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Efficiency of County Public Hospitals in Shandong Province, China: the effect of scale

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Abstract

Objective: The relationship between hospital scale and efficiency is of interest to hospital administrators. The study intends to evaluate the efficiency of 68 county public hospitals in Shandong Province after the new medical reform in China and compare the efficiency of hospitals with different bed sizes.

Design and setting: Cross-sectional study of 68 county-level public hospitals in Shandong Province, China in 2017.

Outcome measures: Data Envelopment Analysis (DEA) was used to calculate the efficiency scores of 68 hospitals and analyzed the slack values of non-effective hospitals. Kruskal-Wallis H test was employed to compare the efficiency of hospitals of different bed sizes. Chi-square (χ^2) test was used to compare the returns to scale (RTS) of hospitals with different bed sizes.

Results: 20 (29.41%) hospitals were effective. There are 27 hospitals with increasing returns to scale（IRS）, 23 hospitals with constant returns to scale（CRS）, and 18 hospitals with

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decreasing returns to scale（DRS）. The difference of the technical efficiency (TE, $p=0.248$, $p>0.05$) and the pure technical efficiency (PTE, $p=0.073$, $p>0.05$) were not statistically significant. However, the difference of scale efficiency (SE, $p=0.047$, $p<0.05$) and returns to scale (RTS, $p=0.000$, $P<0.05$) were statistically significant.

Conclusions: 70.59% of county public hospitals have problems with excessive input or insufficient production. When the hospital bed size exceeds 885 beds, it will bring about a decrease in scale efficiency (SE) of the hospital.

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Strengths and limitations of this study

The study evaluated the status of the county public hospitals in Shandong after the new medical reform, which played a certain warning role for hospital administrators.

This study explored the efficiency differences of hospitals in Shandong Province from the scale, and the scale difference was a good research direction.

Although the research raised doubts to the blind expansion of the hospital scale, it failed to propose a scientific scale prediction model.

This study only had hospital data for 2017, failed to form panel data and lacked longitudinal analysis and comparison.

Keywords: County public hospital, Data envelopment analysis, Technical efficiency, Scale

Introduction

The pursuit of efficiency has become the central objective of policy-makers and hospital administrator.[1] By studying hospital efficiency, hospital policy makers can develop effective policies to guide the hospital to improve inefficiencies. Hospital administrators can understand whether medical resources are optimally allocated and fully utilized. Initially, there was a lack of international consensus on the best way to evaluate the efficiency of hospital operations. Researchers in various countries have tried various methods. The evaluation of hospital efficiency now focuses on the use of economic models, especially in developing countries.[2 3] Many studies have shown that data envelopment analysis （DEA） is an important tool in evaluating hospital efficiency.[4-6]

More recent studies on hospital scale efficiency (SE) have been focusing on analysing the appropriate use of resources[7 8] and estimating the optimal size of hospitals[9-11] to improve hospital performance. In the process of maintaining and promoting people's health, county public hospitals in China provide more and more high-quality and accessible health services. However, the status of service in county public hospitals in China is far worse than expected. There are some problems such as the blind expansion of scale. Whether it is a county secondary hospital or a city's tertiary hospital, it relies too much on scale expansion to bring benefits to the hospital. Unexpectedly, the number of beds in a hospital in China has reached 10,000. The more hospital beds, the better the hospital's efficiency? In order to answer the above doubts, this study evaluated the efficiency of county public hospitals and discussed the impact of scale on hospital efficiency. We are looking forward to this study to provide reference for other countries to evaluate hospital efficiency and develop hospital scale.

Methods

Sample and data selection

County public hospitals are important carriers for the Chinese government to provide basic medical and health services to residents in county areas. These hospitals mainly undertake the diagnosis and treatment of common diseases and frequently-occurring diseases of county residents, the rescue of critically ill patients and the referral of patients with difficult diseases, and are responsible for training and guiding grassroots medical personnel. The original data initially included 71 county public hospitals of Shandong Province. Considering the integrity and availability of data, 68 county public hospitals that met the study inclusion criteria were eventually included. These hospitals comed from 68 municipal districts(county cities,counties) distributed in 15 prefecture-level cities in Shandong Province.

Located in the eastern part of China, Shando ng Province is one of the major coastal

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provinces in China. There are a total of 17 prefecture-level cities, which cover 49 municipal districts, 31 county cities and 60 counties. It is also a populous province in China. At the end of 2017, the total resident population reached more than 100 million. Shandong Province took the lead in starting comprehensive reform of county public hospitals in China, and had exemplary role in the country. In 2017, the average annual number of visits per hospital in the county public hospitals in Shandong Province was 527,816. Therefore, using Shandong Province as a sample to study the efficiency of China's county public hospitals was representative.

The data set of the research was collected from the health statistics information reporting system of the Hospital Management Research Institute of Qingdao University, Shandong Province, which mainly included the operational data of the county public hospitals in 2017. This research finally determined seven indicators that meet the efficiency evaluation criteria of hospitals. The study used the actual number of open beds, the number of doctors, the number of nurses, and the total expenditure as input indicators, representing the investment in three aspects of human, financial and material resources. The total number of annual visits, the number of discharged, and the total income were used as output indicators to represent the quantity, quality and benefits of medical services. The evaluation index was comprehensively determined by combining many previous literatures and the characteristics of the research objects.[12-16] The calculation process was implemented by means of DEAP(V2.1) software. The specific indicators were explained in Table 1.

Table 1 Definition of input and output indicators

Category	Indicators	Definition
Inputs	Actual number of open beds	The number of beds actually opened at the end of the year.
	Number of doctors	The number of practicing (assistant) physicians.
	Number of nurses	The number of qualified nurse practitioners.
	Total expenditure	The expenses incurred by the hospital at the end of the year.
Outputs	Total number of annual visits	All the number of visits counted by the number of registrations.

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	Number of discharged	The number of all discharged patients after hospitalization.
	Total income	The total income earned by the hospital at the end of the year.

Data Envelopment Analysis（DEA）

Introduction to DEA

Data Envelopment Analysis (DEA) is a method of evaluation by using the concepts and connotations of relative efficiency[17] and the convex analysis method and linear programming method as tools by the famous American operations research experts A.Charnes and W.W. Cooper in 1978.[4 18] Since DEA was introduced to health econometrics in the mid-1980s, it has become more and more widely used in the field of health care, and has become an important method for evaluating hospital efficiency. The main evaluation models of DEA are CCR, BCC, CCW, CCGSS, CCWH and so on. The most commonly used models for evaluating hospital relative efficiency are the CCR and BCC models.[1]

Through the comprehensive analysis of the input and output data, DEA can obtain the technical efficiency index of each decision-making unit (DMU), and according to the score, the effective DMUs can be determined. It can not only evaluate and rank the relative effectiveness of the same type of DMUs, but also further analyze the reasons and improvement directions of each non-effective DMU. At the same time, DEA determines the weights based on the actual data of the input-output of DMUs, and eliminates the influence of many subjective factors and artificial tendencies.

