Measuring Efficiency of Public Hospitals in Iran: A Comparative Study Using Extended Data Envelopment Analysis, 2012-2016

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Measuring efficiency of public hospitals in Iran: a comparative study using extended data envelopment analysis, 2012-2016

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Abstract:

Background: Aiming to enhance quality of care and increase efficiency, public hospitals have undergone several reforms in the course of last two decades in Iran. This paper reports the result of a national research that aimed to measure the technical efficiency and productivity change of public hospitals during 2012-2016 in Iran.

Methods: We used Extended Data Envelopment Analysis (Extended-DEA) (an innovative modification to conventional DEA) to measure technical efficiency and productivity of 568 public hospitals. Nationally representative data were extracted from the official annual health reports. Data were analysed using GAMS software 24.3.

Results: The average efficiency score of all hospitals was 0.733. 10.1% of all hospitals were efficient while 2.68% of them were under 0.2. The Malmquist Productivity Index (MPI) progressed in 49.3% of hospitals, remained constant in 2.3%, while 48.2% of hospitals regressed during 2015-2016. The average of MPI was 1.07 over the period of analysis.

Conclusions: Extra efforts seem to be essential to enhance the efficient use of resources and develop appropriate policy solutions and tools. In particular, to increase the return to scale, we advocate the merger of small-size district hospitals towards establishing bigger efficient hospitals in various geographical regions across the country.
Keywords: Data envelopment analysis (DEA), Hospital Efficiency, Productivity, Malmquist Productivity Index (MPI), Technical Efficiency, Hospital Performance.

1. Background

Efficiency is one of the main goals of the health systems worldwide [1,2]. Hospital expenditures represent around 30-50% of the total health expenditures in low-middle income countries (LMICs) [3,4], hence assessing the efficiency and productivity of hospitals is of triumph importance for any healthcare system. Further, hospital is a very complex social organization that plays a significant role in the maintenance and promotion of social health [5]. Pursuing their goals in providing healthcare services to citizens, education and research, the ultimate goal of a hospital is to meet the societal health needs effectively and efficiently [6]. Let alone, the inappropriate use of new diagnostic and treatment technologies, ageing, escalating burden of

chronic conditions, ever-increasing demand for healthcare services, plus the consequences of health professionals' errors and their negative side effects, have all imposed heavy costs on the health systems [7].

Productivity is the sum of the effectiveness (doing the right things) and the efficiency (doing the things right) of an organization. Effectiveness means achieving organizational goals, while efficiency relates to achieving the desired outputs at a lower cost [8], which indicates the ratio of outputs to inputs. The goal of efficiency is to maximize benefits against the costs incurred or to minimize costs for a given benefit. Various models and methods are used to measure the performance of organizations. These include DEA, Stochastic Frontier Analysis (SFA), and efficiency indicators [9,10], among others, all of which operate based on two criteria of input (minimizing the use of inputs) and output (maximizing the output with a fixed input) [11].

Many studies have been conducted on the efficiency measurement using the DEA approach in different context and countries, for example, studies of Ersoy et al[12], which were among the first efforts in the field of efficiency analysis using the DEA technique, Krijia et al[13], and Rhamk Rishnan[14], Ghaderi et al[15], Ardekani et al[16], and Azad et al[17], have used the frontier data analysis method to evaluate the efficiency of hospitals.

In study of Pérez-Romero[18], concluded 230 NHS hospitals, the average rate of overall technical efficiency (OTE) was 0.736 in 2012. Also, Dong et al, conducted a systematic review and result showed statistical significances were found in indicators such as number of Decision Making Units (DMUs), percentage of allocative efficiency studies, ratio of studies with multiple years, number of studies with monetary indicators in input and output sets, etc[19]. Another systematic review conducted by Pelone et al(reviewed 39 DEA applications in PC) to understand how methodological frameworks impact results and influence the information provided to decision makers. Studies were combined using qualitative narrative synthesis. This paper reports data for each efficiency analysis on the: 1) evaluation context; 2) model specifications; 3) application of methods to test the robustness of findings; 4) presentation of results[20]. A systematic review conducted with another approach to search articles applying combined DEA and SFA in order to facilitate a common comprehension about the adequacy of these methods, defining any differences in healthcare efficiency estimation and the reasons that are behind this[21].

Several studies have used DEA to assess the efficiency of hospitals, including in Iran [22].

These studies have alluded to, although partially, the inefficiency of public hospitals, between 0.584 and 0.998 in Iran [17]. For instance, a comparison between the average length of stay and average occupancy rate indices in hospitals in Iran with other LMICs reveals the inappropriate utilization of existing resources [23,24]. Nevertheless, all studies used a single method for calculating the efficiency, and as a result, failed to provide a comprehensive picture of the

hospitals' efficiency nationwide. No previous research has determined the current status of efficiency within all public hospitals in Iran [25].

In the course of last two decades, public hospitals in Iran have undergone several reforms to enhance quality of care[26] and increase efficiency, i.e. decentralization, accreditation, and since 2014, improving hospitals' productivity through health transformation plan (HTP)[27]. Our team conducted a national research to measure the efficiency of the entire health system in Iran. This paper reports the findings of a study that aimed to measure the efficiency of all public hospitals during 2012-2016 in Iran.

2. Methods

Setting

Both private and public sectors contribute to providing hospital care in Iran. All hospitals are regulated under the supervision of the ministry of health and medical education (MoHME). In 2016, there were 921 active hospitals in the country, 80% of them were governmental and 20% were nongovernmental hospitals (Appendix 1), scattered across 31 provinces in Iran. In this research, we included governmental public hospitals, affiliated to the MoHME, and divided them into two categories: general and specialized hospitals. General hospitals were divided into three sub-categories: medical-non-educational, medical-educational, and medical- educational-research centers. Specialized hospitals were divided into eight sub-categories: Orthopedic, Accidents and Burns, Pediatric, Ophthalmology, Psychiatry, Gynecology and Obstetrics, Cardiology, Cancer and Oncology (This classification has been made by the MoHME). The average bed occupancy in public hospitals was 73% in 2014 [28].

Study design

This was a quantitative and descriptive- analytical study. Our sample included all governmental public hospitals affiliated to the MoHME in Iran. We extracted data from secondary databases linked to the MoHME's health information system (HIS). We measured the efficiency score, the MPI and provided the benchmark for each of the indicators. First, we conducted a literature review and used the classic DEA method to measure efficiency. However, the initial results did not make sense for the research team. This was because the units that used only minimal inputs were efficient, while the health output had not been adjusted for both quality and equity aspects simultaneously. In other words, the reality of resource distribution, their case mix, and other contextual factors that may affect hospitals efficiency, were not taken into consideration in DEA conventional method. To overcome this challenge, we, in collaboration with a scholarly team in applied mathematics began a modification process, so-called extended-DEA to balance and rationalize the results. We will explain the three consecutive steps below:

Step 1: definition of input-output indicators

We conducted a qualitative analysis, i.e. literature review and collecting experts' opinions, to identify the input and output indicators. First, a scoping review of related studies identified a list of related indicators to the objectives of our research[29]. Second, we examined the existence of data associated with each indicator and the reliability of the data source, according to which, many indicators were excluded. Finally, the included indicators were reviewed and approved by an expert panel, comprising of the research team plus selected key informants in the field of heath management, policy and economics (Appendix 2).

