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

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Abstract

Background: In pursuing improving healthcare quality and enhancing efficiency, public hospitals in Iran have undergone numerous reforms over the past two decades. This study aimed to assess the efficiency of all public hospitals in Iran from 2012 to 2016.

Methods: This study was conducted as a quantitative and descriptive-analytical research project. The authors employed an innovative approach called Extended Data Envelopment Analysis (Extended-DEA), a modification of conventional DEA, to assess the technical efficiency and productivity of 568 public hospitals. They obtained nationally representative data from official annual health reports. The data were analyzed using GAMS software version 24.3.

Results: The study found that the average efficiency score for all hospitals was 0.733. Among all the hospitals, 10.1% were deemed efficient, while 2.68% had low-efficiency scores below 0.2. The Malmquist Productivity Index (MPI) showed improvement in 49.3% of hospitals and remained unchanged at 2.3%. In comparison, 48.2% of hospitals experienced a regression in productivity from 2015 to 2016. On average, the MPI was 1.07 throughout the analysis.

Conclusion: The findings of this study suggest that there is a need for increased efforts to improve the efficient utilization of resources in public hospitals. It highlights the importance of developing appropriate policy solutions and tools to address these efficiency challenges. In particular, one proposed strategy is the merger of small-sized district hospitals to establish larger and more efficient hospitals in different geographical regions across the country.

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Introduction

Efficiency is one of the main goals of health systems worldwide.[1, 2] Hospital expenditures represent around 30-50% of the total health expenditures in low-middle income countries (LMICs);[3, 4] therefore, assessing the efficiency and productivity of hospitals is of great importance for any healthcare system. Further, the hospital is a complex social organization that plays a significant role in maintaining and promoting social health.[5] Pursuing their goals of providing healthcare services to citizens, education, and research, the ultimate goal of a hospital is to meet societal health needs effectively and efficiently.[6] The inappropriate use of new diagnostic and treatment technologies, aging, the escalating burden of chronic conditions, the ever-increasing demand for healthcare services, and The consequences of errors made by health professionals and their associated negative side effects have imposed significant costs on healthcare systems.[7]

Productivity is the sum of an organization's effectiveness (doing the right things) and efficiency (doing the things right). Effectiveness means achieving organizational goals, while efficiency is 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 models include Data envelopment analysis (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]

Among the studies that have worked on this subject in the world, the following can be mentioned, including 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] 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.

The study of Pérez-Romero[18] concluded that in 230 NHS hospitals, the average overall technical efficiency (OTE) rate was 0.736 in 2012. Also, Dong et al. conducted a systematic review, showing statistical significance in indicators such as the number of decision-making units (DMUs), the percentage of allocative efficiency studies, the ratio of studies with multiple years, the number of studies with monetary indicators in input and output sets, etc.[19] Another systematic review was 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, and 4) presentation of results.[20] A systematic review was conducted using a unique approach to search for articles that applied combined Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The goal was to facilitate a comprehensive understanding of the suitability and effectiveness of these methods in assessing healthcare efficiency. The review aimed to identify variations in healthcare efficiency estimation resulting from the combined use of DEA and SFA and to explore the underlying reasons for these differences.[21]

Several studies, both in Iran and globally, have utilized Data Envelopment Analysis (DEA) to assess the efficiency of hospitals.[22]

These studies have indicated, albeit partially, the inefficiency of public hospitals in Iran, with efficiency scores ranging from 0.584 to 0.998.[17] For instance, comparing 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, failing to provide a comprehensive picture of the hospitals' efficiency nationwide. No previous research has determined the current efficiency status within all public hospitals in Iran.[25]

Over the past two decades, public hospitals in Iran have experienced significant reforms to improve the quality of care[26] and increase efficiency. These reforms include decentralization, accreditation, and, since 2014, improving hospitals' productivity through a health transformation plan (HTP).[27] Our team conducted a national research study to evaluate the efficiency of the healthcare system in Iran. Specifically, this paper focuses on assessing the efficiency of all public hospitals during 2012-2016 in Iran.