The principle of DEA

The most commonly used CCR and BCC models have both input and output oriented types. The input-oriented model refers to how to reduce the proportion of input in order to optimize efficiency without changing the quantity of output. The output-oriented model refers to how to increase or maximize output without changing the proportion of input.[4 16] In this study, a two-stage DEA was used to conduct research using the CCR and BCC models of the output-oriented model.

Charnes extended and developed the DEA approach assuming constant return to

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scale(CRS) as a sensitive model for measuring technical efficiency (TE).[19] The CCR model is based on the assumption of the CRS, which is mainly used to measure the TE score of the DMUs, with a score of 0-1. When the score is 1, it indicates that the DMU is effective. When the efficiency score value is less than 1, the DMU is considered to be inefficient. The closer the efficiency score is to 1, the higher the technical efficiency of the DMU is.

$$(D_{CCR})\begin{cases} \max \phi \\ \sum_{j=1}^{n} x_j \lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j \lambda_j \ge \phi y_0 \\ \lambda j \ge 0, j = 1,2,\cdots,n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0, y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0}, y_0 = y_{j0}, 1 \le j_0 \le n$$

The predecessors then developed a second DEA model based on the variable return to scale(VRS) to separate pure technical efficiency (PTE) from scale efficiency.[20] The BCC model is based on the assumption of the VRS, and is mainly used to measure the pure technical efficiency (PTE) and scale efficiency (SE) of the DMU.[21] The BCC model is an extension of the CCR model.

$$(D_{BCC})\begin{cases} \min \phi \\ \sum_{j=1}^{n} x_j \lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j \lambda_j \ge \phi y_0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \ge 0, j = 1,2,\cdots n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0, y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0}, y_0 = y_{j0}, 1 \le j_0 \le n$$

Statistical methods

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This study defined the size of the hospital based on the actual number of open beds. According to the standard of 500 beds and below, 501-1000 beds, 1001-1500 beds and 1501 beds and above, 68 sample hospitals were divided into small, medium, large and oversized groups. Kruskal-Wallis H non-parametric test was used to analyze and compare the efficiency of county public hospitals with different bed sizes. Efficiency included technical efficiency(TE), pure technical efficiency (PTE), and scale efficiency (SE). The Chi-square (χ^2) test was used to compare the differences in the scale returns of county public hospitals with different bed sizes. Statistical analysis was performed using SPSS 25.0 software (IBM, Armonk, NY).

Results

Description of input and output indicators.

Table 2 was a descriptive summary of the input and output indicators of 68 sample hospitals. The results showed that in 2017, the average number of open beds per hospital was 991.0. The average number of doctors and nurses per hospital was 352.7 and 529.3 respectively, and the ratio of doctors to nurses was 1:1.5. With an average of 527,816.1 visits per hospital per year, the efficiency of the county public hospitals was commendable.

Table 2 Description of input and output indicators

Indicators	Minimum	Maximum	Average	Sd
Input indicators				
Actual number of open beds	185.0	2220.0	991.0	373.6
Number of doctors	101.0	670.0	352.7	126.3
Number of nurses	149.0	971.0	529.3	191.5
Total expenditure	8184.0	90030.0	41587.8	17910.3
Output indicators				
Total number of annual visits	87116.0	1511751.0	527816.1	257916.2

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Number of discharged	8689.0	99565.0	43127.6	17099.7
Total income	8133.3	91991.0	42958.6	18356.4

Hospital efficiency score from the DEA model

Table 3 showed the distribution of efficiency scores for 68 sample hospitals. Only 20 (29.41%) hospitals which technical efficiency calculated to be 100% effective, and 53 hospitals (77.94%) were ineffective. The pure technical efficiency of 26 (38.24%) hospitals was effective, and the remaining 42 (61.76%) were ineffective. All 68 hospitals had a scale efficiency score above 0.900, but only 23(33.82%) were fully effective.

Table 3 Distribution of efficiency scores

Efficiency	1.000	0.999-0.900	0.899-0.800	0.799-0.700
Technical efficiency	20（29.41%）	32（47.06%）	15（22.06%）	1（1.47%）
Pure technical efficiency	26（38.24%）	30（44.12%）	11（16.18%）	1（1.47%）
Scale efficiency	23（33.82%）	45（66.18%）	0（0.00%）	0（0.00%）

Figure 1 depicted the returns to scale of 68 hospitals. 23 hospitals with a scale efficiency score equal to 1 were constant scale returns. This meaned that these hospitals were not only at the optimal bed size, but also had the lowest production and operation costs, and the inputs and outputs were also in balance. Hospitals with ineffective scale were divided into two categories: increasing returns to scale (IRS) and decreasing returns to scale (DRS). The 27 hospitals with IRS had insufficient resources and needed to continue to expand their scale to achieve better conditions. The 18 hospitals with DRS had over-invested in health resources, and needed to scale down and optimize the allocation of existing health resources.

Figure 1 Distribution of return to scale in sample hospitals

Slack value of input and output indicators of inefficiency hospitals

The study analyzed the slack values of 48 ineffective county public hospitals. In other words, it was to analyze the difference between the actual value and the ideal value of the hospital

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input indexes at a certain output level. The slack value of the input index refered to the amount that the input should be reduced in order to achieve efficiency optimization under current technical and output conditions. The slack value of the output indicator refered to the amount that the output should be increased under the existing output conditions. Taking H1 hospital as an example, the actual number of doctors in H1 hospital was 38.83 more than the ideal standard compared with effective hospitals. There were certain gaps between the hospital's output indicators and the ideal values. As shown in Table 4, H1 hospital should increase the total number of annual visits by 15%, the number of discharged by 6%, and the total income of 6% to fully utilize the existing resources.

Table 4 The slack value of input and output indicators of hospital H1

DMU	Slack value	Input and output indicators						
		Beds	Doctors	Nurses	Expenditure	Visiting	Discharged	Income
H1	Actual value	717.0	300.0	344.0	27508.0	418402.0	35536.0	28743.0
	Ideal value	717.0	261.2	344.0	27508.0	479793.2	37800.8	30574.8
	Slack value	0.00	38.83	0.00	0.00	-61391.24	-2264.77	-1831.84
	Change ratio	0%	13%	0%	0%	-15%	-6%	-6%

Differences in efficiency between hospitals of different bed sizes

Differences in TE，PTE and SE between hospitals of different bed sizes

Hypothesis testing was performed using the Kruskal-Wallis H test to compare the efficiency differences of county public hospitals of different bed sizes. The result demonstrated that there were no significant difference in TE (P=0.248, P>0.05) and PTE (P=0.073, P>0.05) between the four comparison groups in 2017. However, it can be seen that the difference in SE was statistically significant (P=0.047, P<0.05). See Table 5 for details.

