Efficiency and Optimal size of Italian Public Hospitals: Results from Data Envelopment Analysis

Monica Giancotti [1], Giorgia Rotundo [2], Vito Pipitone [3], Marianna Mauro [1]

(1) Department of Clinical and Experimental Medicine, Magna Graecia University, Viale Europa, Catanzaro, Italy
(2) Department of Legal, Historical, Economic and Social Sciences, Magna Graecia University, Catanzaro, Italy
(3) National Research Council, Mazzara del Vallo, Italy

CORRESPONDING AUTHOR: *Monica Giancotti, Post Doctoral Researcher. Department of Clinical and Experimental Medicine. Magna Graecia University, Viale Europa, Catanzaro, Italy. E-mail: mgiancotti@unicz.it; Telephone number: +39 0961 369 4374; ORCID: 0000-0003-1584-6845.*

***DOI:* 10.2427/12929**
Accepted on December 4, 2018

ABSTRACT

Background: One of the major issues discussed in the literature about hospital efficiency is the impact of hospital size on technical efficiency. Many studies have observed that in some cases, hospital technical inefficiency is correlated with an incorrect size. This paper addresses this topic. In particular, we attempt to identify an optimal size of hospitals in terms of beds.
Methods: The study is organized as follow: first, we performed the Data Envelopment Analysis in order to calculate the technical and scale efficiency scores for a sample of 41 Italian public hospitals during the period 2010-2013; second, we investigated the impact of size on hospital efficiency, identifying the magnitudes of input reductions needed to make inefficient public hospitals efficient. Finally, we calculated the most productive scale size for each hospital in the sample. According to these results, through an overall observation, we attempted to identify an optimal size for hospitals in terms of beds.
Results: Most of the hospitals were inefficient and most of the inefficiency was the results of the presence of waste in terms of input resources. During the period considered, we found that inputs could be reduced by 22% on average. Economies of scale were found around 200 beds for 20.000 discharges per year.
Conclusions: The identification of an optimal size of hospitals in terms of beds still requires further efforts in the literature. However, this study contributes to support hospital managers in resource allocation choices through a quantitative approach.

Key words: Hospitals, Italy, Optimal Size, Beds, Dea Analysis

INTRODUCTION

One of the major issues discussed in the literature about hospital efficiency is the impact of the size of a hospital on its technical efficiency [1]. Many studies on hospitals have observed that in some cases, technical inefficiency is correlated with an incorrect size [1-4].

For hospitals, the wrong size leads to the waste of resources, especially in terms of beds and staff, resulting in increased health care spending. Indeed, one important source of potential inefficiency in the hospital sector relates to hospitals' scale and scope [5].

The question is whether larger hospitals are more, or less, efficient than smaller ones. Research undertaken chiefly in the USA and the United Kingdom indicates that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds [6].

Scale efficiency indicates the ability of a decision-making unit to identify the "optimal" productive size in terms of resources used, which allows the decision making unit to take full advantage of economies of scale by producing maximum output per unit of input and reducing the average unit costs of production. Indeed, smaller hospitals might be inefficient due to the fact that fixed infrastructural and administrative costs are spread across a limited caseload, thereby pushing up the cost of an average hospital visit.

According to the concept of economies of scale, increasing the size of a very small operating unit (assigning to it, for example, two or three times the amount of resources) creates economies of scale, i.e., the resulting product increases by more than two or three times.

Thus, efficiency gains could be made by expanding firm size if so doing gives rise to economies of scale.

It might make good economic sense to enlarge the size and scope of a hospital to make better use of available expertise, infrastructure and equipment [4].

However, at some point, a hospital goes beyond its optimal level of efficiency and begins to show diseconomies of scale. The optimum size is, therefore, found when all economies of scale have been exploited, but without yet creating diseconomies.

In this context, the ability to measure technical and scale efficiency is crucial to addressing the question of optimal productive size and to managing a fair allocation of resources [7]. Indeed, hospitals are the key resource units in the health care system. They are at the heart of many pressing healthcare issues, as they consume a majority of a nation's health expenditures and play an important role in the delivery of health care services [8].

In Italy, the rise in health care spending has required a number of interventions and reforms.

The Italian National Health System (INHS) reform started with a gradual decentralization process, from national to regional and local levels.

Specifically, the reform adopted in 2001 (by legislative decree n. 56/2000) in order to ensure the financial accountability of regional governments, attributed fiscal, financial and managerial responsibilities to the regions, which were already responsible for the organization of health care services.

However, the fiscal federalism scheme was not sufficiently implemented because the central government and the regions failed to agree on funding arrangements.

Thus, the stronger regions succeeded in autonomously steering their systems to good service levels and balanced budgets, while weaker regions experienced both economic and service shortfalls [9].

Since 2007, the INHS has experienced a turnaround with the development of a formal regional recovery plan (RRP) for the weakest regions, with the aim of reducing their healthcare expenditures.

In the worst cases, the national Minister of Health (MoH) appointed a Commissioner to pursue the central government's targets, thus overruling many of the powers of the regional governments.

Since the introduction of RRPs, the INHS has started a broad reorganization of local hospital services.

Specifically, the rationalization of inpatient facilities reduced the number of public and private beds by 25% (-71,985) between 2000 and 2014: the numbers of acute care beds are now in line with or lower than other European countries.

The adoption of measures to increase efficiency and reduce deficits (such as RRPs) was part of a wider process of reform in the supply-side of Italian health care.

Among other reforms, hospital downsizing was a widely adopted in Italy with the aim of both containing health care costs in the short-term and improving performance in the long-run [10].

In this regard, RRPs (since 2007) and the reform law no. 135/2012 (the "Spending review"), which set a number of 3.7 beds per 1,000 inhabitants. This law had a great impact on the reorganization of inpatient facilities, forcing hospital downsizing and mergers.

It should be noted that no question about "optimal" size was considered, which was a main criticism of this reform process.

Indeed, the literature has long debated on this, and has observing that there is a strong correlation between size and hospital performance [3, 4]. Hospital mergers seemed to stem from a conviction among policy makers that larger hospitals lead to lower average costs, improved financial performance and also improved clinical outcomes [11]. However, with regard to the latter, the findings in the literature are mixed. Indeed, some authors show that although high-volume institutions do have better outcomes on average, important caveats in the volume-outcome relationship have implications for how hospital mergers should be evaluated with respect to the delivery of health care; larger is not always better [11].

