationally adopted input orientation in the assessment. However, DEA methodology also permits the assumption of output orientation. We did not apply output-oriented DEA models because outputs of different type than the ones used in the current study would need to be available.

In this study we provide the optimal levels of resources that render efficient each hospital given the health services levels that each one of them provides. Further to estimating the optimal levels of resources, a different yet important assessment is to examine the allocation of these resources among the hospitals. This extension is left for future research. Despite a few limitations, the study site (KSA), and data sources might create strong interest among policy-makers, stakeholders, researchers and academics. This is the first research study of technical efficiency based on official data from KSA, that has considered public hospital capacities and geographical locations.

Conclusions

Given the scarcity of resources, growing expenditure on health and demand for health services, more attention should be paid to improving the efficiency of healthcare by better utilization of current resources. In this study, inefficiency existed in most public hospitals, and these could reduce their inputs by 24% without any reduction in service provision. Small hospitals and hospitals in the central region of KSA were relatively more efficient. A high proportion of hospitals were operating at non-optimal scale size, while an efficient scale of operation was observed in medium-sized hospitals. The finding suggests that it would be helpful to adjust production capacity by downsizing hospitals operating on DRS and reallocating the resources to hospitals on the IRS, as reflected in the scale analysis. Performance analysis shows the surplus of the health workers and a shortage of health services to be major causes of inefficiency, implying that health regulators might redeploy their labour forces for effective utilization of medical capacity. A possible reallocation of resource must take place without compromising patients' current access to public-funded health services.

Acknowledgement

We are grateful for the Ministry of Education and the government of Saudi Arabia for unlimited support. The authors would like to thank of the Administration of Statistics and Information and the Administration of Research and Studies in the Ministry of Health for providing access to the hospital's databases. Special gratitude to Mr Nabil A. Othman and Ms Nuwayyir Alshalawi at Administration of Statistics and Information for their contributions through permitting to use the administration's access to the necessary databases to complete the data collection.

Contributors

AA, LN and JK contributed to conceptualizing the research question, study design and settings and literature search. AA contributed to data collection and variable extraction. AA and JK conducted the data analysis, interpretation, and writing the manuscript. AA, LN and JK contributed to writing, reviewing and revising the manuscript. All authors finally reviewed the manuscript critically and approved the final version for submission.

Funding

There is no funding agency in the public, commercial or not-for-profit sectors to report for this submission.

Competing interest

None declared.

Data sharing statement

Data were extracted from the hospital databases at Administration of Statistics and Information in The Ministry of Health. Additional data are available if requested.

Ethics approval

Ethics approval was obtained from the Ethics Committee of Institutional Review Board (IRB) of King Fahad Medical City, the Ministry of Health in Saudi Arabia (IRB log No. 18-166E).

Patient consent for publication

Not required.

References

1. Khoja T, Rawaf S, Qidwai W *et al*. Health care in Gulf Cooperation Council countries: a review of challenges and opportunities. *Cureus* 2017;9(8):e1586. DOI 10.7759/cureus.1586.
2. Ardent Advisory & Accounting. *GCC healthcare sector report. A focus area for governments.* Abu Dhabi, UAE, 2015 Accessed: January 2018: DOI: http://www.ardentadvisory.com/files/GCC-Healthcare-Sector-Report.pdf
3. Ram P. Management of healthcare in the Gulf Cooperation Council (GCC) countries with special reference to Saudi Arabia. *International Journal of Academic Research in Business and Social Sciences* 2014; 4(12). DOI: 10.6007/IJARBSS/v4-i11/1326.
4. The World Bank. *2019 Country Data*. Available at: https://data.worldbank.org/country/saudi-arabia (accessed January 2019).
5. MOH portal.com. *2017 Annual Statistical Book* Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/ANNUAL-STATISTICAL-BOOK-1438H.pdf (Accessed Oct. 2018).