Step 2: data collection and cleaning

We used a checklist for data collection that was designed based on the input and output variables and the years studied. An Excel sheet was used to enter the data, acquired from the hospitals and workforce information database of the MoHME, for all public hospitals, as "Decision Making Units (DMUs)".

We then cleaned up the data to ensure the existence and accuracy of all data for each indicator per each DMU throughout all years of the study period. Irregular data was compared with other sources to ensure data integrity. We include all Iranian public hospitals, but due to limited number of input and output indicators; we exclude the DMUs without data for one indicator in one particular year (or years). Data collection and cleaning lasted six months. Following the opinions of selected key informants, we classified hospitals based on their specialty, teaching and non-teaching, as well as their performance indicators. To compare heterogeneous hospitals included in our study, we used the "level of specialty" variable, which let us classify similar hospitals in certain designated groups in a meaningful manner and conduct a meaningful fair comparison [30] (Appendix 2).

Step 3: data analysis and modelling

Each indicator was weighed and given a value using the standards set of the MoHME as well as the enjoying the views of an external advisory board. The more important an indicator was classified, the more influence it had on the efficiency score (Appendix 2).

DEA is a mathematically-based technique to determine the relative efficiency of a congruent DMUs.

Initially, in the DMU community, a point is determined and fixed as a benchmark for the DMU under evaluation, on the basis of alleviating the policies defined by the management. Subsequently, relative efficiency of the DMU under assessment is calculated on the basis of benchmarking, which ranges between 0 and 1. The efficiency of a DMU under evaluation is signified by equating to 1, whereas, if this value is less than 1, it denotes the inefficiency of the DMU under investigation. Therefore, higher efficiency could be a sign of the DMU's better performance. In this article, we considered each hospital as a DMU, while hospitals were

categorized into various specialty groups and EDEA models were independently implemented to each categorization.

We spouse to each hospital uses 4 inputs to create 7 outputs. we use the following symbols to show the values of inputs and outputs of the hospital j (j = 1,…, n).

x_{ij}: Value of ith input of hospital j , $i = 1,..,4, j = 1,...,n.$

y_{rj}: Value of rth output of hospital j , $r = 1,...,7, j = 1,...,n.$

As described above, we determined the inputs and outputs for each hospital for modelling as follows:

Inputs	Symbols	Outputs	Symbols
n. Physician	x_{1j}	n. Inpatient	(D) y_{1j}
n. Nurse	x_{2j}	n. Outpatient	(D) y_{2j}
n. Other staff	x_{3j}	n. Surgical operation	(D) y_{3j}
n. Hospital bed	x_{4j}	Degree of accreditation	(D) y_{4j}
		Average length of stay	(U.D) y_{5j}
		Bed Occupancy	(D) y_{6j}
		Number of bed days	(D) y_{7j}

Symbols D and U.D are desirable and undesirable respectively. In other words, increase of desirable outputs is considered by management which improves productivity. However, the undesirable outputs are not considered by manager which have adverse effect on productivity. Since the fifth output (Average length of stay) is an undesirable output. We make the following changes to make it a desirable output.

$$y_{5j\ new} = 1 / y_{5j\ previous} \quad (1)$$

As we mentioned in method, given the definitions of each the input and output, the following constraints are taken for them based on the opinions of experts.

$$\begin{array}{lll} v_1 \geq 1.3v_2, & u_7 \geq u_1, & u_6 \geq u_3, \\ v_2 \geq 1.3v_3, & u_2 \geq u_1, & u_3 \geq 1.5u_4 \\ v_2 \geq 3.9v_4, & u_3 \geq u_5, & \end{array} \quad (2)$$

Relationships (2) show relative weight of indicators. For example, the importance of the seventh output is at least equal to the first output, and the importance of the first input to the second

input is at least 1.3. Since the design of this research requires a restriction, the modeling is done in envelopment form. Therefore, constraints (2) appear in trade-off in the envelopment form with symbols α and β. Also, the variables γ and μ are correspond of this trade-off in envelopment form.

On the other hand, the sixth output is expressed as a "percentage", so its value must always be between $[0,100]$. Therefore, the following constraints are considered in modelling.

$$0 \le \sum_{j=1}^{315} \lambda_j y_{6j} + \sum_{j=1}^{5} \gamma_j \beta_{6j} \le 100 \tag{3}$$

The number of bed days is also dependent on the number of bed, which is why the following model constraints are considered in modelling.

$$\sum_{j=1}^{315} \lambda_j y_{7j} + \sum_{j=1}^{5} \gamma_j \beta_{7j} \le 365 * \left(\sum_{j=1}^{315} \lambda_j x_{4j} + \sum_{j=1}^{3} \mu_j \alpha_{4j}\right) \tag{4}$$

According to the above description, the radial model in the envelopment form, taking into according to the trade-off and limitations on the template, will be as follows:

The final model to calculate the relative efficiency of hospital p has come to hand by solving the model hereunder:

$$
\begin{aligned}
&\text{Min} \quad \theta \\
&\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_{1j} + \sum_{j=1}^{3} \mu_j \alpha_{4j} \le \theta x_{ip}, && i = 1,\dots,4, && \text{(a)} \\
&\qquad \sum_{j=1}^{n} \lambda_j y_{rj} + \sum_{j=1}^{5} \gamma_j \beta_{rj} \ge y_{rp}, && r = 1,\dots,7, && \text{(b)} \\
&\qquad \sum_{j=1}^{n} \lambda_j y_{6j} + \sum_{j=1}^{5} \gamma_j \beta_{6j} \le 100, && && \text{(c)} \\
&\qquad \sum_{j=1}^{n} \lambda_j y_{6j} + \sum_{j=1}^{5} \gamma_j \beta_{6j} \ge 0, && && \text{(d)} \\
&\qquad \sum_{j=1}^{n} \lambda_j y_{7j} + \sum_{j=1}^{5} \gamma_j \beta_{7j} \le 365 * \left(\sum_{j=1}^{n} \lambda_j x_{4j} + \sum_{j=1}^{3} \mu_j \alpha_{4j}\right) && && \text{(e)} \\
&\qquad \lambda_j \ge 0, && j = 1,\dots,n, \\
&\qquad \gamma_j \ge 0, && j = 1,\dots,5, \\
&\qquad \mu_j \ge 0, && j = 1,2,3.
\end{aligned} \tag{5}
$$

The optimal value of the objective function of the model (5) can be denoted as a relative efficiency of hospital p. It is obvious that, if the optimal value of the objective function of model (5) is equivalent to 1, then hospital p (efficient). Similarly, if the optimal value of the objective function of model (5) is less than 1, then the hospital p can be called as being inefficient, so its coordinates of benchmark will be as the following:

$$\text{Benchmark} = (\sum_{j=1}^{n} \lambda^*{}_j x_{1j} + \sum_{j=1}^{n'} \mu^*{}_j \alpha_{4j}, \sum_{j=1}^{n} \lambda^*{}_j y_{rj} + \sum_{j=1}^{n''} \gamma^*{}_j \beta_{rj})$$

In order to calculate the progressive and unprogressive aspects of each of the hospitals on the basis of efficiency or performance, the Malmquist Productivity Index (MPI) has been computed. This index is derived from the comparison of efficiency changes to technological modifications [31], according to which, we divided hospitals into three groups:

- Hospitals showing progress during (if MPI>1);
- Hospitals showing regression (if MPI<1); and

Hospitals whose performance remained constant during their period of study (if MPI=1).