The volume-outcome relationship varies widely across conditions and outcomes, with the largest benefits occurring among a small number of technically difficult surgical operations. Volume might simply be a proxy for other processes, such as having systems in place to recognize and effectively manage complications.

To improve the delivery of high-quality care, hospitals should instead focus on improving processes that create better outcomes for patients.

Indeed, relying on increased volume to create quality might be confusing cause and effect [12]. High-quality hospitals often have a larger market share due to their good reputation.

Greater uniformity in the literature is shown with regard to the optimal size of hospitals in terms of beds. Most studies report the consistent presence of economies of scale for hospitals with 200–300 beds [7, 13], while diseconomies of scale may occur below approximately 200 beds and above 600 beds [6, 7].

This paper is an attempt to identify an optimal size of the Italian public hospitals in terms of beds.

To achieve this goal, the study was performed as follows: first, we conducted a Data Envelopment Analysis (DEA) in order to calculate the technical and scale efficiency scores for a sample of 41 Italian public hospitals during the period 2010-2013. This timeframe was selected considering different factors, including the availability of data and the fact that the earliest RRP effects can be measured starting from 2010, while 2013 is the year in which most of the changes introduced by the spending review of 2012 should be detected.

Second, we studied the impact of size on hospital efficiency, identifying the magnitudes of input reductions needed to address the inefficiency of certain hospitals.

Finally, we calculated the most productive scale size (MPSS) for each hospital in the sample.

According to these results, through an overall observation, we tried to identify an optimal size for the hospitals in terms of beds.

The paper is organized as follows: section 2 presents the DEA methodology and describes the dataset, section 3 presents the results of the efficiency analysis, section 4 discusses the conclusions, implications, and limitations of this study.

METHOD

Research questions and objectives

In this study we addressed the following research questions:

- What was the overall, pure technical and scale efficiency of public hospitals in Italy in financial years (FY) 2010/2013?
- How much can hospitals increase or decrease inputs without affecting the amount of output provided?
- What is the Most Productive Scale Size (MPSS) of hospitals during the evaluated period?
- Finally, what is the hospitals "optimal" size in terms of numbers of beds?

On these bases, using the DEA technique, the specific objectives of our study were: (a) to estimate the overall, pure technical and scale efficiency of public hospitals in Italy in FY 2010/2013; (b) to estimate the magnitudes of inputs increases/decreases that would have been required to make relatively inefficient hospitals more efficient; (c) to determine the MPSS for each hospital during each year, and (d) to estimate an "optimal" size of hospitals in terms of beds.

The Data Envelopment Analysis

DEA is a non-parametric, mathematical programming technique, developed by Charnes, Cooper and Rhodes [14], which measures the relative efficiency of a set of similar decision-making units (DMU) in the presence of multiple inputs and outputs. It remains the preferred method among researchers in the field for the measurement of the technical and scale efficiency of hospitals [15]. DEA identifies which units operate efficiently, and therefore belong to the efficient frontier, and which of them do not operate efficiently. Inefficient units should make appropriate adjustments in their outputs or inputs in order to increase efficiency.

The technical efficiency index of one DMU is in the form of an output-to-input ratio. DEA models can be either input or output-oriented. In the former case, technical inefficiency is defined as the proportional reduction in input usage achievable when output is constant. In the latter case, technical inefficiency is defined as a proportional increase in output with given input levels.

We used an input-oriented approach [15] in order to examine whether the hospitals increased or decreased the input of resources while keeping the level of output constant. According to input-oriented DEA, for a given amount of output, the units using lower amounts of inputs are deemed efficient.

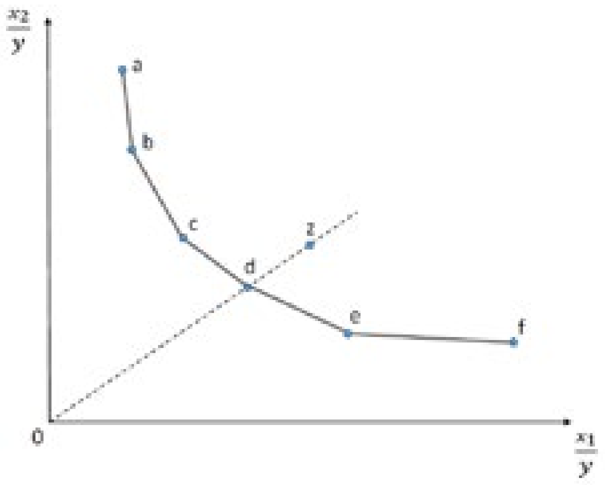
Figure 1 illustrates the case in which there are different DMUs (A, B, C, D, E, F, Z), each using two inputs (x1 and x2) to produce a single output (y). Knowledge of the unit isoquant of the fully efficient firm, represented by the curve af in the figure, permits the measurement of technical efficiency. If a given unit uses quantities of inputs, defined by the point z, to produce a quantity of output, the technical inefficiency of that firm could be represented by the distance dz, which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is expressed in percentage terms by the ratio dz/oz, which represents the percentage by which all inputs could be reduced. The technical efficiency (TE) of a firm is most commonly measured by the ratio:

$$\text{TE input oriented measure} = od/oz$$

which is equal to one minus dz/oz. It will take a value between zero and one, and hence provides an indicator of the degree of technical efficiency of the firm. A value of one indicates the firm is fully technically efficient. For example, the point d is technically efficient because it lies on the efficient isoquant.

DEA models can also assume either constant returns-to-scale (CRS) [14] , or variable returns-to-scale (VRS) [16, 17]. The CRS captures the result of both scale efficiency and pure technical efficiency. Moreover, the VRS model captures pure technical efficiency devoid of scale efficiency effects and the comparison between CRS and VRS models allows the identification of which decision units operate at increasing, decreasing or optimal scale conditions. Both models have been applied in our study.

FIGURE 1. Illustration of input-oriented DEA



Data and sample

From 2010 to 2013, the number of public hospitals in Italy declined from 63 to 58. For reasons related to the need to conduct the analysis over a period of 4 years and to ensure data consistency, as a result of an agreement among the authors, we considered public hospitals present throughout the period, excluding those that during the 4 years were subject to aggregation and merger. For the same reason, we also excluded hospitals for which data on selected input and output variables were unavailable. The analysis also excluded teaching hospitals for reasons connected to the complexity of data. The final sample was composed of 41 public hospitals.