Methods

Setting

Both private and public sectors provide hospital care in Iran. All hospitals are regulated under the Ministry of Health and Medical Education (MoHME) supervision. In 2016, there were 921 active hospitals in the country; 80% were governmental, and 20% were nongovernmental hospitals (Appendix 1), scattered across 31 provinces in Iran. In this research, we included governmental public hospitals affiliated with the MoHME and divided them into general and specialized hospitals. General hospitals were divided into three sub-categories: medical-non-educational, medical-educational, and educational-research centers. Specialized hospitals were divided into eight sub-categories: Orthopaedic, Accidents and Burns, Paediatric, Ophthalmology, Psychiatry, Gynaecology and Obstetrics, Cardiology, Cancer and Oncology (The MoHME has made this classification). The average bed occupancy in public hospitals was 73% in 2014.[28]

Study Design

This was a quantitative and descriptive-analytical study. The study's sample included all governmental public hospitals affiliated with the MoHME in Iran. The authors extracted data from secondary databases linked to the Ministry of Health and Medical Education's (MoHME) Health Information System (HIS). They measured the efficiency score and the MPI and provided the benchmark for each indicator. First, they 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 units utilizing minimal inputs were considered efficient, while the health output had not been simultaneously adjusted to account for quality and equity aspects. In other words, the reality of resource distribution, their case mix, and other contextual factors affecting hospitals' efficiency were not considered in the DEA conventional method. In collaboration with a scholarly team in applied mathematics, the authors began a modification process, the so-called extended DEA, to balance and rationalize the results to overcome this challenge. Three consecutive steps are as follows:

Step 1: Definition of Input-output Indicators

The authors performed a qualitative analysis to identify input and output indicators, including a literature review and expert opinion collection. Initially, a scoping review of relevant studies generated a list of indicators aligned with our research objectives.[29] Second, the authors scrutinized the data linked to each indicator and assessed the reliability of the data source, resulting in the exclusion of numerous indicators. Finally, the included indicators were reviewed and approved by an expert panel comprising the research team and selected key informants in health management, policy, and economics (Appendix 2).

Step 2: Data Collection and Cleaning

The authors employed a data collection checklist designed in accordance with the input and output variables for the entire study period. Data obtained from the Ministry of Health and Medical Education's hospitals and workforce information database for all public hospitals were entered into an Excel sheet, treating them as 'Decision-Making Units (DMUs)'.

We conducted data cleaning to verify the presence and accuracy of data for each indicator within each Decision-Making Unit (DMU) over the entire study period. Irregular data were compared with other sources to ensure data integrity. The authors include all Iranian public hospitals. However, due to limited input and output indicators, they excluded 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, the authors classified hospitals based on their specialty, teaching, non-teaching, and performance indicators. To compare heterogeneous hospitals included in our study, the authors used the "level of specialty" variable, which let them classify similar hospitals in certain designated groups in a meaningful manner and conduct a meaningful and fair comparison[30] (Appendix 2).

Step 3: Data Analysis and Modeling

Each indicator was weighed and given a value using the standards set by the MoHME, 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 congruent DMUs.

Initially, in the DMU community, a point is determined and fixed as a benchmark for the DMU under evaluation based on alleviating the policies defined by the management. Subsequently, the relative efficiency of the DMU under assessment is calculated based on benchmarking, which ranges between 0 and 1. An efficiency value of 1 indicates a DMU's efficiency, while less than 1 signifies inefficiency. Therefore, higher efficiency could indicate the DMU's better performance. In this article, the authors considered each hospital a DMU, while hospitals were categorized into various specialty groups, and EDEA models were independently implemented for each categorization.

The authors suppose that each hospital employs four inputs to generate seven outputs. They utilized the following symbols to represent the values of these inputs and outputs for each hospital j (j=1, …, n).

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

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

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

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

Symbols D and U.D are desirable and undesirable, respectively. In other words, management considers increasing desirable outputs to improve productivity. However, the manager does not consider the undesirable outputs adversely affecting productivity. Since the fifth output (Average length of stay) is undesirable, the authors made the following changes to make it a desirable output.

$Y_{5j}=1/y_{5j}$ (1)

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

$$v_1 \geq 1.3v_2, \quad u_7 \geq u_1, \quad u_6 \geq u_3,$$
$$v_2 \geq 1.3v_3, \quad u_2 \geq u_1, \quad u_3 \geq 1.5u_4 \quad (2)$$
$$v_2 \geq 3.9v_4, \quad u_3 \geq u_5,$$

Relationships (2) show the relative weight of indicators. For example, the importance of the seventh output is equal to the first output, and the importance of the first input to the second input is at least 1.3. Since this research design requires a restriction, the modeling was done in envelopment form. Therefore, constraints (2) appeared in trade-offs in the envelopment form with symbols β. Also, the variables corresponded to this trade-off in envelopment form.