The notation $(x_p^2, y_p^2), (x_p^1, y_p^1)$ for allocating to $DMU_p (p = 1,...,n)$ is used in periods 1 and 2 respectively. Two factors are effective in measuring productivity:

(i) Catch-up Effect (ΔE): A degree that indicates the improvement or deterioration in efficiency and is calculated as follows:

$$\Delta E = \frac{\delta_2^2}{\delta_1^1}$$

Where δ_{t+1}^t is efficiency at time t + 1 to real time t. In other words, the Catch-up Effect is the efficiency in the second to first periods.

(ii) Frontier-shift Effect5: Calculates the boundaries of performance between the two periods and calculates the following.

$$\Delta T = \sqrt{\frac{\delta_1^2 \times \delta_2^2}{\delta_1^1 \times \delta_2^1}}$$

The Malmquist Index is the ratio of efficiency changes and efficiency boundary changes that calculated as follows.

$$(\frac{\Delta E}{\Delta T}) = [\frac{\delta_2^1 \times \delta_2^2}{\delta_1^1 \times \delta_1^2}]^{\frac{1}{2}} \quad MI = \tag{6}$$

For example, we solve the following model for δ_2^1.

$$
\begin{aligned}
\delta_2^1 = \text{Min} \quad & \theta \\
\text{s.t.} \quad & \sum_{j=1}^{n} \lambda_j x^1_{1j} + \sum_{j=1}^{3} \mu_j \alpha_{4j} \le \theta x^2_{ip}, && i = 1, \dots, 4, \\
& \sum_{j=1}^{n} \lambda_j y^1_{rj} + \sum_{j=1}^{5} \gamma_j \beta_{rj} \ge y^2_{rp}, && r = 1, \dots, 7, \\
& \sum_{j=1}^{n} \lambda_j y^1_{6j} + \sum_{j=1}^{5} \gamma_j \beta_{6j} \le 100, \\
& \sum_{j=1}^{n} \lambda_j y^1_{6j} + \sum_{j=1}^{5} \gamma_j \beta_{6j} \ge 0, \\
& \sum_{j=1}^{n} \lambda_j y^1_{7j} + \sum_{j=1}^{5} \gamma_j \beta_{7j} \le 365 * (\sum_{j=1}^{315} \lambda_j x^1_{4j} + \sum_{j=1}^{3} \mu_j \alpha_{4j}) \\
& \lambda_j \ge 0, && j = 1, \dots, 315, \\
& \gamma_j \ge 0, && j = 1, \dots, 5, \\
& \mu_j \ge 0, && j = 1, 2, 3.
\end{aligned} \tag{7}
$$

3. Results

We analyzed 568 hospitals within 2 categories and 11 subcategories. Initially, we began our study based on conventional DEA to measure the efficiency of hospitals. The primary results were difficult to interpret in the context of the Iranian healthcare system. Therefore, we started to categorized hospitals based on their specialty, the mix case, whether they are research oriented and/or train residents and fellows. To determine this criteria, we convened an expert meeting of some pioneers, including chancellors of medical universities, officials of the MOHME, some hospital managers and academics. Appendix 3 is a summary of categorized hospitals.

The descriptive statistics of inputs, outputs and explanatory variables are shown in Tables 1 and 2. We summarized the efficiency score and MPI of hospitals in Tables 3 and 4. Tables 5 and 6 show the efficiency score and MPI of the general and specialized hospitals during 2012–2016 in Iran. Finally, Table 7 presents the total inputs that need to be reduced and the outputs that need to be promoted for 2015.

Psychiatry Hospitals are kind of specialized hospitals, but we report all of the data and results of this group of hospitals separately to prevent the impact of their indicators on results. The

standards and constrains of performance indicators in these hospitals are different from other specialized hospitals; for example, we set "X<3.5" for "Average length of stay" indicator, while the Average length of stay in Psychiatry Hospitals is more than Twenty days.

Table 1. Descriptive statistics of inputs and explanatory variables

Input variables	Summary statistics	General Hospitals					Specialized Hospitals					Psychiatry Hospitals				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
n. Physician	Sum	14917	17263	19052	18990	20670	2180	2513	2772	2777	2997	335	393	440	435	466
	Max	286	332	365	362	389	129	149	164	163	175	32	37	40	40	43
	Min	2	3	2	2	2	2	2	2	2	2	4	4	5	5	5
	Mean	33.6	38.9	42.4	41.6	44.4	25.6	29.2	32.2	31.9	34.4	12.9	14.6	15.7	15.5	16.6
	SD	32.3	37.4	41.1	40.4	43.3	22.1	25.5	28.1	27.9	29.8	8.2	9.6	10.3	10.3	10.9
	Median	24	27	29	29	31	18	20.5	23	22	24	10	11	11.5	11.5	12.5
n. Nurse	Sum	68327	74579	74743	74203	91307	10611	11579	11561	11793	14495	2239	2499	2553	2527	3055
	Max	1114	1215	1212	1200	1464	712	777	775	767	936	202	221	220	218	266
	Min	15	17	23	21	25	14	15	15	15	18	18	19	19	19	23
	Mean	153.9	168.0	166.5	162.0	195.5	124.8	134.6	134.4	137.1	166.6	86.1	92.6	91.2	90.3	109.1
	SD	142.0	154.3	153.5	150.6	183.3	100.4	109.2	108.9	114.9	139.5	52.5	56.6	55.8	55.3	66.3
	Median	113	124	123	120.5	147	105	112.5	112.5	111.5	130	68	70	68	67.5	82
n. Other staff	Sum	77982	78055	83868	82291	90456	14325	14410	15375	15110	16685	3124	3175	3509	3438	3707
	Max	1945	1947	2085	2043	2227	886	886	949	930	1014	584	585	626	614	627
	Min	13	18	19	21	26	18	18	20	19	21	17	17	18	17	19
	Mean	174.8	175.0	186.4	179.7	194.1	168.5	167.6	178.8	175.7	191.8	120.2	117.6	125.3	122.8	132.4
	SD	178.2	178.4	190.5	185.2	200.1	138.5	138.5	147.5	145.0	160.9	115.5	114.3	120.1	117.8	122.0
	Median	129.5	129.5	138	133	144	139	139	149	146	159	89.5	87	96	94	102.5
n. Hospital bed	Sum	61078	61517	62418	63787	67145	12825	12917	12218	12585	12858	7374	7432	6362	6208	6209
	Max	973	973	909	871	860	2159	2159	1165	1177	1177	2159	2159	1165	1177	1177
	Min	23	23	27	27	27	16	18	18	18	18	47	47	19	32	32
	Mean	137.6	138.6	138.7	139.0	143.8	150.9	150.2	142.1	146.3	147.8	283.6	275.3	227.2	221.7	221.8
	SD	127.9	128.8	128.5	128.7	132.8	243.2	241.6	151.7	153.2	153.7	425.6	419.2	259.1	239.9	240.6
	Median	108.5	109	106	107	110	104	105.5	107.5	112	114	177.5	175	170	176	176

Table 2. Descriptive statistics of outputs and explanatory variables.