Input and output variables

DEA was performed using 2 inputs: 1) *hospital beds* (total number of hospital beds for each year) and 2) *hospital staff* (total number of doctors, nurses, administrative personnel and other personnel).

Three different output variables were used: 1) *number of discharges* (total number of discharges for each year), in-patient days (total number of inpatient days for each year) and 3) *average length of stay* - ALOS, (average number of days that patients spend in hospital, measured by dividing the total number of inpatient days for a year by the number of discharges).

The dataset was compiled from various sections of the 2010/2013 Ministry of Health (MoH) website. Data were used as reported, without any processing or manipulation.

The choice of these variables was guided by three considerations: 1) the presumption that these include most of the hospital activities; 2) the use of similar inputs and outputs in past studies [15]; 3) the availability of data.

RESULTS

Descriptive analysis of input and output variables

Table 1 presents the descriptive statistics for inputs and outputs variables.

During the period under analysis, the 41 hospitals studied provided 8,008,531 inpatient days of care in 2010, 7,914,434 in 2011, 7,820,317 in 2012, 7,604,404 in 2013. They discharged 1,014.64 patients in 2010, 995,548 in 2011, 976,910 in 2012 and 950,436 in 2013.

These outputs were produced using a total of 96,668 personnel in 2010, 97,192 in 2011, 95,130 in 2012, 94,025 in 2013 and 24,587 hospital beds in 2010, 24,894 in 2011, 24,067 in 2012 and 23,736 in 2013.

There was wide variation in both outputs and inputs across the different hospitals.

The inpatient days of care provided varied from a minimum of 65,241 days to 335,586 days. The number of discharges varied from a minimum of 10,289 to a maximum of 43,661. In terms of inputs, there were considerable differences as well: the number of personnel varied between 758 and 4,569; and the number of hospital beds varied between 213 and 1,215.

Measurement of Technical and Scale efficiency

Table 2 illustrates the scores for each hospital in terms of overall technical efficiency (TE CRS), pure technical efficiency (TE VRS) and scale efficiency (SE). Efficiency scores range from 0 (totally inefficient) to 1 (100% TE).

It is important to recall that efficiency measures under the CRS hypothesis are the result of both scale efficiency and pure technical efficiency. The VRS model captures pure technical efficiency devoid of scale efficiency effects [18].

Starting from 2010, we observed the following results:

- Within our sample, only 2 hospitals (4.87%) were overall efficient (TE CRS= 1) (H7, H13).

TABLE 1. Descriptive Statistics of Study Variables

YEAR	Mean	STD	Min	Max	YEAR	Mean	STD	Min	Max
2010	**Input variables**				**2012**	**Input variables**			
Personnel	2,357.7	838.83	787	4.569	Personnel	2,320.24	811.98	764	4.136
Beds	599.68	230.22	245	1.213	Beds	587	224.46	233	1.091
	Output variables					**Output variables**			
Inpatient days	195,330.02	66,317.7	65.241	335.586	Inpatient days	190,739.4	59,499.6	81.715	318.777
Discharges	24.736	7,958.2	10.752	43.661	Discharges	23,827.07	6,934.8	11.266	40.497
ALOS	7.92	1.14	4.75	10.73	ALOS	8.03	1.04	5.35	9.9
2011	**Input variables**				**2013**	**Input variables**			
Personnel	2,370.54	811.29	758	4.375	Personnel	2,293.29	816.64	758	4.056
Beds	607.17	238.4	244	1.215	Beds	578.93	226.61	213	1.066
	Output variables					**Output variables**			
Inpatient days	193,034.98	62,119.1	73.478	327.182	Inpatient days	185,473.27	58,150.6	81.237	309.465
Discharges	24.282	7,301.6	11.009	41.495	Discharges	23,181.37	6,827.03	10.289	39.223
ALOS	7.97	1.06	5.07	10.31	ALOS	8.03	1.03	5.58	9.94

- 8 hospitals were scale efficient but technical inefficient (H22, H35, H14, H10, H12, H18, H4, H28). For example, with regard to unit 22, DEA allowed us to investigate the reasons for the inefficiency. In this case, the scale efficiency score (SE) was 1, suggesting that the hospital dimension was correct. However, a TE score <1 (0.976) indicates that overall inefficiency was due to the presence of waste. In particular, unit 22 could produce the same number of discharges using the 97% of input resources currently employed. Similar observations can be made regarding the other hospitals included in the sample: all technically inefficient hospitals could reduce their utilization of all inputs without reducing output.
- Only for three hospitals was overall inefficiency due to incorrect size (H31, H23, H9).

During 2011:

- There were three hospitals operating in conditions of total efficiency (7.31%). The remaining 38 hospitals presented a score in terms of overall efficiency <1, and only in four cases (H38, H11, H1, H23) was this result solely attributable to wrong size. For the remaining 34 hospitals, the reasons for inefficiency can be jointly attributed to waste in input resources available and to wrong size.

During 2012 we observed the followings results:

- the number of overall efficient hospitals increased compared with 2010 (+4.88%). In particular, hospital 29 reduced, compared to the previous year, the inputs used to produce the same output, reached the MPSS. 37 hospitals (90%) showed an overall score <1, mainly due to a wrong scale in two cases (H11, H1) and to waste in terms of input resources employed in one case (H12). For the remaining 34 hospitals, the two reasons coexist.

Finally, during 2013:

- There were three overall efficient hospitals (7.3%).

The remaining 38 hospitals showed an overall score <1, due to a wrong size in three cases (H1, H11, H9). For the remaining 35 hospitals the two reasons coexist.

Overall, mean technical efficiency of Italian public hospitals during the investigated period amounted to 0.78. Indeed, only 2 hospitals (4.87%) were overall efficient during the entire period (H7, H13). One hospital (H9) was overall efficient only in 2011 and 2012 and another (H29) was overall efficient only in 2012 and 2013.

If we consider only the pure technical efficiency (TE VRS), we see that 3 hospitals (H7, H13, H9) were efficient during the entire period (12.19 %), while (H38) and (H31) were efficient only during 2011 and 2010 respectively. Two hospitals (H11, H1) were efficient from 2011 to 2013. One hospital was technically efficient alone in 2012 and 2013 (H29) and one in 2010 and 2011 (H23).