Table 5 Comparison of technical efficiency of hospitals with different bed sizes

Efficiency	Hospital scale	$\bar{X}\pm S$	χ^2 value	P value

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Technical efficiency	Small scale	0.965±0.049	4.131	0.248
	Medium scale	0.927±0.064		
	Large scale	0.957±0.045		
	Oversized scale	0.930±0.046		
Pure technical efficiency	Small scale	0.983±0.031	6.954	0.073
	Medium scale	0.934±0.060		
	Large scale	0.967±0.041		
	Oversized scale	0.979±0.037		
Scale efficiency	Small scale	0.989±0.022	10.321	0.047
	Medium scale	0.992±0.011		
	Large scale	0.989±0.013		
	Oversized scale	0.951±0.032		

Differences in returns to scale between hospitals of different bed sizes

When sorting out the data, it was found that when the number of beds in the sample hospitals was more than 885, the RTS began to enter a decreasing state. A large number of hospitals in large-scale and super large-scale groups were already in a state of decreasing returns to scale (DRS). Since the data of scale remuneration was disorderly classification data, the Chi-square (χ^2) test was used to analyze the difference in the status of RTS of hospitals in different groups. The findings in table 6 suggested that the difference of the RTS of hospitals with different bed sizes was significant (P=0.000, P<0.05).

Table 6 Comparison of the scale returns of hospitals with different bed sizes

	Decreasing	RTS constant	Increasing	χ^2 value	P value
Small scale	2（50%）	2（50%）	0（0%）		
Medium scale	23（63.89%）	11（30.56%）	2（5.56%）	32.023	0.000
Large scale	2（8.70%）	9（39.13%）	12（52.17%）		

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Oversized scale	0（0%）	1（20%）	4（80%）

Discussion

More and more countries have been using DEA to evaluate hospital efficiency.[1 2 13 22] However, due to different national backgrounds and management models, the focus of research on hospital efficiency is different. The blind expansion of bed size is a common problem in Chinese hospitals. Whether in public hospitals or private hospitals, China still has controversy about the size of hospital beds. Our research not only evaluated the efficiency of 68 county public hospitals, but also further explored the difference in hospital efficiency based on the problems found, and predicted the optimal size of the hospital.

The findings indicated that 48 (70%) of the 68 county public hospitals in Shandong Province were ineffective. That was to say, more than 70% of hospitals had problems of excessive investment or insufficient output, which was consistent with the findings of many experts.[23-25] Zhaohui Cheng, et al, [23] suggested that only 8.8% of the 114 sample hospitals in Henan county hospital of China in 2012 were defined as overall technically effective, indicating the need to improve efficiency. Qin Liu, et al,[26] investigated the operational efficiency of 36 county public general hospitals in Guangxi in 2016. It was found that the average technical efficiency of hospitals was 0.957, and only 14 hospitals were effective. This study also identified the level of increase or decrease in output that inefficient hospitals need to make in order to become relatively efficient. For example, H1 hospital should increase the total number of annual visits by 15%, the number of discharged by 6%, and the total income of 6% to fully utilize the existing resources. The output indicators of ineffective hospitals generally had relatively high slack values, and a large part of the reason was that the hospital had not realized the full use of resources. Zhang Yue' s research on the equity and efficiency of primary health care resource allocation in mainland China suggested that many provinces have resources that are idle and underutilized.[27] This may be due to the inefficient use of resources by medical staff. It may also be because county hospitals are limited by their own service capabilities, resulting in the loss of patients, which in turn makes resources idle and difficult to use effectively.

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68 county public hospitals scored higher on PTE, with an average score of 0.951. Excluding the impact of scale factors, hospitals have brought better improvements in efficiency through pure technology. Not only Shandong Province, but also other areas of China have given strong support and attention to the investment and renewal of medical equipment, the strengthening of hospital information systerm[28] and the connection of Internet hospitals. The difference of pure technical efficiency was not significant. It can be speculated that the Siphon effect of scale on medical technology and equipment has been alleviated. In the future, no matter the size of the hospital, medical technology and equipment will gradually achieve fairness and homogeneity. This will be a good vision for future hospital development.

After professional analysis, the study found that the size of the bed will affect the SE and RTS of hospitals. The size of hospital beds was not the bigger the better, but subjected to the law of decreasing marginal utility of Economics.[29] Below a critical point, an increase in the number of hospital beds can lead to an increasing efficiency, and beyond this critical point, an increase in the number of beds results in a decreasing efficiency. Research undertaken largely in the USA and the United Kingdom indicated that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds.[30 31] This study revealed that the number of beds in county public hospitals in Shandong Province was more than 885, and began to enter the state of decreasing returns to scale (DRS). However, Siping Dong stated that the vast majority of county hospitals in Hubei Province had more than 335 beds, which was generally in a state of decreasing returns to scale.[32] The results of the two studies were quite different. Over time, this may be related to different factors such as the population base of different provinces and the release of medical service demand due to the expansion of China's medical insurance coverage.

Conclusions

This study evaluated and compared the efficiency of 68 county public hospitals in Shandong Province by using DEA. The county public hospitals had higher efficiency scores, but most hospitals had problems of the unreasonable allocation and inadequate utilization of health resources. Hospitals should fully mobilize the enthusiasm of medical staff, continuously improve human efficiency, and improve the hospital's medical service capabilities. Moreover, pure technical efficiency is a mediator between human efficiency and higher output levels in hospitals. The synergy between human efficiency and pure technical efficiency will bring higher operational efficiency to hospitals.

The study further demonstrated that blind expansion of bed size does not lead to greater hospital efficiency. County general hospitals should avoid blindly expanding the scale of hospitals and take various effective measures to improve the efficiency. As a main body serving county residents, county general hospitals should accurately locate the hospital's service content according to the function of the hospital, the medical service demand categories of the residents within the jurisdiction, the number and structure of the service population. The hospital should further optimize the size of the hospital bed to ensure economies of scale. For hospitals that have a negative effect on bed size, hospitals must focus on improving the efficiency of pure technology in order to improve technical efficiency.

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Figure 1 depicted the returns to scale of 68 hospitals. 23 hospitals with a scale efficiency score equal to 1 were constant scale returns. This meaned that these hospitals were not only at the optimal bed size, but also had the lowest production and operation costs, and the inputs and outputs were also in balance. Hospitals with ineffective scale were divided into two categories: increasing returns to scale (IRS) and decreasing returns to scale (DRS). The 27 hospitals with IRS had insufficient resources and needed to continue to expand their scale to achieve better conditions. The 18 hospitals with DRS had over-invested in health resources, and needed to scale down and optimize the allocation of existing health resources.