Output variables	Summary statistics	General Hospitals (N= 467)					Specialized Hospitals (N=73)					Psychiatry Hospitals (N=28)				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
n. Inpatient	Sum	5287795	5523056	5762557	6230901	6483827	841920	880945	905318	959929	982771	80644	101308	81890	92606	94523
	Max	90157	90157	86479	93868	95706	48618	50932	54988	55379	57858	16218	16218	15105	14870	13191
	Min	22	22	31	146	93	256	325	305	249	332	256	325	156	249	332
	Mean	11909.4	12439.3	12834.2	13634.4	13884.0	9904.9	10243.5	10527.0	11162.0	11296.2	3101.7	3752.1	2924.6	3307.4	3375.8
	SD	11425.5	11340.1	11992.9	12295.6	12876.1	9377.4	9245.3	10394.7	10177.8	10519.7	3236.8	3596.9	3028.2	3138.5	3055.4
	Median	10,003	10,608	10,651	11,863	11,840	8,020	8,049	7,769	8,678	7,920	1,883	2,406	1,780	2,654	2,599
n. Outpatient	Sum	263479021	326320477	344805782	592477961	659592515	40019821	50725069	53499735	70178688	71158752	7547671.5	9635074.3	11997864	15266615	39101261
	Max	6217523	6771325	7443500	13571550	13542100	2633856	3292320	3465600	4891850	4884500	2653097.3	3316371.6	3490917.5	5090860	19635125
	Min	1462	1828	1924	2028	2258	2953	3691	3885	3726	3104	47	47	46	47	48
	Mean	593421	734956	766235	1296451	1415435	470821	589826	622090	816031	817917	290295	356855	428495	545236	1396474
	SD	862507.8	1061558.8	1119376.9	1652515.1	1712257.8	568590.3	714386.9	753874.1	1041391.2	1032358.6	558246.9	685137.9	760983.2	1032480.7	3889545.4
	Median	271320	337402	347855	794440	917730	298802	340148	358050	425880	442220	71,091	88,265	113,180	148,650	228,700
n. Surgical operation	Sum	2376015	2407909	2652601	2838129	2990767	361483	377386	433591	443593	467554	21662	26172	30434	30457	30931
	Max	40674	36093	38878	42006	44318	55438	66930	74015	83072	88607	6125	6846	6912	6874	6752
	Min	6091	6457	7602	7873	8806	149	165	231	242	228	0	0	0	0	0
	Mean	5099	5167	5620	5925	6116	4253	4388	5042	5158	5374	833	969	1087	1088	1105
	SD	5330	5296	5676	5936	6160	6781	7898	8885	9788	10389	1610	1887	1911	1878	1916
	Median	3,609	3,524	3,951	4,117	4,241	2,912	2,585	2,734	2,760	2,894	1,600	2,115	2,638	2,468	2,742
Average length of stay	Max	7.6	7.4	7.4	6.4	10.2	104.2	102.1	101.1	118.6	83.9	339.7	333.0	329.7	389.4	117.2
	Min	1.0302	1.01	1	1	1	0.9859014	1	0.957	1	1	2.4508458	2.40279	2.379	2.279	2.388
	Mean	2.6	2.5	2.5	2.5	2.6	8.2	8.1	8.0	7.8	6.8	39.8	38.1	36.7	37.0	23.9
	SD	0.9	0.9	0.9	0.9	1.0	17.2	16.8	16.6	17.7	12.1	66.2	63.9	62.3	73.9	24.8
	Median	2.4	2.3	2.3	2.4	2.4	2.9	2.9	2.8	2.8	2.9	18.8	18.2	17.9	16.2	16.7
Bed occupation (%)	Max	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Min	4.7	4.3	5	9.3	9.8	10.04404	10.24902	10.566	13.998	12.484	31.143557	31.77914	32.762	54.974	62.846
	Mean	59.4	60.6	62.0	68.3	67.5	68.6	69.8	72.0	73.2	73.5	75.1	75.8	77.0	80.7	84.6
	SD	19.8	20.2	21.1	20.9	21.5	19.1	19.5	20.0	20.0	18.5	13.4	14.0	15.5	10.8	9.8
	Median	63.48	64.77	66.63	72.70	72.16	72.21	73.68	75.96	78.10	78.97	77.21	78.52	80.36	81.88	86.74
Number of bed days	Sum	14795982	15574706	16075248	17692832	19072542	3059691.8	3236509.8	3336591	3510362	3362968.1	1687675.6	1792351.5	1849818	1833137	1671906
	Max	226937	238881	246269	263241	342302	303974	319973	329869	325735	220594	303974	319973	329869	325735	220594
	Min	29	30	31	129	16	1066	1122	1157	1411	1367	5510	5800	2033	6242	8990
	Mean	33324	35078	35723	38800	40928	35996	37634	38798	40818	39104	64911	66383	66065	65469	59711
	SD	35919	37809	38904	41257	45171	43402	45480	46887	46897	38132	71400	74387	76293	69647	49952
	Median	23834	25088	25609	28579	29422	26600	27823	28684	29100	29527	47645	47244	47597	53144	55920
Degree of accreditation *	Max	4	4	4	4	4	4	4	4	4	3	4	4	4	4	3
	Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mean	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	SD	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.6	0.5	0.4	0.6	0.6	0.7	0.7	0.5
	Median	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

*Degree of accreditation: 4= Excellent/ 3= Degree of 1/ 2= Degree of 2/ 1= Degree of 3/ 0= Degree of 4

- **Efficiency of hospitals and their MPI**

Tables 3 and 4 present overall results of the efficiency scores and MPI. The average efficiency score of all hospitals was 0.733. 10.11% of all hospitals had a score of 1 and 2.68% of them had efficiency scores below 0.2. MPI had also progressed in 49.3% of hospitals, 2.3% of them did not change and 48.2% of them had regressed in 2015-2016. The mean of MPI was 1.07 over the analysis years.

Table 3. Overall efficiency results 2012-16.

Summary statistics		2012	2013	2014	2015	2016	Mean
N		542	543	549	557	568	551
Mean		0.732	0.731	0.718	0.735	0.748	0.733
Max		1	1	1	1	1	1
Min		0.158	0.158	0.159	0.158	0.159	0.159
SD		0.166	0.166	0.163	0.172	0.159	0.150
Median		0.709	0.691	0.684	0.729	0.729	0.712
Efficient (N)		56	56	54	57	56	56
Efficient (%)		10.3	10.3	9.8	10.2	9.9	10.1
Inefficient(N)		486	487	495	500	512	496
Inefficient (%)		89.7	89.7	90.2	89.8	90.1	89.9
Range of efficiency score (%)	E<0.1	0	0	0	0	0	0
	0.1≤E<0.2	3.14	2.76	3.10	1.44	2.99	2.68
	0.2≤E<0.3	18.45	22.47	15.85	14.00	20.42	18.24
	0.3≤E<0.4	23.99	20.44	24.04	23.70	20.42	22.52
	0.4≤E<0.5	23.06	23.39	21.86	24.06	23.42	23.16
	0.5≤E<0.6	6.64	5.89	9.65	10.59	7.22	8.00
	0.6≤E<0.7	11.62	11.79	12.20	12.03	11.80	11.89
	0.7≤E<0.8	2.03	2.21	2.55	3.23	3.35	2.67
	0.8≤E<0.9	0.74	0.74	0.91	0.72	0.53	0.73
	0.9≤E<0.99	0	0	0	0	0	0.00
	E=1	10.33	10.31	9.84	10.23	9.86	10.11

Table 4. Overall MPI results, 2012-16.