As regards scale efficiency, only nine hospitals (22%) were overall technical inefficient despite their having an optimal size. These included eight hospitals during 2010 (hospitals 22, 35, 14, 10, 12, 18, 4, 28) and one in 2012 (H12).

In the period considered, certification was positively associated with only VRS efficiency. This finding may be attributed to efficiency enhancing innovations in the delivery of home health care during the period.

TABLE 2. Technical and Scale Efficiency Scores of Hospitals

H	2010 SCORES			2011 SCORES			2012 SCORES			2013 SCORES			MEAN SCORES		
ID	TE CRS	TE VRS	SE	TE CRS	TE VRS	SE	TE CRS	TE VRS	SE	TE CRS	TE VRS	SE	Mean TE CRS	Mean TE VRS	Mean SE
1	0.847	0.965	0.878	0.903	1	0.903	0.926	1	0.926	0.987	1	0.987	0.916	0.991	0.923
2	0.631	0.651	0.969	0.623	0.647	0.963	0.612	0.633	0.967	0.618	0.635	0.973	0.621	0.642	0.968
3	0.547	0.667	0.82	0.603	0.741	0.814	0.643	0.708	0.908	0.632	0.686	0.921	0.606	0.701	0.866
4	0.595	0.595	1	0.594	0.607	0.979	0.601	0.622	0.966	0.579	0.61	0.949	0.592	0.609	0.974
5	0.667	0.677	0.985	0.663	0.68	0.975	0.654	0.673	0.972	0.614	0.675	0.91	0.65	0.676	0.96
6	0.698	0.785	0.889	0.705	0.846	0.833	0.699	0.839	0.833	0.725	0.816	0.888	0.707	0.822	0.861
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	0.768	0.816	0.941	0.753	0.873	0.863	0.763	0.894	0.853	0.726	0.93	0.781	0.753	0.878	0.859
9	0.997	1	0.997	1	1	1	1	1	1	0.903	1	0.903	0.975	1	0.975
10	0.828	0.828	1	0.838	0.841	0.996	0.825	0.83	0.994	0.795	0.802	0.991	0.822	0.825	0.995
11	0.952	0.992	0.96	0.964	1	0.964	0.964	1	0.964	0.969	1	0.969	0.962	0.998	0.964
12	0.784	0.784	1	0.789	0.791	0.997	0.815	0.815	1	0.831	0.832	0.999	0.805	0.806	0.999
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	0.868	0.868	1	0.871	0.879	0.991	0.887	0.897	0.989	0.867	0.877	0.989	0.873	0.88	0.992
15	0.796	0.855	0.931	0.806	0.864	0.933	0.799	0.859	0.93	0.817	0.856	0.954	0.805	0.859	0.937
16	0.775	0.776	0.999	0.757	0.764	0.991	0.752	0.764	0.984	0.771	0.782	0.986	0.764	0.772	0.99
17	0.819	0.895	0.915	0.823	0.982	0.838	0.814	0.996	0.817	0.805	0.938	0.858	0.815	0.953	0.857
18	0.667	0.667	1	0.648	0.66	0.982	0.609	0.624	0.976	0.583	0.611	0.954	0.627	0.641	0.978
19	0.601	0.622	0.966	0.617	0.639	0.966	0.623	0.647	0.963	0.613	0.635	0.965	0.614	0.636	0.965
20	0.857	0.878	0.976	0.848	0.885	0.958	0.849	0.877	0.968	0.845	0.894	0.945	0.85	0.884	0.962
21	0.653	0.709	0.921	0.677	0.78	0.868	0.727	0.78	0.932	0.707	0.789	0.896	0.691	0.765	0.904
22	0.976	0.976	1	0.863	0.875	0.986	0.725	0.728	0.996	0.633	0.637	0.994	0.799	0.804	0.994
23	0.875	1	0.875	0.767	1	0.767	0.838	0.873	0.96	0.78	0.863	0.904	0.815	0.934	0.876
24	0.716	0.751	0.953	0.73	0.789	0.925	0.693	0.717	0.967	0.643	0.71	0.906	0.696	0.742	0.938
25	0.737	0.738	0.999	0.706	0.714	0.989	0.688	0.712	0.966	0.681	0.73	0.933	0.703	0.724	0.972
26	0.82	0.821	0.999	0.786	0.795	0.989	0.78	0.79	0.987	0.796	0.825	0.965	0.796	0.808	0.985
27	0.71	0.711	0.999	0.695	0.699	0.994	0.705	0.708	0.996	0.645	0.659	0.979	0.689	0.694	0.992
28	0.504	0.504	1	0.532	0.535	0.994	0.561	0.57	0.984	0.543	0.559	0.971	0.535	0.542	0.987
29	0.898	0.899	0.999	0.916	0.926	0.989	1	1	1	1	1	1	0.954	0.956	0.997
30	0.699	0.7	0.999	0.691	0.701	0.986	0.698	0.703	0.993	0.683	0.684	0.999	0.693	0.697	0.994
31	0.902	1	0.902	0.868	0.893	0.972	0.859	0.91	0.944	0.867	0.954	0.909	0.874	0.939	0.932
32	0.632	0.633	0.998	0.683	0.69	0.99	0.731	0.747	0.979	0.69	0.724	0.953	0.684	0.699	0.98
33	0.718	0.72	0.997	0.546	0.555	0.984	0.656	0.671	0.978	0.687	0.71	0.968	0.652	0.664	0.982
34	0.901	0.902	0.999	0.849	0.863	0.984	0.891	0.895	0.996	0.887	0.889	0.998	0.882	0.887	0.994
35	0.875	0.875	1	0.846	0.871	0.971	0.805	0.853	0.944	0.76	0.819	0.928	0.822	0.855	0.961
36	0.843	0.844	0.999	0.807	0.808	0.999	0.771	0.78	0.988	0.834	0.847	0.985	0.814	0.82	0.993
37	0.92	0.921	0.999	0.93	0.939	0.99	0.963	0.967	0.996	0.833	0.85	0.98	0.912	0.919	0.991
38	0.993	0.994	0.999	0.971	1	0.971	0.917	0.966	0.949	0.882	0.957	0.922	0.941	0.979	0.96
39	0.777	0.778	0.999	0.678	0.687	0.987	0.779	0.812	0.959	0.764	0.824	0.927	0.75	0.775	0.968
40	0.995	0.996	0.999	0.96	0.97	0.99	0.943	0.944	0.999	0.92	0.927	0.992	0.955	0.959	0.995
41	0.556	0.647	0.859	0.645	0.777	0.83	0.665	0.772	0.861	0.651	0.746	0.873	0.629	0.736	0.856
Total	32.397	32.44	39.72	31.951	33.566	39.1	32.23	33.576	39.385	31.566	33.282	38.903	32.036	33.466	39.277
Mean	0.79	0.816	0.969	0.779	0.819	0.954	0.786	0.819	0.961	0.77	0.812	0.949	0.781	0.816	0.958

Input variation needed to make inefficient hospitals efficient

DEA has demonstrated that most of the hospitals during the period under analysis were run inefficiently; accordingly, they need to either reduce their input or increase their output in order to become efficient. Table 3 presents total mean input variations needed to make inefficient public hospitals efficient.