On the other hand, the sixth output was expressed as a "percentage", so its value must always be between [0.100]. Therefore, the following constraints were considered in the modeling.

$$0 \leq \sum_{j=1}^{315}\lambda_j y_{6j} + \sum_{j=1}^{5}\gamma_j \beta_{6j} \leq 100 \qquad (3)$$

The number of bed days also depends on the number of beds, which is why the following model constraints were considered in the modeling.

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

According to the above description, the radial model in the envelopment form, taking into account the trade-off and limitations of 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:

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

The optimal value of the objective function of model (5) can be denoted as a relative efficiency of hospital p. It is evident that if the optimal value of the objective function in Model (5) equals 1, then hospital p is considered efficient. Similarly, suppose the optimal value of the model's objective function (5) is less than 1. In that case, the hospital p can be considered inefficient, so its coordinates of the benchmark will be as follows:

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

To calculate the progressive and unprogressive aspects of each of the hospitals based on efficiency or performance, the Malmquist Productivity Index (MPI) was 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 study period (if MPI=1).

The notation for allocating 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 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 Effect 5: 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, and boundary changes are calculated as follows.

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

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

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

Results

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

Hospitals' efficiency score and MPI were summarized in Tables 1 and 2. Tables 3 and 4 show the efficiency score and MPI of the general and specialized hospitals during 2012–2016 in Iran. Finally, Table 5 presents the total inputs that need to be reduced and the outputs that need to be promoted for 2015.

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

Efficiency of Hospitals and Their MPI

Tables 1 and 2 present the 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% did not change, and 48.2% had regressed in 2015-2016. The mean of MPI was 1.07 over the analysis years.

Table 1: Overall efficiency results 2012-16

Summary statistics		2012	2013	2014	2015	2016	Mean
Number		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
Standard Deviation (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≤ Efficiency <0.2	3.14	2.76	3.10	1.44	2.99	2.68
	0.2≤ Efficiency <0.3	18.45	22.47	15.85	14.00	20.42	18.24
	0.3≤ Efficiency <0.4	23.99	20.44	24.04	23.70	20.42	22.52
	0.4≤ Efficiency <0.5	23.06	23.39	21.86	24.06	23.42	23.16
	0.5≤ Efficiency <0.6	6.64	5.89	9.65	10.59	7.22	8.00
	0.6≤ Efficiency <0.7	11.62	11.79	12.20	12.03	11.80	11.89
	0.7≤ Efficiency <0.8	2.03	2.21	2.55	3.23	3.35	2.67
	0.8≤ Efficiency <0.9	0.74	0.74	0.91	0.72	0.53	0.73
	0.9≤ Efficiency <0.99	0	0	0	0	0	0.00
	Efficiency=1	10.33	10.31	9.84	10.23	9.86	10.11

Table 2: 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

*Malmquist Productivity Index (MPI)

Table 3: 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

*Malmquist Productivity Index (MPI)

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

Table 3 shows that, on average, 7 out of 315 general hospitals had efficiency scores above 0.8, with a 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).