Summary statistics		2012-2013	2013-2014	2014-2015	2015-2016
Mean		1.041	1.009	1.189	1.043
Max		1.269	1.82	8.541	6
Min		0.619	0.593	0.266	0.256
SD		0.053	0.057	0.335	0.290
Median		1.049	1.017	1.086	0.992
Range of MPI	MPI>1 (N)	491	374	450	275
	MPI>1 (%)	90.59	68.75	82.12	49.37
	MPI=1 (N)	9	11	6	13
	MPI=1 (%)	1.66	2.02	1.09	2.33
	MPI<1 (N)	42	159	92	269
	MPI<1 (%)	7.75	29.23	16.79	48.29

The average efficiency in specialized hospitals i.e. Cancer and Oncology, Orthopedic and Ophthalmology was higher than other hospitals. Medical and non-educational hospitals had the lowest efficiency scores (Figure 1). We indicate extended data envelopment analysis models are independently implemented to each categorization. Hence,

the hospitals in the different categorizations face the different technologies, and the efficiencies of the hospitals cannot be compared among categorizations. The purpose of this figure is to show the average efficiency at a glance.

Figure 1. Average efficiency score by hospital type, 2012-16.

Table 5 shows that, on average, 7 out of 315 general hospitals had the efficiency scores of above 0.8, with the mean efficiency score of 0.357 over the analysis years. The lowest efficiency score was in 2016 (M=0.157, SD=0.15). The variation range (R) of the scores in this group was high (R=0.841). The MPI improved in most general hospitals (Mean=220); the highest and the lowest improvement was during 2014-2015 (MPI = 8.54) and 2015-2016 (MPI = 0.256), respectively.

The mean efficiency score in teaching hospitals was less than 0.5 (M= 0.488), the lowest score observed in 2014 (Min = 0.333). The range of efficiency scores in these hospitals was 0.645. In the study years, on average, 7 teaching hospitals had a score of above 0.8. The MPI mean score in teaching hospitals indicates a slight improvement in hospital efficiency score (MPI=1.02). On average, 94 of 130 teaching hospitals had an MPI of more than 1. The lowest (0.561) and the highest (1.710) progress in this index was during 2014-2015 and 2015-2016, respectively.

The average efficiency scores in teaching and research hospitals was 0.760 over the study years, while the lowest score observed in 2013 -2014 (Min=0.576). On average, 8 out of 22 hospitals had a score of above 0.8 in this group. The range of efficiency scores was 0.405 in these hospitals. The highest MPI score was in 2014-2015 (R=4.460). On average, the lowest improvement was 0.768 in this index. In addition, 16 out of 22 hospitals had efficiency improvement over the analysis years.

The average efficiency score of orthopedic hospitals was 0.899 over the analysis years. The lowest efficiency score in these hospitals was in 2015 (Min=0.588); with the lowest average in 2015 (0.814) and the highest average in 2014 (0.923). Three hospitals were mostly efficient (E> 0.8) in this group. The MPI in orthopedic hospitals showed progress in 2012 and 2013. Efficiency scores were progressed in 50% of hospitals during 2013-2016 (N=397). The highest progress rate (1.96) was observed in 2015-2016.

Among nine accidents & burn specialist hospitals, three hospitals had a score of above 0.8. The range of scores was 0.425 in this group, which was lower than that of general hospitals. Minimum score and standard deviation were 0.574 and 0.16, respectively, in this group.

The average efficiency score in 13 specialized pediatric hospitals was 0.796 (SD=0.15, R=0.353), five of which operated efficiently (E> 0.8) with the average efficiency score of 0.646. On average, the MPI showed progress in nine pediatric hospitals during the analysis years, with the highest improvement in 2014-2015 (MPI=2.429). The average efficiency improvement in these hospitals was 1.08, while the average efficiency score was 0.863 (R=0.21, SD=0.18).

The efficiency scores showed progress in most Ophthalmology hospitals, with the maximum improvement in 2015-2016 (MPI = 2.832). The average MPI was 1.2 in this group.

The average efficiency score was 0.733 (R=0.395) in psychiatric hospitals, with the minimum efficiency score of 0.604 (SD= 0.11). Seven out of the total of 28 psychiatric hospitals had a score of above 0.8. On average, the efficiency score in 21 psychiatric specialized hospitals showed progress (MPI> 1). The highest progress was in 2015-2016 (MPI=3.98), while 2014-2015 showed the biggest efficiency regression (MPI=0.84) in this group.

The average efficiency score in gynecology and obstetrics specialized hospitals was 0.740 (R=0.192). Out of 25 hospitals in this group, nine showed the efficiency scores higher than 0.8, while the minimum efficiency score was 0.579 (SD=0.14, R= 0.42) during the study years. On average, four out of 25 hospitals showed progress in their scores (MPI> 1). The maximum MPI progress was 1.439 during 2014-2015.

The average efficiency score in nine specialized Cardiology hospitals was 0.769 (SD=0.16). On average, three hospitals were efficient (E> 0.8) and the range of efficiency scores was 0.376. The MPI progressed in all Cardiology hospitals 2012-2013, and regressed 2013-2016. The highest MPI score was observed 2015-2016 (MPI=1.12) in this group.

The average efficiency score was 0.866 (R=0.337) in cancer and oncology hospitals, with the minimum efficiency score of 0.663 (SD= 0.12). Moreover, the MPI progressed in cancer and oncology hospitals 2012-2014 (MPI=1.05) and regressed during 2014-2016 (MPI=0.97).

Table 5. Efficiency score and MPI of general hospitals, and their frequency distribution, 2012–2016.

Specialty of hospitals	Summary statistics	Efficiency score						MPI			
		2012	**2013**	**2014**	**2015**	**2016**	**Mean**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**
Medical and Non- educational	Max	1	1	1	1	1	1	1.269	1.82	8.541	6
	Min	0.158	0.158	0.159	0.158	0.159	0.159	0.619	0.593	0.266	0.256
	Mean	0.356	0.354	0.368	0.386	0.349	0.357	1.047	1.005	1.265	1.063
	SD	0.161	0.177	0.168	0.158	0.147	0.138	0.058	0.091	0.524	0.435
	Median	0.318	0.305	0.328	0.350	0.318	0.331	1.029	1.026	1.171	1.004
	CV	0.454	0.501	0.455	0.410	0.423	0.385	0.056	0.091	0.414	0.409
	No. of E>0.8/ MPI>1	12	16	13	11	9	7	268	196	258	157
Medical and educational	Max	1	1	1	1	1	1	1.108	1.277	1.471	1.711
	Min	0.342	0.354	0.334	0.359	0.357	0.355	0.702	0.630	0.561	0.683
	Mean	0.477	0.469	0.489	0.499	0.506	0.488	1.020	1.010	1.069	1.002
	SD	0.133	0.105	0.132	0.130	0.139	0.101	0.034	0.058	0.119	0.121
	Median	0.438	0.444	0.448	0.465	0.461	0.452	1.020	1.031	1.058	1
	CV	0.278	0.224	0.271	0.261	0.274	0.208	0.033	0.058	0.111	0.120
	No. of E>0.8/ MPI>1	7	4	7	7	8	4	112	100	104	62
Medical, educational and research	Max	1	1	1	1	1	1	1.177	1.130	4.460	1.274
	Min	0.593	0.577	0.577	0.621	0.604	0.594	0.997	0.924	0.768	0.873
	Mean	0.777	0.753	0.745	0.765	0.761	0.760	1.055	1.016	1.272	1.014
	SD	0.159	0.141	0.158	0.152	0.144	0.151	0.048	0.046	0.749	0.101
	Median	0.697	0.662	0.675	0.695	0.683	0.720	1.048	1.024	1.069	0.993
	CV	0.205	0.187	0.212	0.198	0.190	0.198	0.045	0.046	0.589	0.100
	No. of E>0.8/ MPI>1	7	5	7	7	5	8	21	14	19	9

Table 6. Efficiency score and MPI of specialized hospitals, and their frequency distribution, 2012–2016.