In terms of beds and hospital staff, during the period considered, we found that in the pure technical efficiency model (VRS efficiency), inputs could be reduced by 21 % on average, and if hospitals operate at the correct size (CRS efficiency), inputs could be reduced by a further 2 %. Hospitals wasted a mean of 5,093 beds in the VRS model and 5,777 beds in the CRS model. Additionally, hospitals studied wasted a mean of 19,834 units of personnel in the pure technical efficiency model and 22,779 units in the overall technical efficiency model (TE CRS).

The Most Productive Scale Size (MPSS)

In this section, we extend the DEA to the estimation of the MPSS. The MPSS for a given input and output mix is the scale size at which the outputs produced 'per unit' of input is maximized. The concept of MPSS is based on the comparison of average productivity. In order to maximize the average productivity of one inefficient unit, the scale size should be increased if increasing returns to scale prevail, or decrease, if decreasing returns to scale prevail.

The DEA allows us to identify, for each inefficient unit, the standard ideal, for bringing the inefficient unit on the frontier of efficiency.

Each hospital should have one or more standard

TABLE 3. Total Hospitals Beds and Staff Variation Needed to Make Inefficient Public Hospitals Efficient. Mean scores 2010-2013

H			VRS STRATEGY				CRS STRATEGY			
ID	Number of Beds	Hospital staff	Virtual beds	Wasted beds	Virtual hospital staff	Wasted hospital staff	Virtual beds	Wasted beds	Virtual hospital staff	Wasted hospital staff
1	240.75	2,214.25	238.43	2.32	2,194.80	19.45	219.5	21.25	2,027.91	186.34
2	535.25	3,636.75	343.41	191.84	2,332.88	1,303.87	332.43	202.82	2,258.32	1,378.43
3	339	3,242.75	237.11	101.89	2,271.56	971.19	204.63	134.37	1,965.29	1,277.46
4	1146.25	3,881.75	697.03	449.22	2,362.31	1,519.44	679.09	467.16	2,298.97	1,582.78
5	573.25	1,916.00	387.7	185.55	1,295.73	620.27	372.97	200.28	1,244.61	671.39
6	340.5	2,115.00	279.7	60.8	1,737.77	377.23	240.6	99.9	1,494.86	620.14
7	242.25	2,487.25	242.25	0	2,487.25	0	242.25	0	2,487.25	0
8	368.75	1,703.75	322.17	46.58	1,495.39	208.36	278.04	90.71	1,282.26	421.49
9	412.25	766.75	412.25	0	766.75	0	402.59	9.66	747.78	18.97
10	576.25	2,304.50	475.66	100.59	1,901.62	402.88	473.53	102.72	1,892.94	411.56
11	349	1,896.00	348.29	0.71	1,892.16	3.84	335.8	13.2	1,824.33	71.67
12	617.75	3,608.00	496.96	120.79	2,906.38	701.62	496.49	121.26	2,903.66	704.34
13	467	3,119.25	467	0	3,119.25	0	467	0	3,119.25	0
14	487.25	3,091.00	428.83	58.42	2,720.87	370.13	425.47	61.78	2,699.21	391.79
15	320	2,438.25	274.72	45.28	2,093.28	344.97	257.39	62.61	1,961.49	476.76
16	550	2,808.50	424.29	125.71	2,166.69	641.81	420.12	129.88	2,144.70	663.8
17	358.25	1,280.00	341.03	17.22	1,219.21	60.79	292.1	66.16	1,043.52	236.48
18	1039.5	3,634.00	666.31	373.2	2,326.91	1,307.09	652.16	387.34	2,276.77	1,357.23
19	550	3,205.25	349.53	200.47	2,037.20	1,168.05	337.31	212.69	1,965.94	1,239.31
20	423.5	1,708.50	374.08	49.42	1,509.41	199.09	359.93	63.57	1,451.84	256.67
21	480.5	1,424.75	367.23	113.27	1,087.68	337.07	331.93	148.57	982.81	441.94

TABLE 3 (CONTINUED). Total Hospitals Beds and Staff Variation Needed to Make Inefficient Public Hospitals Efficient. Mean scores 2010-2013

H			VRS STRATEGY				CRS STRATEGY			
ID	Number of Beds	Hospital staff	Virtual beds	Wasted beds	Virtual hospital staff	Wasted hospital staff	Virtual beds	Wasted beds	Virtual hospital staff	Wasted hospital staff
22	746.75	2,524.50	603.1	143.65	2,049.68	474.82	599.65	147.1	2,037.77	486.73
23	370.25	1,281.25	341.47	28.78	1,196.09	85.16	300.88	69.37	1,040.81	240.44
24	516.75	1,547.50	382.42	134.33	1,148.40	399.1	358.52	158.23	1,077.29	470.21
25	558	1,860.50	403.76	154.24	1,346.41	514.09	392.87	165.13	1,309.56	550.94
26	711.25	2,256.75	574.52	136.73	1,822.69	434.06	565.81	145.44	1,794.99	461.76
27	701	2,261.50	487.09	213.91	1,570.53	690.98	483.35	217.66	1,558.22	703.28
28	1024.5	4,284.00	555.19	469.31	2,317.06	1,966.94	548.01	476.49	2,288.25	1,995.76
29	548.5	1,407.75	523.04	25.46	1,341.71	66.04	521.44	27.06	1,337.62	70.13
30	795	2,318.75	554.42	240.58	1,616.62	702.13	550.95	244.05	1,606.71	712.04
31	947.75	3,173.25	891.12	56.63	2,984.71	188.54	829.19	118.56	2,777.03	396.22
32	842.75	2,894.50	588.06	254.69	2,016.52	877.98	575.83	266.92	1,975.95	918.55
33	898.75	2,017.25	590.97	307.78	1,325.35	691.9	578.97	319.78	1,299.47	717.78
34	628.5	1,642.00	557.32	71.18	1,456.34	185.66	553.86	74.64	1,447.41	194.59
35	910.25	2,678.25	778.26	131.99	2,288.13	390.12	748.55	161.7	2,199.23	479.02
36	558	1,778.50	457.37	100.63	1,456.23	322.27	454.04	103.96	1,446.04	332.46
37	574.25	1,653.25	528.24	46.01	1,521.10	132.15	523.94	50.31	1,508.61	144.64
38	750.75	1,843.00	735	15.75	1,804.31	38.69	705.74	45.01	1,732.79	110.21
39	798.25	2,537.50	618.67	179.58	1,967.07	570.43	596.39	201.86	1,896.94	640.56
40	586.5	1,495.25	563.04	23.46	1,435.79	59.46	560.31	26.19	1,428.70	66.55
41	436	1,816.25	320.68	115.32	1,329.18	487.07	274.35	161.65	1,137.07	679.18
Total	24321	95,753.75	19227.7	5093.31	75,919.03	19,834.72	18544	5777.03	72,974.16	22,779.59