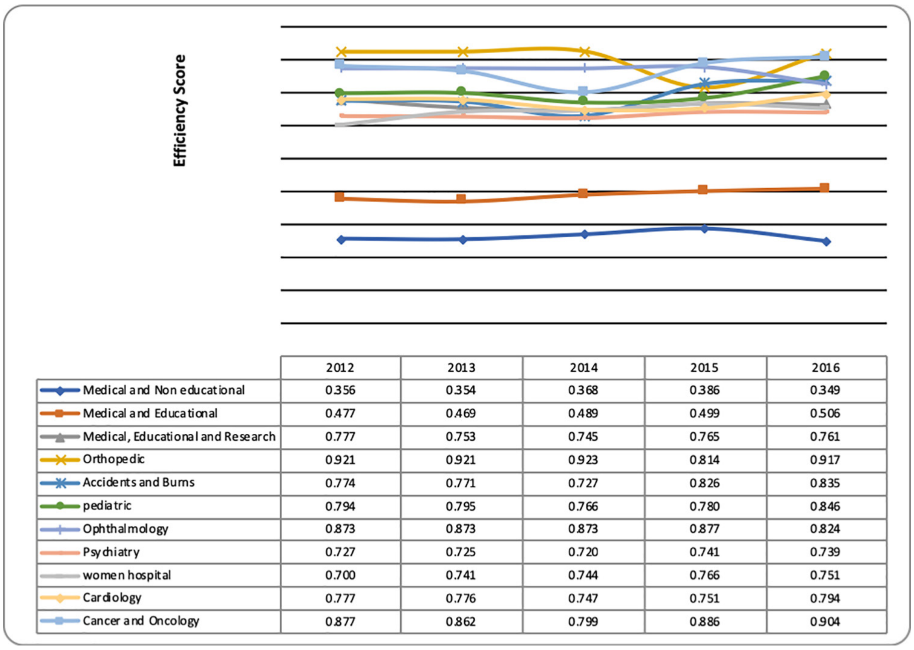

Figure 1: Average efficiency score by hospital type, 2012-16.

Table 4: 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

*Malmquist Productivity Index (MPI)

Table 5: Total input reductions and output improvement are needed to improve hospitals' efficiency

Input/output variables	General hospitals			Specialized hospitals			Psychiatry		
	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
The 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

The range of efficiency scores in these hospitals was 0.645. In the study years, seven teaching hospitals scored above 0.8 on average. 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. This index's lowest (0.561) and the highest (1.710) progress were during 2014-2015 and 2015-2016, respectively.

The average efficiency score in teaching and research hospitals was 0.760 over the study years, while the lowest score was observed in 2013 -2014 (Min=0.576). On average, 8 out of 22 hospitals scored 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 accident and burn specialist hospitals, three scored above 0.8. The range of scores was 0.425 in this group, which was lower than that of general hospitals. The minimum score and standard deviation in this group were 0.574 and 0.16, respectively.

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 an average efficiency score of 0.646. On average, the MPI progressed 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 this group's biggest efficiency regression (MPI=0.84).

The average efficiency score in gynecology and obstetrics specialized hospitals was 0.740 (R=0.192). Nine of 25 hospitals in this group showed 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 from 2012 to 2013 and regressed from 2013 to 2016. The highest MPI score was observed in 2015-2016 (MPI=1.12) in this group.

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

Benchmarking

Two general ways to improve hospitals'

productivity are reducing input and/or increasing output. Table 5 presents the total inputs that need to be reduced and the outputs that need to be increased to improve hospitals' efficiency in 2015.

Discussion

This study aimed to analyze the efficiency of government public hospitals, categorized by specialty, from 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 and public hospitals is 0.488 and 0.357, respectively, in line with the results of some other studies.[22, 32] Only seven 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 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 the 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 several hospitals in this study were in the early years of their establishment. Newly established hospitals operate inefficiently in the early years due to shortcomings they may experience at the outset of their activities. The MPI indicates progress in the average efficiency score of these hospitals over the analysis period.

The average efficiency score of teaching hospitals varied between 0.354 and 1. Only four out of the 130 teaching hospitals had scores above 0.8 on average. The overall low efficiency of these hospitals might be due to more input required for the 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 many patients.

The efficiency score of accident and burn hospitals in provincial centers and other regions was one 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 improvements 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 these hospitals' bed numbers and performance levels in less populated areas may improve 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 in other specialized hospitals (R=0.420), and their efficiency score was low. This could be due to these hospitals' low bed occupancy rate (Mean<75%), which might result from 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.

Like other hospitals, Cardiology specialized hospitals in the capital city of Tehran had an efficiency score of 1. In contrast, the score in similar hospitals in other cities was below 0.7. Again, this calls for reviewing 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 scored above 0.8.

In Iran, Educational hospitals are less efficient than Non-educational hospitals, and specialized hospitals are also the most efficient. The fact that they are targeting different patients and may have different technologies remains the same because the efficiency measures how input mobilization translates into outputs. So, the study demonstrates that the productivity of the workforce and beds is higher in specialized hospitals than in other categories. Also, the limited efficiency of Educational hospitals can be related to the measurement of staff as part of their time can be dedicated to education. This could be better incorporated into the existing information system by adopting an approach based on Full Time Equivalent (FTE) measurements of staff instead of headcount. For instance, a doctor dedicated 50% of the time to education would be considered 0.5 FTE for clinical activities, and so on.

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

A recent study calculated and analyzed the efficiency of all public hospitals in Spain in 2017[18] and reported an average efficiency score of 0.736, 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 the 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 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. They calculated the average efficiency score of 0.748, while the 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 service 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 ten 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 efficiency rate 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.