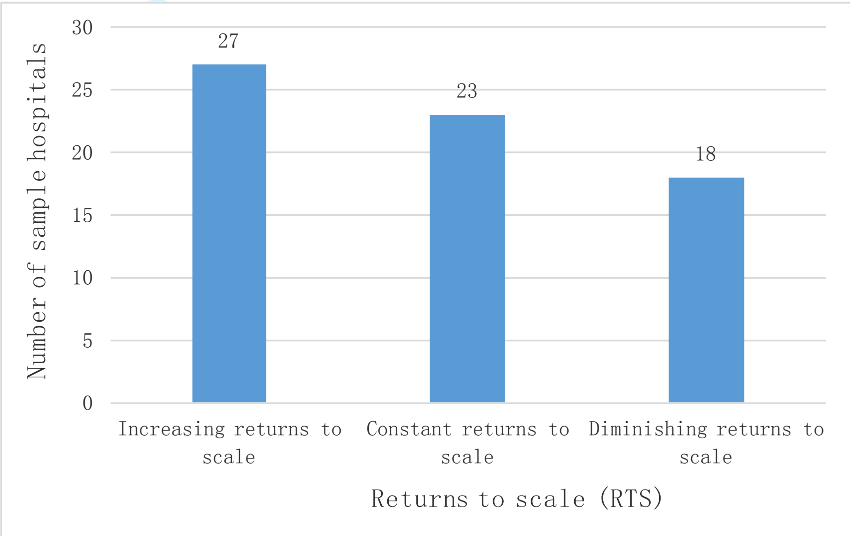

Figure 1 Distribution of return to scale in sample hospitals

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A Study on the Efficiency and Scale Effect of County Public Hospitals in Shandong Province, China

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Abstract

Objective: To evaluate the efficiency of county-level public hospitals in Shandong Province following China's new medical reform and to compare the efficiency of hospitals with different bed size.

Design and setting: This was a cross-sectional study on the efficiency and size of 68 county-level public hospitals in China in 2017.

Outcome measures: Data envelopment analysis (DEA) was used to calculate the efficiency scores of hospitals and to analyse the slack values of inefficient hospitals. The actual number of open beds, doctors and nurses and total expenditure were selected as inputs, and the total number of annual visits and discharges and total income were selected as outputs. The Kruskal-Wallis H test was employed to compare the efficiency of hospitals with different bed size. The Chi-square (χ^2) test was used to compare the returns to scale (RTS) of hospitals with different bed size.

Results: Twenty (29.41%) hospitals were efficient. There were 27 hospitals with increasing returns to scale (IRS), 23 hospitals with constant returns to scale (CRS), and 18 hospitals with decreasing returns to scale (DRS). The differences in technical efficiency (TE, P=0.248, P>0.05) and pure technical efficiency (PTE, P=0.073, P>0.05) were not statistically significant. However, the differences in scale efficiency (SE, P=0.047, P<0.05) and returns to scale (P<.001) were statistically significant. Hospitals with DRS began to appear at 885 beds.

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All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.

Conclusions: The government and hospital managers should strictly control the bed size in hospital and make hospitals resume operating in the interests of public welfare. Interventions that rationally allocate and use health resources and improve the efficiency of doctors and nurses are conducive to solving redundant inputs and insufficient outputs.

Strengths and limitations of this study

The DEA accommodated multiple inputs and multiple outputs, which is in line with the characteristics of hospitals.

The DEA did not need to use a common denominator, ensuring the diversity of indicators.

This study determined the extent and source of hospital inefficiencies to help hospitals take remedial measures.

The results produced by the DEA were sensitive to measurement errors and may underestimate or overestimate the efficiency scores.

Due to the objective limitations of the data, the study included hospitals only in eastern China.

Introduction

The unreasonable allocation and utilization of resources have seriously affected the production efficiency of health services.[1] Pursuing efficiency is of vital importance to policy-makers and hospital managers.[2] Evaluating of hospital efficiency can help hospital policy-makers improve inefficiencies with rational policies, and managers can know whether medical resources are optimally allocated and fully utilized.

The focus of medical reform in China has been on hospital efficiency and quality. Prior studies held that the efficiency of hospitals needed to be further improved, and there were some problems such as the inefficient allocation of resources and the blind expansion of scale.[3 4] In 2016, with regard to the healthcare sector, the "Guiding Principles for the Planning of Medical Institutions (2016-2020)" were issued; these principles required hospitals to strictly control the bed size. Unfortunately, there has been no significant effect. In fact, in most hospitals, the number of beds is still on the rise. The price of medical services in China is regulated by the government, and the zero-price gap policy for drugs and consumables has

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severely curtailed the sources of hospital revenue. Although it is a public hospital, government investment is insufficient to meet the needs of hospital development. The expansion of scale can attract more health resources and financial investment for hospitals, and it can also reduce the unit cost. Therefore, the benefits of hospital expansion in China are compelling. Of course, the reasons for expansion do not rule out the increase in demand for health services.

Unexpectedly, the number of beds in the largest public hospital in China has reached 10000. Is it the case that the more hospital beds there are, the better the hospital's efficiency? Most studies on scale efficiency (SE) have focused on analysing the appropriate use of resources[5 6] and estimating the optimal size of hospitals.[7-9] Novosadova et al[10] compared the efficiency of large and small acute hospitals and gave scores in terms of technical and scale efficiency. It turned out that smaller hospitals tend to be more efficient than larger ones. Fidler et al[11] examined the size effect of reorganized hospitals in Austria and Estonia. Policy-makers believed that the combined large hospitals can reduce average costs and improve clinical outcomes. In contrast, employees argued that the merger neither generated economies of scale nor significantly improved quality. In short, regardless of whether hospitals are in China or elsewhere, conducting studies on hospital efficiency and scale economies is crucial to address the question of the optimal productive size and to manage a fair allocation of resources.[12]

General hospitals have always been the pioneer in the reform of county public hospitals, and the primary carrier for the government to provide basic medical services to residents living in counties. Shandong Province, located in eastern China, is one of the major coastal provinces in China. It is also a populous province. At the end of 2017, the total residential population reached more than 100 million. Shandong Province took the lead in starting a comprehensive reform of county public hospitals, and played an exemplary role for the country as a whole. Therefore, this province is representative for evaluating the efficiency of county public hospitals and exploring scale effect by taking county public general hospitals in Shandong Province as a sample. We anticipate that this study will provide a reference for other regions in regard to efficiency evaluation and scale development.

Methods

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Sample and variable selection

The data set was collected from the health statistics information reporting system of the Hospital Management Research Institute of Qingdao University and was provided by 71 county public hospitals from March to June 2018. First, DEA premised on the selection of similar decision-making units; thus, the sample consists of county public general hospitals. Second, all no variables in the sample hospitals should include missing or abnormal values. Third, this study selected counties with one and only one general hospital. Two hospitals were removed for missing data. Another hospital was removed because the district it belonged to was merged. Therefore, combining the above requirements, the study finally identified 68 hospitals.

The study selected seven input and output variables that fit the characteristics of hospital efficiency. The actual number of open beds, the number of doctors, the number of nurses, and total expenditure were used as inputs, to represent human, financial and material resources. The total number of annual visits, the number of discharges, and total income were used as outputs to represent the quantity, quality and benefits of medical services. The variables were determined under the guidance of several previous empirical studies.[13-17] The calculation process was implemented by means of DEAP 2.1 software. The specific indicators are explained in Table 1.

Table 1 Definition of the inputs and outputs

Category	Variable	Definition
Inputs	Actual number of open beds	The number of beds actually opened at the end of the year.
	Number of doctors	The number of practising (assistant) physicians.
	Number of nurses	The number of qualified nurse practitioners.
	Total expenditure	The expenses incurred by the hospital at the end of the year.
Outputs	Total number of annual visits	The number of visits, counted by the number of registrations.
	Number of discharges	The number of all discharged patients after hospitalization.
	Total income	The total income earned by the hospital at the end of the year.