ideals. In order to calculate efficiency scores, the DEA technique compares each unit with others characterized by the same productive mix. The model allows us to identify many production techniques, and, within each unit's group characterized by the same productive mix, identifies the standard ideal. Therefore, there are many ideals to be imitated, and each unit is compared with those that have similar operating conditions. Standard ideals are technically and scale efficient so, for these units, the overall efficiency score is 1.

As we can observe, units that have an optimal size must not make any changes in personnel or in beds.

On the contrary, inefficient units are those with a score less than one. The presence of inefficiencies indicates that a hospital has excess inputs or insufficient outputs compared to hospitals on the efficient frontier. With respect to its standard ideal, these units are located above the frontier (and therefore too large), or below the frontier (and therefore too small). Therefore, it is necessary to modify their size in terms of input or output, by reducing it (in case of decreasing returns to scale - drs) or increasing it (in case of increasing returns to scale - irs). To understand the magnitude of the change, it is necessary to look towards the unit to be emulated (peer), which can be one or several. At each ideal to emulate, the DEA assigns a weight (peer weight) to be taken as a reference for the calculation of optimal size.

The achievement of MPSS requires changes not only in input but also in the output produced.

Results obtained using DEA for the optimal size for each hospital are set out in Table 4, which shows the amount of input and output resource variations required to align the hospital production process on the frontier, with a particular focus on hospital discharges.

During 2010, hospitals 7 and 13 were the standard ideal. Hospital 7 presented the same productive mix of hospitals 1, 15 and 3. On the contrary, hospital 13 was characterized by the same productive mix of the other hospitals. As far as returns to scale are concerned, the results show that only one hospital (H31) should reduce its size (drs). On the contrary, 29 hospitals should increase their size in order to reach MPSS.

In 2011, only 3 hospitals had the MPSS (H 7, 9, 13). 19 hospitals were too small (drs) and 19 hospitals too large (irs).

During 2012, four hospitals were technically and scale efficient (hospitals 7, 9, 13, 29). 15 hospitals were too large (drs) and 21 hospitals too small (irs). Finally, during 2013, four hospitals reached the MPSS (hospitals 7, 9, 13, 29). 11 hospitals were too large (drs) and 26 were too small (irs).

What is the optimal size of hospitals in terms of beds?

The estimation of the optimal number of beds is important for the improvement of overall hospital performance [19].

Our study shows that economies of scale are found around 200 beds for 20,000 discharges per year. Hospitals that were overall efficient during the entire period had a number of beds between 240 and 526, with a mean of 30,000 discharges per year (Figure 2).

In particular, overall efficient hospitals had a number of beds ranging, during 2010, between 245 and 424 (H7, H13), 244 and 483 during 2011 (H7, H9, H13), 240 and 526 in 2012 (H7, H9, H13, H29), 240 and 505 in 2013 (H7, H13, H29).

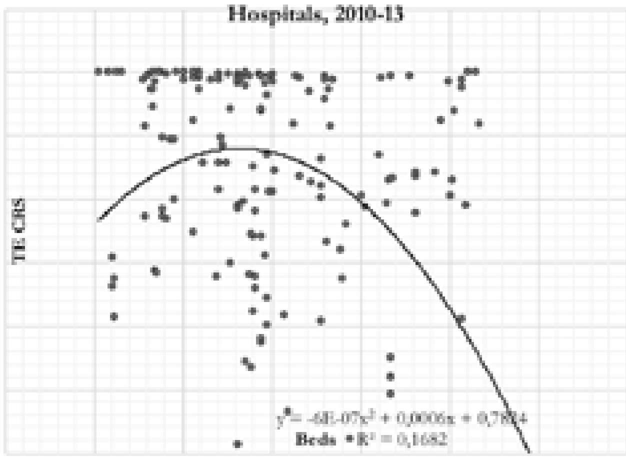
Our analysis confirms the data widely shared in the literature. Indeed, previous studies have observed the presence of economies of scale from 200 to 300 beds [7, 13]. Diseconomies of scale are observed, on the contrary, below 200 and above 600 beds [6, 7].

CONCLUSIONS

From 2010 to 2013, our analysis of overall technical, pure technical and scale efficiency shows that most of the Italian public hospitals were inefficient.

In terms of wasted resources, during the period considered, we found that in the pure technical efficiency model (VRS efficiency), inputs could be reduced by 21% on average, and if inefficient hospitals correct their size

FIGURE 2. Overall Technical Efficiency (TE CRS) vs Beds



(CRS efficiency), inputs could be reduced by a further 2%.

From our findings, managers of public hospitals and policy makers should focus on the efficient use of inputs to produce health care services and be aware that it is possible to reduce inputs without compromising the health status and care services provided to patients. Understanding the key-factors that lead to inefficiency allows hospitals to improve output without seeking additional resources.

Moreover, from these findings, there is an opportunity to improve productive practices within these hospitals, which would lead to further potential cost savings. Evidence of possible cost reductions represents an important policy issue.