6. Mourshed M, Hediger V, Lambert T. Gulf Cooperation Council healthcare: challenges and opportunities. 2007; *Arab World Competitiveness Report (Part 5)*;55–64, World Economic Forum, Geneva, Switzerland 2007. DOI: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.183.7279&rep=rep1&type=pdf
7. MOH portal.com. *Ministry of Health Strategic Plan 2010–2020*. Available at: https://www.moh.gov.sa/Portal/WhatsNew/Documents/OKIstragi260p.pdf.(Accessed October 2018).
8. Albejaidi F. Healthcare system in Saudi Arabia: an analysis of structure, total quality management and future challenges. *Journal of Alternative Perspectives in the Social Sciences* 2010;2(2):794-818.
9. Jacobs R, Smith P, Street A. *Measuring efficiency in health care: analytic techniques and health policy.* Cambridge; Cambridge University, p3–39/91-127, 2006.
10. Farrell MJ. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society* 1957;120(3):253–290.
11. Hanson K, Atuyambe L, Kamwanga J *et al*. Towards improving hospital performance in Uganda and Zambia: reflections and opportunities for autonomy. *Health Policy* 2002;61, 73–94.
12. Hollingworth B. Non-parametric and parametric applications measuring efficiency in health care. *Healthcare Management Science* 2003;6:203–218.
13. Kelly E, Stoye G, Vera-Hernández M. Public hospital spending in England: evidence from National Health Service administrative records. *Fiscal Studies* 2016;37(3-4), pp.433–459.
14. Alatawi A, Ahmed S, Niessen L *and Khan J*. Systematic review and meta-analysis of public hospital efficiency studies in Gulf region and selected countries in similar settings. Cost Effectiveness and Resource Allocation 2019;17(17). Doi.org/10.1186/s12962-019-0185-4
15. Helal S, Elimam H. Measuring the efficiency of health services areas in Kingdom of Saudi Arabia using data envelopment analysis (DEA): a comparative study between the years 2014 and 2006. *International Journal of Economics and Finance* 2017;9(4) pp172–184.

16. Abou El-Seoud M. Measuring efficiency of reformed public hospitals in Saudi Arabia: An application of data envelopment analysis. *International Journal of Economics and Management Sciences* 2013;2(9):44–53.

17. Hussey P, de Vries H, Romley J *et al*. A systematic review of health care efficiency measures. *Health Services Research and Educational Trust* 2009; 44(3):784–805. DOI: 10.1111/j.1475-6773.2008.00942.

18. Kiadaliri A, Jafari M, Gerdtham U. Frontier-based techniques in measuring hospital efficiency in Iran: a systematic review and meta-regression analysis. *BMC Health Services Research* 2013;13:312. http://www.biomedcentral.com/1472-6963/13/312

19. Hollingsworth B. The measurement of efficiency and productivity of health care delivery. *Health Economics* 2008;17:1107–28. DOI: 10.1002/hec.1391

20. Varabyova Y, Müller JM. The efficiency of health care production in OECD countries: a systematic review and meta-analysis of cross-country comparisons. *Health Policy* 2016;120(3) 252–263. http://dx.doi.org/10.1016/j.healthpol.2015.12.005

21. Al-Homayan A, Shamsudin F, Subramaniam C, Islam R. Analysis of health care system — resources and nursing sector in Saudi Arabia. *Advances in Environmental Biology* 2013;7(9), pp. 2584-2592.

22. Almalki M, FitzGerald G, Clark M. Health care system in Saudi Arabia: an overview. *Eastern Mediterranean Health Journal* 2011;17(10).

23. MOH portal.com. *2015 Annual Statistical Book*. Available at: https://www.moh.gov.sa/en/Ministry/Statistics/book/Documents/StatisticalBook-1436.pdf.

24. Atilgan E. The technical efficiency of hospital inpatient care services: an application for Turkish public hospitals. *Isletme ve Ekonomi Arastirmalari Dergisi/Business and Economics Research Journal* 2016;7(2): 203–214. DOI: 10.20409/berj.2016217537.

25. Pelone F, Kringos, DF, Romaniello A *et al*. Primary care efficiency measurement using data envelopment analysis: a systematic review. *Journal of Medical Systems* 2015;, 39(1):156.

26. Cooper W, Seiford L, Tone K. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Springer, New York, p1-85, 2007. DOI: 10.1007/978-0-387-45283-8

27. Gok MS, Sezen B. Analyzing the ambiguous relationship between efficiency, quality and patient satisfaction in healthcare services: the case of public hospitals in Turkey. *Health Policy* 2013;111(3), pp 290-300. http://dx.doi.org/10.1016/j.healthpol.2013.05.010
28. Afzali HH, Moss JR, Mahmood MA. A conceptual framework for selecting the most appropriate variables for measuring hospital efficiency with a focus on Iranian public hospitals. *Health Services Management Research* 2009;22(2):81–91. DOI: 10.1258/hsmr.2008.008020
29. Sahin I, Ozcan YA. Public sector hospital efficiency for provincial markets in Turkey. *Journal of Medical Systems* 2000;24(6), pp 307–320.
30. Ahmed S, Hasan MZ, MacLennan M, et al. Measuring the efficiency of health systems in Asia: a data envelopment analysis. BMJ Open 2019;9: e022155. doi:10.1136/bmjopen-2018-022155
31. Dyson R, Allen R, Camanho A *et al*. Pitfalls and protocols in DEA. European *Journal of Operational Research* 2001;132(2):245–259.
32. Hollingsworth B. Evaluating efficiency of a health care system in the developed world. *Encyclopedia of Health Economics* 2014;1(18) pp.292-299.
33. Charnes A, Cooper W, Rhodes E. Measuring the efficiency of decision-making units. *European Journal of Operational Research* 1978;2(6), 429–444 (1978)
34. Banker R, Charnes A, Cooper W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science* 1984;30(9), 1078–1092
35. Chuang CL, Chang PC, Lin RH. An efficiency data envelopment analysis model reinforced by classification and regression tree for hospital performance evaluation. *Journal of Medical Systems* 2010;35(5):1075-83. Doi:10.1007/s10916-010-9598-5.
36. Gok MS, Altindag E. Analysis of the cost and efficiency relationship: experience in the Turkish pay for performance system. *European Journal of Health Economics* 2015;16(5), pp 459–469. DOI 10.1007/s10198-014-0584-6
37. O'Neill L, Rauner M, Heidenberger K *et al*. A cross-national comparison and taxonomy of DEA-based hospital efficiency studies. *Socio-Economic Planning Sciences* 2008;42:158–189.