Efficiency evaluation methods

Currently, the evaluation of hospital efficiency focuses on the use of economic models.[18 19] Stochastic frontier analysis (SFA) and the technique for order preference by similarity to an ideal solution (TOPSIS) are also commonly used in efficiency evaluation.[20 21 22] SFA is limited to evaluateing the objects of multipke- inputs and a single- output. Although absolute efficiency can be measured, the ability to distinguish allocation efficiency from technical efficiency is weak.[6] With the TOPSIS method, the weight of the indexes is subjective, which may affect the accuracy of the results.[22] International studies have shown that data envelopment analysis (DEA) is an important tool in evaluating hospital efficiency.[23-25] DEA is a mature and advanced non- parametric method that compensates for the shortcomings of the above methods. It can solve problems with multiple- inputs and multiple- outputs. Not only can efficiency be evaluated and ranked, but the source of inefficient decision making units (DMUs) and the extent of improvement can also be further tracked.[13 19]

Data envelopment analysis

Data envelopment analysis is an evaluation method that was first proposed by the famous American operations researcher A.Charnes and scholar W.W.Cooper in 1978 [23 26] based on the concept and connotation of relative efficiency.[27] CCR and BCC are the most commonly used models.[2] In this study, a two-stage DEA was used to conduct research using the CCR and BCC models of the output-oriented model. The output-oriented model involves how to increase or maximize output without changing the proportion of input.[17 23] Based on the assumption of a constant return to scale (CRS), Charnes [28] extended and developed the DEA-CCR, which is mainly used to measure the TE score of DMUs. A score equal to 1 indicates that the DMU is efficient. A score of less than 1 indicates that the DMU is inefficient.

$$(D_{CCR})\begin{cases} \max \phi \\ \sum_{j=1}^{n} x_j \lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j \lambda_j \ge \phi y_0 \\ \lambda j \ge 0,\ j = 1,2,\cdots,n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0,\ y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0}, y_0 = y_{j0}, 1 \le j_0 \le n$$

The scholars then developed the BCC model based on variable return to scale (VRS) to separate pure technical efficiency (PTE) from scale efficiency (SE).[29] The BCC model mainly measures the PTE and SE of the DMU.[30] The BCC model is an extension of the CCR model.

$$(D_{BCC})\begin{cases}\min \phi \\ \sum_{j=1}^{n} x_j \lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j \lambda_j \ge \phi y_0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \ge 0,\ j = 1,2,\cdots n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0, y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0}, y_0 = y_{j0}, 1 \le j_0 \le n$$

Statistical methods

This study defined the size of hospitals based on the actual number of open beds. The sample hospitals are divided into four groups: 500 beds and below, 501-1000 beds, 1001-1500 beds and 1501 beds and above. The Kruskal-Wallis H non-parametric test was used to compare the efficiency of hospitals with different bed size. Efficiency included technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed size. Statistical analysis was performed using SPSS 25.0.

Results

Description of the inputs and outputs

Table 2 is a descriptive summary of the inputs and outputs of the 68 sample hospitals. The data indicate that the average number of open beds per hospital was 991.0 in 2017. The average number of doctors and nurses per hospital was 352.7 and 529.3 respectively. With an average of 527,816.1 visits per hospital per year, the efficiency of the hospitals was commendable.

Table 2 Descriptive statistics of inputs and outputs

Indicators	Minimum	Maximum	Average	SD
Inputs				
Actual number of open beds	185.0	2220.0	991.0	373.6
Number of doctors	101.0	670.0	352.7	126.3
Number of nurses	149.0	971.0	529.3	191.5
Total expenditure (ten thousand)	8184.0	90030.0	41587.8	17910.3
Outputs				
Total number of annual visits	87116.0	1511751.0	527816.1	257916.2
Number of discharges	8689.0	99565.0	43127.6	17099.7

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Total income (ten thousand)	8133.3	91991.0	42958.6	18356.4

Hospital efficiency scores from the DEA

Table 3 showes the distribution of the efficiency scores for the sample hospitals. Only 20 (29.41%) hospitals had TE showing 100% efficient, and 48 (70.59%) hospitals were inefficient. The PTE of 26 (38.24%) hospitals was efficient, while the remaining 42 (61.76%) were inefficient. All hospitals had scale efficiency scores above 0.900, but only 23 (33.82%) were fully efficient. The efficiency score of all sample hospitals are shown in Appendix 1.

Table 3 Distribution of the efficiency scores for the sample hospitals

Efficiency \ Scoring range	1.000	0.999-0.900	0.899-0.800	0.799-0.700
Technical efficiency	20 (29.41%)	32 (47.06%)	15 (22.06%)	1 (1.47%)
Pure technical efficiency	26 (38.24%)	30 (44.12%)	11 (16.18%)	1 (1.47%)
Scale efficiency	23 (33.82%)	45 (66.18%)	0 (0.00%)	0 (0.00%)

Slack value of the inputs and outputs of inefficient hospitals

This study analysed the slack values of 48 inefficient hospitals. In other words, the differences between the actual value and the ideal value of the variables were calculated. Taking hospital H16 as an example, the actual number of doctors in hospital H16 was 38.83 more than the ideal number. As shown in Table 4, hospital H16 needs to increase the total number of visits by 15%, the number of discharges by 6% and total income by 6% to make full use of its current resources.

Table 4 The slack value of the inputs and outputs of hospital H16

DMU	Related indicators	Inputs				Outputs		
		Beds	Doctors	Nurses	Expenditure	Visits	Discharges	Income
H16	Actual value	717.0	300.0	344.0	27508.0	418402.0	35536.0	28743.0
	Ideal value	717.0	261.2	344.0	27508.0	479793.2	37800.8	30574.8
	Slack value	0.00	38.83	0.00	0.00	-61391.24	-2264.77	-1831.84
	Change ratio	0%	13%	0%	0%	-15%	-6%	-6%

Differences in TE，PTE and SE among hospitals with different bed size

There were no significant differences in TE (*P*=0.248, *P*>0.05) and PTE (*P*=0.073, *P*>0.05) among the four comparison groups. However, the difference in SE was statistically significant (*P*=0.047, *P*<0.05). See Table 5 for details.

Table 5 Statistical analysis results of the efficiency of hospitals with different bed size

Efficiency	Bed size	$\overline{X}\pm S$	χ^2 value	*P* value
Technical efficiency	≤500 beds	0.965±0.049	4.131	0.248
	501-1000 beds	0.927±0.064		

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	1001-1500 beds	0.957±0.045		
	≥1501 beds	0.930±0.046		
Pure technical efficiency	≤500 beds	0.983±0.031	6.954	0.073
	501-1000 beds	0.934±0.060		
	1001-1500 beds	0.967±0.041		
	≥1501 beds	0.979±0.037		
Scale efficiency	≤500 beds	0.989±0.022	10.321	0.047
	501-1000 beds	0.992±0.011		
	1001-1500 beds	0.989±0.013		
	≥1501 beds	0.951±0.032		

Differences in returns to scale among hospitals with different bed size

The finding in Table 6 suggests that the difference in the RTS of hospitals with different bed size was significant (*P*<.001). Twenty-three hospitals with the scale efficiency score equal to 1 were CRS. This means that these hospitals not only had the optimal bed size, but also had the lowest operation costs; additionally, their inputs and outputs were in balance. The inefficient hospitals were divided into two categories: IRS and DRS. The 27 hospitals with IRS had insufficient inputs and needed to expand their scale to achieve better results. The 18 hospitals with DRS had redundant inputs and needed to scale down and optimize their allocation of resources.