Concerning the optimal number of beds, our findings were similar to those resulting from past studies. Economies of scale are evident around 200 beds per 20,000 discharges. The MPSS is achieved by hospitals with a number of beds that varies between 240 and 526 for a mean of 30,000 annual discharges. Healthcare managers should be able to exploit this knowledge about the appropriate size of hospitals. This still requires some effort in the literature. However, decisions on allocation of resources in hospitals should also be based on quantitative surveys.

These are three reasons why this paper adds to the literature on health care services.

Firstly, unlike previous studies using DEA on hospitals, we deconstructed overall efficiency into pure technical and scale efficiency and calculated the wasted inputs for each hospital during each year. Finally, we estimated the MPSS for each hospital during the period considered.

Secondly, we assessed the variations (negative or positive) in efficiency scores obtained with the DEA methodology over the time-series (2010-2013). The measurement of technical efficiency over time allows us to understand how a firm responds to external pressures (like increased competition, reduced reimbursements, etc.) and makes the necessary operational adjustments.

Thirdly, given the possibility to replicate this analysis, further studies along the lines presented here are warranted.

TABLE 4. Total Input and Output variations needed to reach the MPSS

H	2010				2011				2012				2013			
	MPSS Strategy				MPSS Strategy				MPSS Strategy				MPSS Strategy			
ID	Returns to scale	Discharges variation	Hospital staff variation	Beds variation	Returns to scale	Discharges variation	Hospital staff variation	Beds variation	Returns to scale	Discharges variation	Hospital staff variation	Beds variation	Returns to scale	Discharges variation	Hospital staff variation	Beds variation
1	irs	+11882	+559	+67	irs	+8600	+486	+56	irs	+4369	+270	+7	irs	+3409	+243	+27
2	irs	+11261	-513	-119	irs	+10141	-600	-89	irs	+9625	-653	-99	irs	+9228	-639	-92
3	irs	+12632	-519	-61	irs	+6860	-720	-73	irs	+4385	-731	-89	irs	+4834	-751	-73
4	-	+11231	-733	-789	drs	-11948	-2449	-765	drs	-6888	-2063	-578	drs	-6028	-2076	-568
5	irs	+24671	+1151	-180	irs	+2570	-458	-141	irs	+8221	-38	-62	irs	+8921	-92	-25
6	irs	+22569	+1018	+77	irs	+18656	+783	+130	irs	+20660	+952	+147	irs	-16043	+955	+148
7	-	0	0	0	-	0	0	0	-	0	0	0	-	0	0	0
8	irs	+24254	+1369	-2	irs	+10771	+371	+82	irs	+17582	+958	+139	irs	-8060	+929	+173
9	irs	+31741	+2314	-2	-	0	0	0	-	0	0	0	irs	+9111	+532	+120
10	irs	+16548	+813	-169	drs	-1962	-514	-133	irs	+1885	-275	-50	irs	+2507	-289	-71
11	irs	+17463	+1183	+69	irs	+8271	+549	+106	irs	+11198	+780	+157	irs	-16091	+791	+145
12	-	+4096	-474	-225	drs	-3144	-1000	-180	-	+1081	-577	-110	-	-33927	-595	-95
13	-	0	0	0	-	0	0	0	-	0	0	0	-	0	0	0
14	-	+5848	+19	-81	irs	+3337	-150	-24	irs	+3936	-13	-19	irs	+4793	-27	-4
15	irs	+15323	+623	+84	irs	+10700	+364	+48	irs	+10347	+379	+40	irs	+9710	+375	+48
16	-	+13548	+377	-153	irs	+2132	-522	-107	irs	+6790	-192	-33	irs	+5746	-208	-38
17	irs	+27989	+1809	+53	irs	+7433	+318	+91	irs	+10949	+557	+169	irs	+602	+515	+143
18	-	+9413	-521	-643	drs	-10867	-2056	-608	drs	-5713	-1864	-489	drs	-14571	-1888	-531
19	irs	+15253	-204	-151	irs	+8853	-562	-101	irs	+12731	-204	-38	irs	-19837	-266	-44
20	irs	+22317	+1382	-21	irs	+5433	+139	+34	irs	+8788	+400	+84	irs	-6745	+385	+92
21	irs	+29046	+1599	-63	irs	+5291	-93	-31	irs	+6547	+80	+47	irs	+4298	+66	+23
22	-	+5689	+350	-378	drs	-8254	-958	-267	drs	-1251	-759	-212	irs	+1618	-754	-235
23	irs	+28757	+1956	+136	irs	+12630	+609	+140	irs	+6049	+214	+88	irs	+3223	+188	+64
24	irs	+26672	+1489	-72	irs	+4355	-100	-31	irs	+4941	-140	-15	irs	+4523	-128	-47
25	irs	+22627	+1133	-162	irs	+1110	-476	-151	irs	+6865	-70	-7	irs	-1181	-81	-24
26	irs	+17468	+875	-288	drs	-4841	-841	-261	drs	-1837	-630	-192	drs	-2957	-667	-210
27	irs	+20142	+805	-310	drs	-2288	-869	-271	irs	+1761	-527	-167	irs	+3312	-551	-165
28	-	+10947	-1468	-619	drs	-4142	-2354	-537	drs	-4442	-2155	-517	drs	-16483	-2105	-534
29	irs	+23685	+1573	-161	drs	-3085	-346	-134	-	0	0	0	-	0	0	0
30	irs	+18868	+635	-420	drs	-5360	-1123	-398	drs	-11	-664	-254	irs	+512	-661	-216
31	drs3	-1168	-432	-612	drs	-18533	-1791	-529	drs	-11796	-1265	-392	drs	-11756	-1217	-366
32	-	+15755	+16	-438	drs	-5797	-1356	-388	drs	-5214	-1148	-292	drs	-10525	-1153	-359
33	irs	+27294	+1557	-184	drs	-3608	-1306	-571	drs	-1358	-822	-443	drs	-1839	-767	-501
34	irs	+20834	+1347	-240	drs	-5061	-629	-245	drs	-719	-228	-75	irs	-270	-147	-56
35	-	+10760	+453	-498	drs	-13374	-1374	-476	drs	-8426	-1112	-405	drs	-12349	-1146	-370
36	irs	+21141	+1253	-140	irs	+78	-351	-105	irs	+1363	-354	-40	irs	-1200	-136	-47
37	irs	+20407	+1349	-203	drs	-3594	-379	-128	drs	-765	-118	-32	irs	+2180	-111	-38
38	irs	+17665	+1277	-298	drs	-9856	-753	-314	drs	-5524	-532	-242	drs	-5450	-583	-252
39	irs	+21668	+1145	-167	drs	-6003	-1310	-418	drs	-7498	-1155	-348	drs	-7258	-1149	-367
40	irs	+21133	+1534	-211	drs	-3527	-316	-115	drs	-442	-119	-34	drs	-379	-140	-86
41	irs	+26892	+1052	-12	irs	+9751	+89	+22	irs	+11374	+260	+74	irs	+11342	+234	+60
Total	-	+704321	+29152	-7586	-	+11729	-22050	-6884	-	+109565	-13558	-4278	-	-103076	-13116	-4373

There are a number of limitations that should be considered when assessing the results of this study.