Specialty of hospitals	**Summary statistics**	**Efficiency score**						**MPI**			
		2012	**2013**	**2014**	**2015**	**2016**	**Mean**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**
Orthopedic	Max	1	1	1	1	1	1	1.144	1.039	1.166	1.965
	Min	0.685	0.686	0.691	0.588	0.669	0.680	1.011	0.849	0.452	0.886
	Mean	0.921	0.921	0.923	0.814	0.917	0.899	1.080	0.972	0.908	1.216
	SD	0.158	0.157	0.154	0.217	0.165	0.151	0.061	0.088	0.316	0.507
	Median	1	1	1	0.833	1	0.958	1.082	0.999	1.006	1.0055
	CV	0.171	0.170	0.167	0.267	0.180	0.168	0.056	0.090	0.348	0.417
	No. of E>0.8/ MPI>1	3	3	3	2	3	3	4	2	2	2
Accidents and Burns	Max	1	1	1	1	1	1	1.11	1.062	1.367	1.097
	Min	0.569	0.569	0.556	0.565	0.607	0.575	0.985	0.955	0.702	0.838
	Mean	0.774	0.771	0.727	0.826	0.835	0.787	1.039	1.006	1.091	0.964
	SD	0.191	0.192	0.175	0.200	0.190	0.165	0.044	0.037	0.271	0.083
	Median	0.680	0.669	0.648	0.907	0.832	0.799	1.039	1.011	1.166	0.949
	CV	0.246	0.249	0.241	0.242	0.227	0.210	0.042	0.037	0.248	0.086

	No. of E>0.8/ MPI>1	3	3	2	5	5	3	6	4	5	3
Pediatric	Max	1	1	1	1	1	1	1.148	1.038	2.429	1.527
	Min	0.593	0.593	0.577	0.633	0.678	0.646	0.946	0.953	0.955	0.796
	Mean	0.794	0.795	0.766	0.780	0.846	0.796	1.043	1.010	1.253	1.018
	SD	0.172	0.171	0.168	0.158	0.152	0.156	0.056	0.029	0.373	0.183
	Median	0.688	0.689	0.673	0.714	0.800	0.694	1.034	1.018	1.168	0.971
	CV	0.216	0.215	0.219	0.203	0.179	0.196	0.054	0.028	0.298	0.180
	No. of E>0.8 /MPI>1	5	5	4	4	7	5	11	9	11	5
Ophthalmology	Max	1	1	1	1	1	1	1.203	1.043	2.49	2.832
	Min	0.611	0.612	0.611	0.609	0.628	0.619	0.993	0.991	0.891	0.642
	Mean	0.873	0.873	0.873	0.877	0.824	0.864	1.104	1.015	1.454	1.236
	SD	0.197	0.196	0.197	0.191	0.193	0.187	0.097	0.024	0.614	0.800
	Median	1	1	1	1	0.832	0.966	1.119	1.012	1.211	1.041
	CV	0.226	0.225	0.226	0.218	0.234	0.216	0.088	0.023	0.422	0.647
	No. of E>0.8/ MPI>1	4	4	4	4	3	4	5	3	5	4
Psychiatry	Max	1	1	1	1	1	1	1.204	1.272	2.522	3.98
	Min	0.577	0.577	0.577	0.609	0.644	0.605	1.020	0.965	0.840	0.842
	Mean	0.727	0.725	0.720	0.741	0.739	0.734	1.053	1.035	1.079	1.143
	SD	0.132	0.127	0.129	0.131	0.114	0.115	0.039	0.054	0.295	0.566
	Median	0.683	0.687	0.675	0.699	0.696	0.700	1.05	1.031	1.033	1.031
	CV	0.181	0.175	0.179	0.177	0.154	0.157	0.037	0.052	0.273	0.495
	No. of E>0.8 /MPI>1	6	5	6	6	4	7	26	22	19	18
Gynecology & obstetrics hospital	Max	1	1	1	1	1	1	1.132	1.165	1.439	1.316
	Min	0.578	0.572	0.574	0.577	0.579	0.580	0.905	0.915	0.685	0.357
	Mean	0.700	0.741	0.744	0.766	0.751	0.740	1.022	1.015	1.058	0.931
	SD	0.145	0.173	0.172	0.170	0.162	0.143	0.038	0.052	0.158	0.185
	Median	0.636	0.642	0.645	0.690	0.686	0.684	1.02	1.019	1.025	0.953
	CV	0.207	0.233	0.231	0.222	0.216	0.193	0.038	0.051	0.149	0.199
	No. of E>0.8/ MPI>1	5	7	8	8	7	9	23	15	17	9
Cardiology	Max	1	1	1	1	1	1	1.126	1.029	1.077	1.12
	Min	0.619	0.620	0.621	0.608	0.648	0.623	1.011	0.764	0.876	0.859
	Mean	0.777	0.776	0.747	0.751	0.794	0.769	1.053	0.969	0.988	0.976
	SD	0.173	0.173	0.160	0.158	0.157	0.161	0.031	0.082	0.066	0.080
	Median	0.660	0.660	0.651	0.668	0.712	0.672	1.049	0.988	1.003	0.977
	CV	0.222	0.223	0.215	0.210	0.198	0.209	0.029	0.085	0.067	0.081

	No. of E>0.8/ MPI>1	3	3	3	3	3	3	9	4	5	3
Cancer and Oncology	Max	1	1	1	1	1	1	1.181	1.147	1.143	1.143
	Min	0.664	0.668	0.648	0.636	0.636	0.663	0.926	0.950	0.530	0.794
	Mean	0.877	0.862	0.799	0.886	0.904	0.866	1.053	1.045	0.964	0.975
	SD	0.160	0.141	0.146	0.151	0.141	0.124	0.076	0.068	0.200	0.134
	Median	1	0.839	0.781	1	1	0.858	1.049	1.029	1.031	0.984
	CV	0.183	0.164	0.183	0.170	0.156	0.144	0.072	0.065	0.207	0.138
	No. of E>0.8/ MPI>1	5	5	2	4	5	4	6	5	5	3

- **Benchmarking**

There are two general ways to improve hospitals' productivity: reducing input and/or increasing output. Table 7 presents the total inputs that need to be reduced and the outputs that need to be increased to improve hospitals' efficiency in 2015.

Table 7. Total input reductions and output improvement needed to improve hospitals' efficiency.