Table 6 Statistical analysis results of the returns to scale of hospitals with different bed sizes

Bed size \ Returns to scale	DRS	CRS	IRS	Total	χ^2 value	*P* value
≤500 beds	2 (50%)	2 (50%)	0 (0%)	4 (100%)	32.023	<.001
501-1000 beds	23 (63.89%)	11 (30.56%)	2 (5.56%)	36 (100%)		
1001-1500 beds	2 (8.70%)	9 (39.13%)	12 (52.17%)	23 (100%)		
≥1501 beds	0 (0%)	1 (20%)	4 (80%)	5 (100%)		
Total	27	23	18	68		

A scatter plot was produced to highlight the relationship between bed size and scale efficiency and returns to scale. As depicted in Figure 1, with the increase in the number of hospital beds, the scale efficiency of hospitals approximately first increased and then decreased. It was obvious that only one hospital was efficient in the ≥1501 bed group, and the remaining four hospitals were not only inefficient, but also had a low scale efficiency score.

In addition, hospitals with DRS began to appear at 885 beds. A large number of hospitals in the 1001-1500 and ≥1501 bed groups already in DRS. Of the 11 hospitals with more than 1300 beds, 9 (81.8%) were DRS. When the bed size exceeded 1100, there were no longer

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hospitals with IRS. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.

Figure 1 Scatter plot of the relationship between bed size and scale efficiency and returns to scale

Discussion

An increasing number of countries have been using DEA to evaluate hospital efficiency.[2 14 18 31] The findings indicated that 48 sample hospitals were inefficient. That is, more than 70% of hospitals had problems of excessive inputs or insufficient outputs, which is consistent with the findings of many experts.[1 32 33] Zhaohui Cheng, et al[32] suggested that only 8.8% of the 114 county hospitals in Henan Province, China, were defined as technically efficient, indicating the need to improve efficiency. Moreover, our study found that the outputs of inefficient hospitals had a high slack value, largely because of underutilized resources. In their research on the equity and efficiency of health resource allocation in mainland China, Zhang Yue, et al[34] pointed out that many provinces in China had problems of idle and underutilized health resources. This may be due to the inefficient use of resources by medical staff. It may also be because county hospitals are limited by their own service capabilities, resulting in a loss of patients, which in turn makes resources idle and difficult to use efficiently.

The blind expansion of bed size is a common problem in Chinese hospitals.[35] In theory, due to economies of scale, more beds should result in higher efficiency score. However, the results did not prove that the scale difference in hospital technical efficiency was significant. This may be because the effect of bed size on technical efficiency is not obvious or the difference depends on a combined effect incorporating other factors. To some extent, the level of GDP per capita represents the purchasing power of the government. As a public welfare undertaking led by the government, the development of hospitals cannot be separated from the support of the government. In recent years, the government has reduced the supply of resources to hospitals with DRS by imposing reasonable controls on hospital construction and the purchase of large equipment.[36] Asmild M et al[37] used DEA to study the optimal size of hospitals, especially the relationship between efficiency and size, and indicated that different hospitals had different efficiencies that depended on location, the population served, and the policies that provincial governments wish to implement.

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The difference in PTE was not significant. It can be speculated that the siphon effect of scale on medical technology and equipment has been alleviated. In the future, regardless of the size of the hospital, medical technology and equipment will gradually achieve fairness and homogeneity. This will be a good vision for future hospital development. The hospitals scored higher on PTE, with an average score of 0.951. Shandong Province and other areas of China have given strong support and attention to the investment and renewal of medical equipment, the strengthening of hospital information systerms[38] and the connection of internet hospitals. Excluding the impact of scale factors, hospitals have produced better improvements in efficiency through pure technology.

This study found that the bed size will affect the SE and RTS of hospitals. Below a critical range, an increase in the number of beds can lead to an increase in efficiency, but beyond the threshold, the increase will result in a decrease in efficiency. The findings indicate that hospitals with DRS began to appear at 885 beds. A large number of hospitals in the 1001-1500 and ≥1501 bed groups were already in DRS. However, Siping Dong stated that the vast majority of county hospitals in Hubei Province had more than 335 beds, and were generally in a state of DRS.[39] The results of Siping Dong's study and our study were quite different. Over time, the difference may be related to different factors such as the population base of different provinces and the unleashing of medical service demand due to the expansion of China's medical insurance coverage.

Internationally, several articles in business and economics journals focused on evaluating the benefits of hospital scale have shown that the IRS appears in hospitals with 300 and 600 beds. [40 41] Banker RD [42] observed that increasing returns to scale could be exploited up to a capacity of approximately 200 beds. Our study concluded that IRS should be controlled below 1100 beds. The scale effect of all sample hospitals with more than 1100 beds was already saturated, and some hospitals even had a negative scale effect. Research undertaken in the USA and the United Kingdom has indicated that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds.[12 43] Weaver M and Deolalikar A[9] concluded that economies of scale depend on the type of hospital, as well as the number of beds and outputs in research on the scale economies of 654 Vietnamese public hospitals. Specifically, central general hospitals had constant returns to scale when the average number

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of beds was 516. China is a country with a large population, and its demand for medical services is higher than that of other countries. The health sector has been implementing a hierarchical diagnosis and treatment model, and striving to make the county hospital visit rate 90% by 2020. The interval of beds for IRS in county public hospitals may be broader than that in other countries.

Limitations

This study evaluated the efficiency of county public hospitals in Shandong Province following the new medical reform, and explored the influence of scale on hospital efficiency. It provides a reference for the government and hospitals to reasonably control bed size, and it offers a warning to hospitals with regard to blindly expanding. However, the study has several limitations. First, the sample hospitals were selected from Shandong Province in eastern China, while hospitals located in central and western areas were excluded. Second, the data in this study cover only 2017, and cannot form panel data, leading to a lack of longitudinal analysis and comparison. Bias adjustments of efficiency scores were not carried out due to limitation of the DEA approach. In the future, we will continue to track the efficiency of county-level public hospitals in Shandong Province

Conclusions

This study evaluated and compared the efficiency of 68 county public hospitals in Shandong Province using DEA. The hospitals had higher efficiency scores, but most hospitals had problems of an unreasonable allocation and inadequate utilization of health resources. Hospitals should mobilize the enthusiasm of medical staff and continuously improve human efficiency. The synergy between human efficiency and pure technical efficiency will lead to higher efficiency in hospitals.