38. Mahate A, Hamidi S. Frontier efficiency of hospitals in United Arab Emirates: An application of data envelopment analysis. *Journal of Hospital Administration* 2016;5(1) pp7–16. DOI: 10.1007/s10916-014-0156-4

39. Ramanathan R. Operations assessment of hospitals in the Sultanate of Oman. *International Journal of Operations and Production Management*, 2005;25(1) pp 39-54. DOI: 10.1007/s10916-014-0156-4

40. Charnes, A. and Cooper, W.W. Programming with Fractional Functions. Naval Research Logistic Quarterly (1962;(9): 181-186. DOI: org/10.1002/nav.3800090303

41. Emrouznejad A, Thanassoulis E. *Performance Improvement Management Software: PIM-DEAsoft-V3.0 User Guide* May 2011; www.DEAsoftware.co.uk,Performance Improvement Management Limited, UKISBN: 1-85449-412-2. Available at: https://deazone.com/en/software

42. Shahhoseini R, Tofighi S, Jaafaripooyan E *et al*. Efficiency measurement in developing countries: application of data envelopment analysis for Iranian hospitals. *Health Services Management Research* 2010;24(2):75-80. DOI: 10.1258/hsmr.2010.010017

43. Kiadaliri A, Haghparast-Bidgoli H, Zarei A. Measuring efficiency of general hospitals in the south of Iran. *World Applied Sciences Journal* 2011;13(6): 1310–1316.

44. Afzali HH, Moss JR, Mahmood AM. Exploring health professionals' perspectives on factors affecting Iranian hospital efficiency and suggestions for improvement. *International Journal of Health Planning and Management* 2011;26: e17–e29. DOI: 10.1002/hpm.1035

45. Al-Salem AA. Renovation of financing healthcare services in Kingdom of Saudi Arabia, by implementing National Health Insurance (NHI). *European Journal of Pharmaceutical and Medical Research*, 2018,5(9), 439-448.

46. World Health Organization. 2010. Health systems financing: the path to universal coverage, World Health Report 2010, Geneva.

Tables

Table 1: Budget appropriations for the MOH with respect to government budget (SR = Saudi Riyal).

Table 2: Descriptive statistics of the inputs and outputs of the 91 hospitals.

Table 3: Technical efficiency scores and return to the scale of the public hospitals in KSA.

Table 4 Technical efficiency scores and returns to the scale of the hospitals categorized by location.

Table 5 Slacks evaluation for inefficient hospitals.