Despite the advantages, this 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 from the MoHME, which is the most reliable and available source in Iran, there still needs to be some limits in data credibility that might affect the reliability of the data source. Nevertheless, this study is the only data source available to analyze.

Our study could have benefited from some technical considerations to enhance the accuracy of the findings. A more robust approach to designing studies on the efficiency of hospitals was advocated. In particular, the use of international standards in selecting input and output indicators and paying enough attention to homogenizing 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 and combine the current two-stage and three-stage DEA models with the Bootstrap-DEA method to calculate more accuracy efficiency.[40]

Conclusion

The study assessed efficiency scores and MPI for 568 public hospitals from 2012 to 2016, utilizing Extended-DEA for the first time in Iran. Given the generally low-efficiency scores of hospitals, particularly general hospitals across various specialties, there is a pressing need for robust, evidence-based measures to enhance resource utilization. As Iran has been implementing its ambitious health transformation plan (HTP) to reach universal health coverage by 2025, and considering the historical shortages in hospitals, 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 enhance their capacity to allocate human resources based on specific needs across different settings, improve the quality of hospital services to boost revenue, and stabilize their financial status, such as through the implementation of prospective payment systems, and effectively optimize the utilization of physical resources, the healthcare system may struggle to meet the growing demand. This could potentially lead to even greater challenges in the future.

Ethics Approval and Consent to Participate

This study was approved by Tehran University of Medical Sciences's ethical committee under license no: IR.TUMS.VCR.REC.1396.4018.

Availability of Data and Materials

The data of this study are available in "Supplementary Material."

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Authors' Contribution

AT, AO, and RM conceived the study and designed its method. EM performed the computations and applied the model, with FHL's help for the analytical method's revision. 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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Appendixes

Appendix 1: Number of hospitals in Iran, based on their ownership

Row	Hospital ownership classification	Number
1	Public hospitals, affiliated to the MoHME	568
2	Private	151
3	Social Security Organization	74
4	Army and police	52
5	Charity	30
6	Martyr Institute and Veterans Affairs	11
7	Azad university	10
8	Ministry of Oil	9
9	Relief Committee	2
10	Banks	1
11	Ministry of Education	1
12	Others	12
Sum		921

Appendix 2: Input-output indicators

Indicators	Definition	Type of indicators (Input/ Output)	Standard of indicator (annual)	Weight indicator
n. Physician	Number of general practitioners and specialists working in the hospital	Input	-	Of high importance
n. Nurse	Number of nurses in the hospital who work in clinical wards	Input	-	Relatively important
n. Other staff	Number of other staff, include administrative units, working in the hospital	Input	-	Important
n. Hospital bed	The number of active beds in hospitals except for temporary beds	Input	-	Of extreme important
n. Inpatient	The number of hospitalized patients over 24 hours in a hospital during one year	Out put	-	Of high importance
n. Outpatient	The number of outpatients referred to the hospital within a year	Out put	-	Of high importance
n. Surgical operation	The number of surgeries performed in the hospital during one year	Out put	X>1440 (per operation room)	Of high importance
Average length of stay	The total number of Patient days divided by the number of admissions and discharges during a specified period of time, which results in an average number of days in the hospital for each person admitted	Out put	X<3.5	Of high importance
Bed occupation (%)	The number of hospital bed days divided by the number of available hospital beds, multiplied by the number of days in a year	Out put	X<70	Of super importance
Number of bed days	A bed-day is a day during which a person is confined to a bed and in which the patient stays overnight in a hospital	Out put	-	Of high importance
Degree of accreditation	All hospitals have an accreditation degree which assigned to them by the Ministry of Health and Medical Education every year. Degree of accreditation: Excellent/ Degree of 1/ Degree of 2/ Degree of 3/ Degree of 4	Out put	-	Of high importance

Appendix 3: Hospital classification and the number of each of them

Type of hospitals	Specialty of hospitals	Number
General Hospitals	Medical and Non educational	315
	Medical and Educational	130
	Medical, Educational and Research	22
Specialized Hospitals	Orthopedic	4
	Accidents and Burns	9
	Pediatric	13
	Ophthalmology	6
	Psychiatry	28
	Women hospital	25
	Cardiology	9
	Cancer and Oncology	7
Sum		568