This study further demonstrated that blindly expanding the bed size does not lead to greater hospital efficiency. County public hospitals should avoid blindly expanding their scale and should take various effective measures to improve their efficiency. As a main body serving county residents, hospitals should accurately determine their service content based on their function of the hospital, the medical service demand categories of residents within their jurisdiction, and the number and structure of the population being served. We hope that this

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study will provide a reference for other regions to evaluate efficiency and control scale.

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Data availability statement The authors will not share the data for this work. The data for this study was obtained by applying to the Institute of Hospital Management of Qingdao University and involved private information such as hospital financial data.

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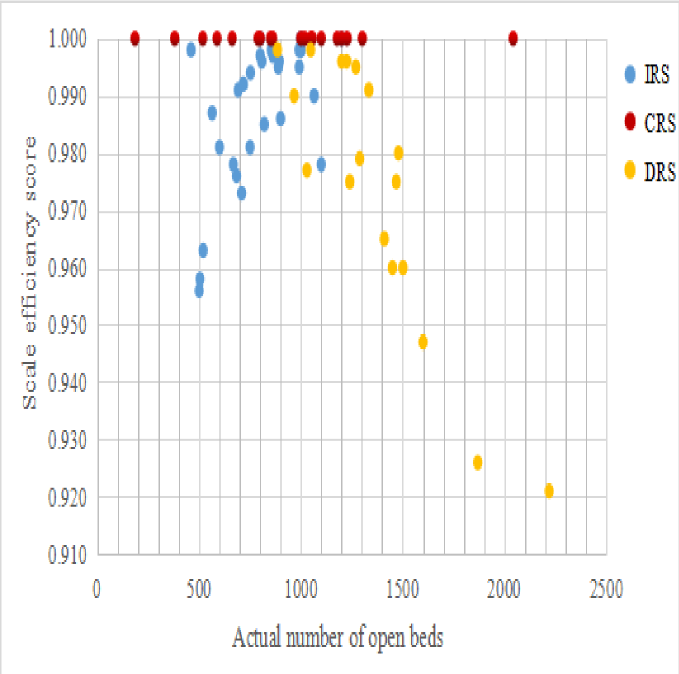

Figure 1 Scatter plot of the relationship between bed size and scale efficiency and returns to scale

Appendix 1.

The efficiency scores of all sample hospitals

DMU	Bed size	TE	PTE	SE	RTS
H1	185	1.000	1.000	1.000	-
H2	380	1.000	1.000	1.000	-
H3	460	0.964	0.996	0.998	irs
H4	500	0.896	0.937	0.956	irs
H5	504	0.878	0.917	0.958	irs
H6	518	1.000	1.000	1.000	-
H7	520	0.963	1.000	0.963	irs
H8	564	0.902	0.914	0.987	irs
H9	588	1.000	1.000	1.000	-
H10	600	0.864	0.881	0.981	irs
H11	662	1.000	1.000	1.000	-
H12	668	0.905	0.925	0.978	irs
H13	684	0.868	0.890	0.976	irs
H14	692	0.977	0.985	0.991	irs
H15	709	0.706	0.726	0.972	irs
H16	717	0.932	0.940	0.992	irs
H17	750	0.853	0.870	0.981	irs
H18	752	0.862	0.867	0.994	irs
H19	790	1.000	1.000	1.000	-
H20	800	0.954	0.957	0.997	irs
H21	800	1.000	1.000	1.000	-
H22	800	1.000	1.000	1.000	-
H23	808	0.907	0.910	0.996	irs
H24	820	0.829	0.841	0.985	irs
H25	850	1.000	1.000	1.000	-
H26	854	0.925	0.926	0.998	irs
H27	862	0.903	0.906	0.997	irs
H28	862	1.000	1.000	1.000	-
H29	885	0.887	0.889	0.998	drs
H30	889	0.900	0.905	0.995	irs
H31	894	0.935	0.939	0.996	irs
H32	900	0.919	0.932	0.986	irs
H33	967	0.934	0.944	0.990	drs
H34	991	0.951	0.953	0.998	irs
H35	992	0.866	0.871	0.995	irs
H36	1000	0.942	0.944	0.998	irs
H37	1000	0.886	0.886	1.000	-
H38	1000	0.975	0.978	0.998	irs
H39	1000	0.946	0.946	1.000	-

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H40	1000	1.000	1.000	1.000	-
H41	1018	1.000	1.000	1.000	-
H42	1030	0.875	0.896	0.977	drs
H43	1048	0.971	0.973	0.998	drs
H44	1050	1.000	1.000	1.000	-
H45	1055	0.884	0.884	1.000	-
H46	1065	0.889	0.898	0.990	irs
H47	1100	0.977	1.000	0.977	irs
H48	1100	1.000	1.000	1.000	-
H49	1178	1.000	1.000	1.000	-
H50	1200	1.000	1.000	1.000	-
H51	1200	0.911	0.915	0.996	drs
H52	1200	1.000	1.000	1.000	-
H53	1225	0.936	0.940	0.996	drs
H54	1227	1.000	1.000	1.000	-
H55	1240	0.975	1.000	0.975	drs
H56	1270	0.976	0.981	0.995	drs
H57	1289	0.898	0.918	0.979	drs
H58	1302	1.000	1.000	1.000	-
H59	1334	0.991	1.000	0.991	drs
H60	1410	0.927	0.960	0.965	drs
H61	1450	0.960	1.000	0.96	drs
H62	1469	0.921	0.944	0.975	drs
H63	1480	0.916	0.934	0.980	drs
H64	1502	0.877	0.914	0.960	drs
H65	1600	0.943	0.996	0.947	drs
H66	1869	0.910	0.983	0.926	drs
H67	2043	1.000	1.000	1.000	-
H68	2220	0.921	1.000	0.921	drs

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

	Item No.	Recommendation	Page No.
Title and abstract	1	(*a*) A Study on the Efficiency and Scale Effect of County Public Hospitals in Shandong Province, China	1
		(*b*) Data envelopment analysis (DEA) was used to calculate the efficiency scores of hospitals. Kruskal-Wallis H and Chi-square (χ2) test were employed to compare the efficiency and returns to scale (RTS) of hospitals with different bed sizes respectively. The study found that the difference of scale efficiency (SE, P=0.047, P<0.05) and returns to scale (RTS, P<0.001) were statistically significant. The findings indicated that hospitals with DRS began to appear at 885 beds. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.	1
Introduction			
Background/rationale	2	The unreasonable allocation and utilization of health resources and the blind explosion of hospital scale have seriously affected the production efficiency of health services. In 2016, with regard to the healthcare sector, the "Guiding Principles for the Planning of Medical Institutions (2016-2020)" were issued; these principles required hospitals to strictly control the bed size. Unfortunately, there has been no significant effect. In fact, in most hospitals, the number of beds is still on the rise. Novosadova et al10 compared the efficiency of large and small acute hospitals and gave scores in terms of technical and scale efficiency. It turned out that smaller hospitals tend to be more efficient than larger ones. Regardless of whether hospitals are in China or elsewhere, conducting studies on hospital efficiency and scale economies is crucial to address the question of the optimal productive size and to manage a fair allocation of resources. In 2015, the comprehensive reform of county public hospitals was fully rolled out in China. The status of hospital efficiency after the reform needs to be evaluated. The relationship between efficiency and bed size is also of great interest to managers. Based on efficiency theory and production theory, data envelopment analysis is used to analyze the efficiency of hospitals and the scale effect of efficiency from	2-3