	General hospitals			Specialized hospitals			Psychiatry		
Input/output variables	**Actual values**	**Target values**	**Difference**	**Actual values**	**Target values**	**Difference**	**Actual values**	**Target values**	**Difference**
N. Physician	20670	19552	-1118	2997	2618	-379	466	373	-93
N. Nurse	91,307	81,262	-10045	14495	12090	-2405	3055	2392	-663
N. Other staff	90456	82669.816	-7786	16685	13424	-3261	3707	2816	-891
N. Hospital bed	67145	66959	-186	12858	9098	-3760	6209	5935	-274
N. Inpatient	6483827	18782446	12298619	982771	1233193	250422	94523	143216	48693
N. Outpatient	659592515	1472166350	812573835	71158752	72284878	1126126	39101261	46673032	7571771.5
N. Surgical operation	2990767	7493631	4502864	467554	545734	78180	30931	44905	13974
Average length of stay	3	3	0	6.8	3	-3.8	24	37	13
Bed occupation (%)	68	85	17	73.5	855.2	781.7	84.6	98.7	14.1
Number of bed days	12,253,963	20,831,736.25	8,577,774	39104	378023	338919	59711	65562	5851
Degree of accreditation	3	4	1	3	4	1	3	4	1

4. Discussion

The objective of this study was to analyze the efficiency of government public hospitals, categorized by their specialty, over the period of 2012 to 2016 in Iran. Our findings revealed the overall low scores in the public hospitals' efficiency. All in all, public hospitals in Iran are not adequately efficient. For example, the average efficiency score in teaching hospitals and public hospitals is 0.488 and 0.357, respectively, which is in line with the results of some other studies [22,32]. Only 7 hospitals had a score of above 0.8 per year. The MoHME's policy and social considerations to ensure the equitable geographical accessibility of hospitals nationwide, irrespective of their economic of scale, might be one of the reasons for low efficiency [22]. In a large country size as Iran, the challenge of improving hospitals' efficiency while ensuring geographical accessibility can be overcome through provision of high-quality clinical services, encouraging patients in need of elective services to use local services, rather than seeking care in provincial centers, and adjusting the bed number with the proportion of physicians and nurses accordingly, in line with the population size and the services they need.

It should be noted that a number of hospitals in this study were in the early years of their establishment. Newly established hospitals operate inefficiently in the early years due to shortcomings that they may experience at the outset of their activities. The MPI indicates progress in the average efficiency score of these hospitals over the period of analysis.

The average efficiency score of teaching hospitals varied between 0.354 and 1. On average, only four out of the 130 teaching hospitals had scores above 0.8. The overall low efficiency of these hospitals might be due to more input required for simultaneous provision of services and training. The efficiency scores in teaching and research hospitals were meaningfully higher than the other two groups of general and teaching hospitals. This could be due to the small difference between hospital inputs and outputs in this group and, conversely, a big difference between input and output variables in the other two hospital groups. Moreover, there are only a limited number of teaching and research hospitals across the country, with more or less bed numbers similar to other hospitals (less than 20 hospitals) that provide specialized, complex and unique services to a large number of patients.

The efficiency score of accident and burn hospitals in provincial centers and other regions was 1 and below 0.7, respectively. Most trauma and burn hospitals witnessed progress in their efficiency scores over the five years (MPI> 1). The highest and the lowest improvement were observed in 2012-2013 (MPI = 1.038) and 2015-2016 (MPI = 0.964), respectively.

The efficiency score in pediatric hospitals, especially in the referral hospitals was high. Adjusting the beds number and performance level of these hospitals in less populated areas may contribute to improving their efficiency. Similar to other specialized hospitals, the efficiency score of psychiatric hospitals was high, while their range of variations was low.

The variations' range (R) in specialized gynecology and obstetrics hospitals was higher than other specialized hospitals (R=0.420), their efficiency score was low. This could be due to the low bed occupancy rate of these hospitals (Mean <75%), which might in turn be the result of the presence of similar wards in many public hospitals. Logical reduction of these wards in general hospitals may enhance the efficiency of these specialized hospitals.

Similar to other specialized hospitals, Cardiology specialized hospitals in the capital city of Tehran had the efficiency score of 1, whereas the score in similar hospitals located in other cities was below 0.7. Again, this calls for the review of the existence or absence of super-specialized hospitals across various geographical regions, aiming to adjust their infrastructures with the existing demand and other social factors.

While the average efficiency score in cancer and oncology specialized hospitals was 0.865 (SD=0.12), it ranged between 0.662 and 1 (R=0.337) over the analysis years. On average, four out of seven hospitals in this group had scores of above 0.8.

In Iran Educational hospitals are less efficient than None-educational hospitals and that specialized hospitals are also the most efficient. The fact that they are targeting different patients and may have different technologies does not change the conclusion because the efficiency is just measuring how input mobilization translates in out puts. So the study demonstrates that productivity of workforce and beds are higher in the specialized hospitals than in other categories. Also, the issue of limited efficient of Educational hospitals can be related to the measurement of staff as part of their time can be dedicated to education, then this could be also better captured in the information system in place with an approach based on the Full Time Equivalent (FTE) measure of staff rather than head count i.e. a doctor dedicated 50% of time for education is considered as 0.5 FTE for clinical activities, etc…

Based on findings, over time the efficiency remains within a category and this is an expected result because changes would take longer period than 4 years to be visible. From previous DEA work efficiency is compared over a period of over 10 years. This is confirming that health policies cannot have short term impact on hospital efficiency.

A recent study calculated and analysed the efficiency of all public hospitals in Spain in 2017 [18] and reported the average efficiency score 0.736, very similar to our revealed score of 0.732. The study compared similar hospitals with each other. In our study, we used more output variables to enhance the reliability of analysis. A systematic review showed that 90% of studies used the DEA method to measure the efficiency of hospitals in Iran, and the calculated score ranged from 0.7 to 0.9 [33].
A similar study in China also used DEA method [34]. They used the number of beds as the input variable and the hospitalization days, the number of visits, and the number of surgical operations as the most used output variables for measuring the efficiency. A Chinese study measured the efficiency of government hospitals to examine the impact of the country-wide development plan of 2009 on the efficiency of a sample of 114 hospitals. They used similar input and output variables to our study and calculated the average efficiency score of 0.748, while significant potential for improving the technical efficiency of the hospitals was reported [35].

Another study used similar input and output indicators to examine the efficiency of health services centers in Indonesia. They used Pabón-Lasso model. Forty percent of hospitals and 33 percent of health centers were located in the high performing sector of the Pabón-Lasso model.
[36]. Another study used 10 variables to measure the efficiency of Turkish hospitals in 2015 and found that only 17% of the total 1103 hospitals were efficient [37]. A similar study in Turkey that examined the efficiency of 1079 hospitals reported that the government hospitals affiliated with the Turkish Ministry of Health were more efficient than the private hospitals [38]. A study conducted in Greece to assess the impact of sanctions on the efficiency of hospitals between 2009 and 2012 found that the rate of efficiency declined over the mentioned years (MPI=0.72)[39]. The MPI in our study was 1.07.
In the end, it should be noted that the efficiency score over the years under review was not significantly altered, and most of the changes were related to Orthopaedics and Accidents and Burns hospitals.