First, we employed the DEA technique using the hospital as a whole as the decision-making unit.

However, the inefficiency/efficiency of a single operating unit within the hospital could have a major impact on the result. Case studies of hospitals wards in inefficient and efficient hospitals would be extremely helpful to confirm the results of the DEA and to identify potential areas for improvement in the future [1].

Second, no data were available on input prices, provision for case mix and quality of outcomes, and the discharge output variable alone cannot reflect the entire hospital production process. This implies that hospitals found to be technically efficient might not be allocatively efficient. Future work should assess both the technical and allocative efficiency of hospitals. Finally, despite our conclusions, changing the size of a hospital is a difficult task and many different obstacles may emerge in doing so.

A major barrier pertains to the lack of autonomy among hospital CEOs in terms of decision making and strategies. There is a culture of consultative decisions in the hospital sector, with the central actors being local politicians, employee representatives, professions and users. Although this is considered to be a barrier for implementation, it also works as a quality assurance mechanism for the decisions taken, in addition to increasing legitimacy and facilitating the implementation of the decisions [20].

In conclusion, more stringent policy changes, such as the elimination of wastages and quality control, must be implemented to improve the performance of the hospital sector. Meanwhile, this study has demonstrated that DEA not only helps health policymakers and managers to answer the question "What is the optimal size of hospitals?" but also "By how much could their performance be improved?"

We recommend (a) future studies to understand the mechanisms through which diseconomies of scale are present in the delivery of health care services; (b) further analyses of the best-performing hospitals and their operating practices, with a view to establishing a set of "best practices" for others to emulate [21]; (c) replication of this analysis in a sample of operational units of the same type, in order to ensure more consistent results, and (d) strengthening of MoH personnel capacity for undertaking efficiency analyses [21].

Acknowledgements

There was no external funding received for this study.

Authors' contributions

The authors contributed equally to this study.

Conflict of interest

The authors declare that they have no conflicts of interest.

Ethical issues

This study did not involve Human Participants and/or Animals

References

1. Mahate A, Hamidi S, Akinci F. Measuring the Effect of Size on Technical Efficiency of the United Arab Emirates Hospitals. Glob J Health Sci 2016; 9(3):116.
2. Jat TR, Sebastian SM. Technical efficiency of public district hospitals in Madhya Pradesh, India: a data envelopment analysis. Glob Health Action 2013;6(1):21742.
3. Azevedo H, Mateus C. Cost effects of hospital mergers in Portugal. Eur J Health Econ 2014; 15(9):999-1010.
4. Kristensen T, Bogetoft P, Pedersen KM. Potential gains from hospital mergers in Denmark. Health Care Manag Sci 2010;13(4):334-345.
5. Varabyova Y, SchreyÖgg J. International comparisons of the technical efficiency of the hospital sector: Panel data analysis of OECD countries using parametric and non-parametric approaches. Health Policy 2013;112(1-2):70–9.
6. Roh CY, Moon MJ, Jung C. Measuring Performance of US Nonprofit Hospitals Do Size and Location Matter?. Public Perform Manag 2010;34(1):22-37.
7. Giancotti M, Guglielmo A, Mauro M. Efficiency and optimal size of hospitals: Results of a systematic search. PLoS One 2017; 12(3):e0174533.
8. Ersoy K, Kavuncubasi S, Ozcan YA, Harris JM 2nd. Technical efficiencies of Turkish hospitals: DEA approach. J Med Syst 1997;21(2), 67-74.
9. Longo F. Lessons from the Italian NHS retrenchment policy. Health Policy 2016; 120(3):306-15.
10. Mauro M, Maresso A, Guglielmo A. Health decentralization at a dead-end: towards new recovery plans for Italian hospitals. Health Policy 2017; 121(6):582-587
11. Fidler AH, Haslinger RR, Hofmarcher MM, Jesse M, Palu T. Incorporation of public hospitals: A "Silver Bullet" against overcapacity, managerial bottlenecks and resource constraints? Case studies from Austria and Estonia. Health Policy 2007; 81(1-2):328-38.
12. Tsai TC, Jha AK. Hospital Consolidation, Competition, and Quality: Is Bigger Necessarily Better?. JAMA 2014; 312(1):29-30.
13. Dranove D. Economies of scale in non-revenue producing cost centers: Implications for hospital mergers. J Health Econ 1998; 17(1):69-83.
14. Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. Eur J Oper Res 1978; 2(6):429-444.
15. Giancotti M, Pipitone V, Mauro M, Guglielmo A. 20 Years of Studies on Technical and Scale Efficiency in the Hospital Sector: a Review of Methodological Approaches. International Journal of

Business and Management Invention 2016; 5(3):34-54.

16. Banker RD, Charnes A, Cooper WW. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Manage Sci 1984;30(9):1078-1092.
17. Ancarani A, Di Mauro C, Giammanco MD. The impact of managerial and organizational aspects on hospital wards' efficiency: Evidence from a case study. Eur J Oper Res 2009; 194(1):280-293.
18. Coelli T. A multi-stage methodology for the solution of orientated DEA models. Oper Res Lett 1998;23(3-5):143-149.
19. Giancotti M, Mauro M. Scale Efficiency of Public Hospital: A Content Analysis of 20 Years of Research. World Review of Business Research 2015;5(2):24-38.
20. Pinheiro R, Aarrevaara T, Berg LN, Geschwind L, Torjesen DO. Strategic mergers in the public sector: Comparing universities and hospitals. Mergers and acquisitions in Practice. London: Routledge, 2017.
21. Kirigia JM, Emrouznejad A, Sambo LG. Measurement of technical efficiency of public hospitals in Kenya: using data envelopment analysis. J Med Syst. 2002; 26(1): 39-45.

*