Figures

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

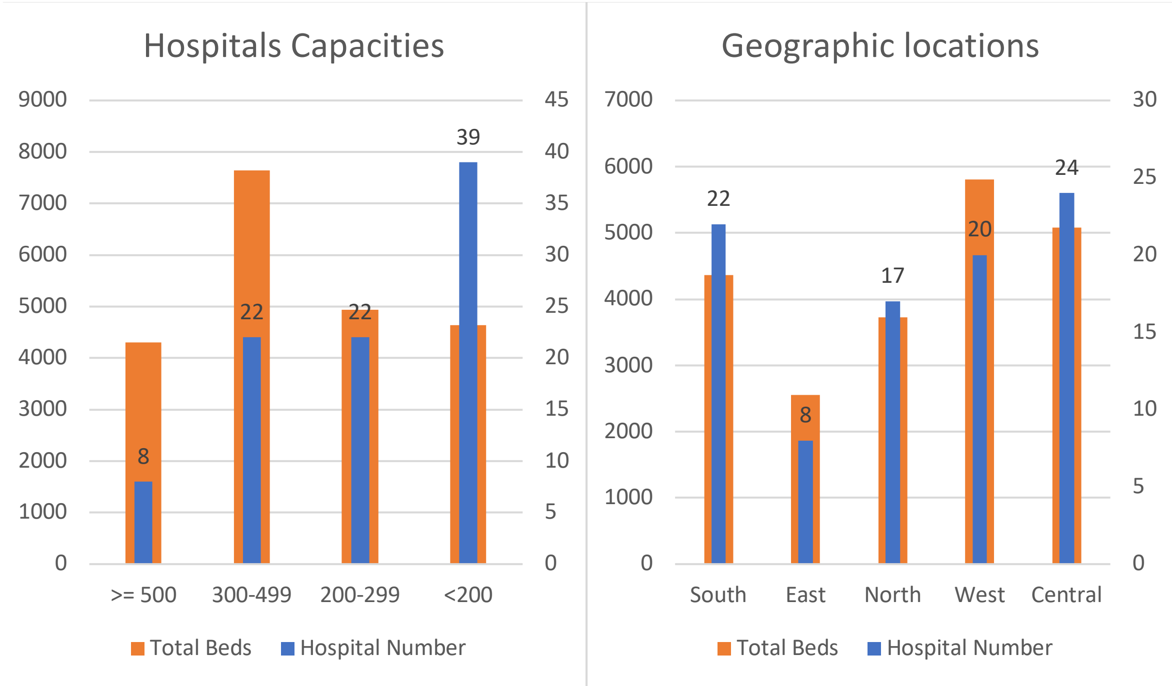

Figure 1: Number of hospitals and hospital beds in each capacity and geographical location, 2017.

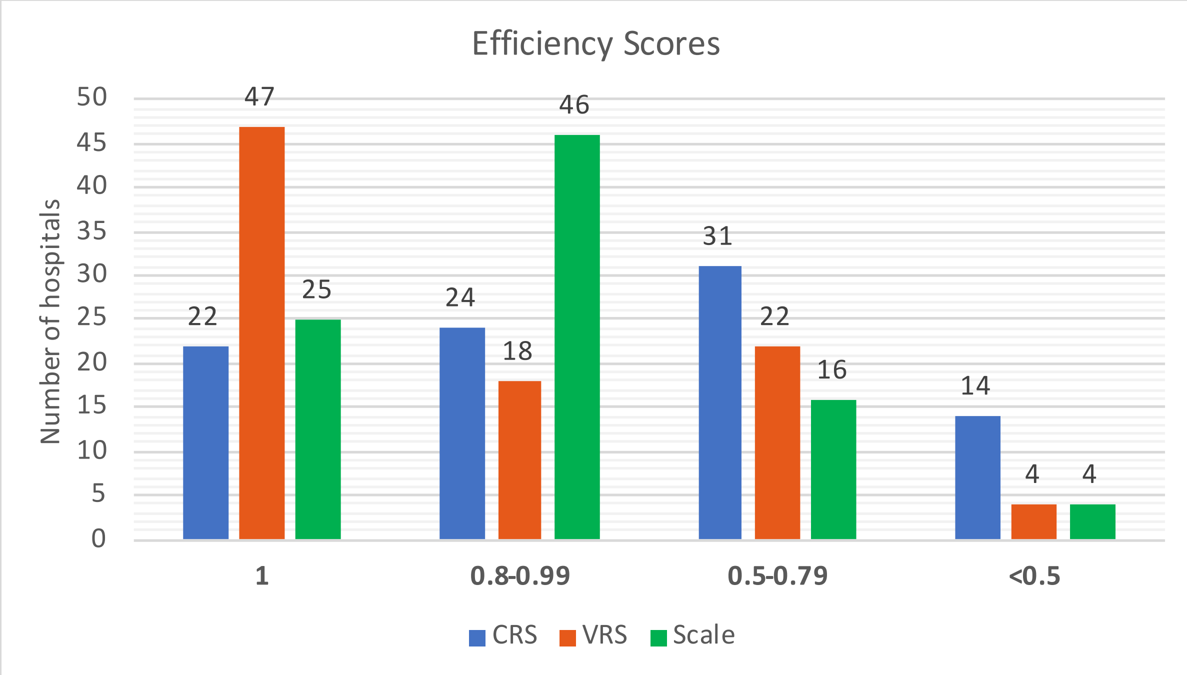

Figure 2. Distribution of technical efficiency scores of the hospitals on technical (CRS), pure technical (VRS) and scale efficiencies.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	0
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2,3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6,7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4,5,6,7
Bias	9	Describe any efforts to address potential sources of bias	*n/a*
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5,6
		(*b*) Describe any methods used to examine subgroups and interactions	7
		(*c*) Explain how missing data were addressed	7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	8
		(*e*) Describe any sensitivity analyses	n/a
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8,9
		(b) Indicate number of participants with missing data for each variable of interest	7
Outcome data	15*	Report numbers of outcome events or summary measures	9,10,11,12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9,10
		(*b*) Report category boundaries when continuous variables were categorized	9,10,11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11,12
Discussion			
Key results	18	Summarise key results with reference to study objectives	12,13,14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14,15
Generalisability	21	Discuss the generalisability (external validity) of the study results	13,14,15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.