Rigor of study

This study began to use the Extended-DEA method as the most utilized technique to measure hospitals' efficiency worldwide. Our findings were hard to interpret, so we engaged with a scholarly team in applied mathematics to revise the method and invented Extended-DEA as a result, which is the main strength of our study. In addition, we included all public hospitals in the country and categorized them into various specialties. Comparing similar DMUs is one of the basic assumptions to

measure efficiency [40], so we classified hospitals in similar groups. We also brought some qualitative variable as output indicators (Accreditation Degree of hospitals) in our calculation, which is usually neglected in efficiency measurement studies. Last but not least, although most similar studies measured efficiency in a cross-sectional study design, we measured the trend of efficiency in all categories of public hospitals over a period of five years (2012-2016).

Limitations

Despite advantages, our study had some limitations. Due to shortages in an established monitoring system to collect the related data on hospital efficiency, reliable and valid hospital data with enough input and output variables is not available in Iran. Further, despite our efforts to obtain data form the MoHME, which is the most reliable and available sources in Iran, there still remains some limits in data credibility that might affect the reliability of our data source. Nevertheless, there is no other source of data available to conduct analysis as in this study.

Our study could have benefited from some technical considerations to enhance accuracy of the findings. We advocate more robust approach in designing studies on the efficiency of hospitals. In particular, use of the international standards in selection of input and output indicators and paying enough attention to homogenization of the unit of indicators (monetary, volumetric, relative, etc.,) are important. Moreover, it is crucial to bring the number of DMUs three times higher than the input and output indicators, as well as combine the current two-stage and three-stage DEA models with the Bootstrap-DEA method to calculate more accuracy efficiency [41].

Policy implications

- Identifying the current status of hospital efficacy is the first step to improve productivity. Executive managers and policy makers can use our findings as reliable evidence for better and more efficient use of resources with the aim of improving productivity.
- Given the country-wide need to employ more healthcare workers in hospitals, decision makers can build on our results that show the possible output expansions and/or the possible input contractions and prioritize efforts for improvements. For instance, hospitals with a surplus capacity of input variables (including health workers and bed), may decide to reduce their additional inputs during a comprehensive planning process.
- To address the lower efficiency of specialized hospitals in some provinces, we recommend redistribution of the specialized beds and other resources in some target regions.

- The integration of small hospitals in some areas can help improve productivity, taking into account the criteria for access to services.
- The hospital efficiency measurement is only valid for homogenous category of hospitals. This is well demonstrated in our fig 1 and is the most important message from future studies.

6. Conclusions

We measured the efficiency scores and MPI for 568 public hospitals during 2012-2016, using an Extended-DEA for the first time in Iran. Given the overall low efficiency scores of hospitals, especially general hospitals that are not adequately efficient or are merely inefficient, within various specialties across the country, robust and evidence-based measures are required for more efficient use of resources. As Iran has been implementing its ambitious health transformation plan (HTP) to reach universal health coverage by 2025, and considering the historical shortages in hospital particularly in deprived areas as well as the financial limitations to build new hospitals, integrating local general clinics and other hospitals in small communities could be a reasonable policy to enhance the efficiency of the existing resources. Unless hospital managers in Iran improve their ability for need-based allocation of human resources among various settings, enhance the quality of hospital services to increase their revenue and stabilize their financial status, e.g. through the use of prospective payment systems, and manage to optimize utilization of the physical resources, hospital care cannot cope with the ever-increasing demand and the health system may suffer from the upcoming challenges even further.

7. Declarations

Ethics approval and consent to participate: This study was approved by the ethical committee of Tehran University of Medical sciences, under the license no: IR.TUMS.VCR.REC.1396.4018.

Consent for publication: Not applicable.

Availability of data and materials: The data of this study are available in "Supplementary Material"

Competing interests: None of the authors have any competing interests.

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Authors' contributions: AT, AO and RM conceived the study and designed its method. EM performed the computations and applied the model, with help from FHL for revision of the analytical method. All authors discussed the results and contributed to the final manuscript. EM HSH and HY carried out the analytical experiment. EM and AHT wrote the manuscript all authors contributed to the development and approved the final manuscript. AT is the guarantor.

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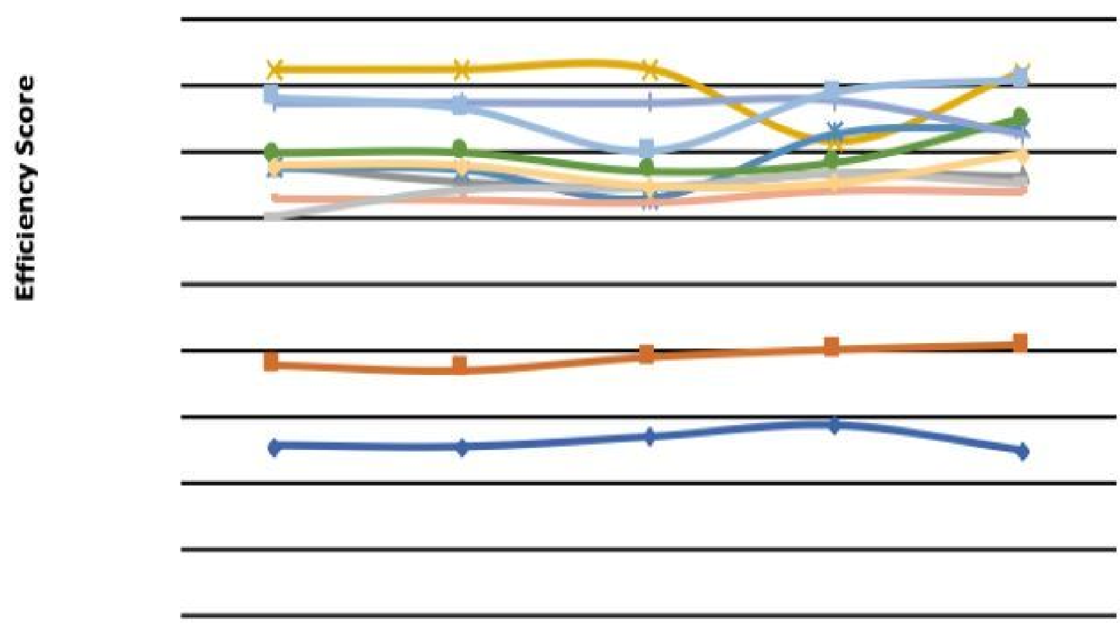
Figures



	2012	2013	2014	2015	2016
Medical and Non educational	0.356	0.354	0.368	0.386	0.349
Medical and Educational	0.477	0.469	0.489	0.499	0.506
Medical, Educational and Research	0.777	0.753	0.745	0.765	0.761
Orthopedic	0.921	0.921	0.923	0.814	0.917
Accidents and Burns	0.774	0.771	0.727	0.826	0.835
pediatric	0.794	0.795	0.766	0.780	0.846
Ophthalmology	0.873	0.873	0.873	0.877	0.824
Psychiatry	0.727	0.725	0.720	0.741	0.739
women hospital	0.700	0.741	0.744	0.766	0.751
Cardiology	0.777	0.776	0.747	0.751	0.794
Cancer and Oncology	0.877	0.862	0.799	0.886	0.904

Figure 1

Average efficiency score by hospital type, 2012-16.

Supplementary Files

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