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		the inputs and outputs.	
Objectives	3	To evaluate the efficiency of county public hospitals in Shandong Province after the new medical reform in China and to explore the scale effect.	3
Methods			
Study design	4	The study selected seven input and output variables that fit the characteristics of hospital efficiency. The main purpose of the study was to use DEA-CCR and DEA-BBC to evaluate the efficiency of county level public hospitals, and to compare the efficiency of hospitals with different bed size groups. Efficiency included technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). The Kruskal-Wallis H non-parametric test was used to compare the efficiency of hospitals with different bed size. Efficiency included technical efficiency, pure technical efficiency, and scale efficiency. The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed size.	4-6
Setting	5	The data set was collected from the health statistics information reporting system of the Hospital Management Research Institute of Qingdao University and was provided by 71 county public hospitals. The data collection time is from March to June 2018. It is mainly provided by the statisticians of each hospital to the Institute of Hospital Management of Qingdao University through electronic data sheets, and then all the data is consolidated by the Hospital Management Institute.	4
Participants	6	Participants came from 68 county public general hospitals. First, DEA premised on the selection of similar decision-making units; thus, the sample consists of county public general hospitals. Second, all no variables in the sample hospitals should include missing or abnormal values. Third, this study selected counties with one and only one general hospital. Therefore, combining the above requirements, the study finally identified 68 hospitals.	4
Variables	7	Variables included 4 inputs and 3 outputs.The study used the actual number of open beds, the number of doctors, the number of nurses, and the total expenditure as inputs, representing the investment in three aspects of human, financial and material resources. The total number of annual visits, the number of	4

		discharges, and the total income were used as outputs to represent the quantity, quality and benefits of medical services. Seven variables were applied to the DEA model to calculate efficiency. We also used the actual number of open beds to explore the impact of bed size on hospital efficiency.	
Data sources/ measurement	8*	The data related to the variables are reported personally by the participating hospitals and derived from the Shandong Province Statistical Yearbook of Health. Actual number of open beds measured by the number of beds actually opened at the end of the year. The number of doctors referred to the number of practising (assistant) physicians. The number of nurses referred to the number of qualified nurse practitioners. Total expenditure calculated by the expenses incurred by the hospital at the end of the year. Total number of annual visits measured by the number of visits counted by the number of registrations. Number of discharges measured by the number of all discharges patients after hospitalization.Total income calculated by the total income earned by the hospital at the end of the year.	4
Bias	9	Bias adjustments of efficiency scores were not carried out due to limitation of Coelli ' s basic DEA approach.	11
Study size	10	Sixty-eight county public general hospitals met the research objectives and inclusion criteria. The sample size is therefore determined.	4
Quantitative variables	11	The sample hospitals are divided into four groups: 500 beds and below, 501-1000 beds, 1001-1500 beds and 1501 beds and above. The difference of hospital efficiency in different bed size was compared by grouping.	6
Statistical methods	12	(a) Kruskal-Wallis H test was used to compare the efficiency of hospitals with different bed sizes.	6
		(b) The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed sizes.	6
		(c) Study removed samples with missing data or abnormal values.	4
Results			

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Participants	13*	(a) Participants included 71 county public general hospitals, but 68 hospitals that passed the audit and participated in the final analysis.	4
		(b) Two hospitals were removed for missing data. Another hospital was removed because the district it belonged to was merged.	4
Descriptive data	14*	(a) The participants were county public general hospitals in Shandong Province, which mainly provide medical services to residents in the county.	4
		(b) A sample hospital without the number of nurse. Another sample hospital without the number of beds. The district to which the third sample hospital belongs was merged. Therefore, the three hospitals was removed.	4
Outcome data	15*	The data indicate that the average number of open beds per hospital was 991.0 in 2017. The average number of doctors and nurses per hospital was 352.7 and 529.3 respectively. With an average of 527,816.1 visits per hospital per year, the efficiency of the hospitals was commendable.	6
		Only 20 (29.41%) hospitals which technical efficiency calculated to be 100% efficient, and 48 (70.59%) hospitals were inefficient.	7
		The difference of the technical efficiency (P=0.248, P>0.05) and the pure technical efficiency (P=0.073, P>0.05) were not statistically significant. The difference of scale efficiency (P=0.047, P<0.05) and returns to scale (P<0.001) were statistically significant.	7-8
Main results	16	(*a*) Most of county public hospitals in Shandong Province were inefficient and had problems of excessive inputs or insufficient outputs.	7
		(*b*) Bed size had an impact on hospital scale efficiency and returns to scale.	8
		(*c*) With more than 885 beds, hospitals were beginning to enter the decreasing returns to scale. When the bed size exceeded 1100, there were no longer hospitals with IRS. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.	8

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Other analyses	17	None	
Discussion			
Key results	18	The efficiency of county public hospitals needs to be improved. Bed size above a certain threshold will lead to decreasing returns to scale .	9
Limitations	19	First, the sample hospitals were selected from Shandong Province in eastern China, while hospitals located in central and western areas were excluded. Second, the data in this study cover only 2017, and cannot form panel data, leading to a lack of longitudinal analysis and comparison.	11
Interpretation	20	There is still room for improvement of hospital efficiency in China, which is consistent with numerous studies. For example, Zhaohui Cheng, et al suggested that only 8.8% of the 114 sample hospitals in Henan Province in China were defined as technically efficient. In addition, When the number of beds exceeds 885, the returns to scale of the hospital began to move into the DRS. However, Siping Dong stated that the vast majority of county hospitals in Hubei Province had more than 335 beds, which was generally in a state of DRS. This may be related to different factors such as the population base of different provinces and the release of medical service demand due to the expansion of China's medical insurance coverage. Internationally, several articles in business and economics journals focused on evaluating the benefits of hospital scale have shown that the IRS appears in hospitals with 300 and 600 beds. Banker RD observed that increasing returns to scale could be exploited up to a capacity of approximately 200 beds. Our study concluded that IRS should be controlled below 1100 beds. The scale effect of all sample hospitals with more than 1100 beds was already saturated, and some hospitals even had a negative scale effect. Research undertaken in the USA and the United Kingdom indicated that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds. Weaver M and Deolalikar A concluded that economies of scale depend on the type of hospital, as well as the number of beds and outputs in research on the scale economies of 654 Vietnamese public hospitals. China is a country with a large population, and its demand for medical services is higher than that of	9

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		other countries. The health sector has been implementing a hierarchical diagnosis and treatment model, and striving to make the county hospital visit rate 90% by 2020. The interval of beds for IRS in county public hospitals may be broader than that in other countries.	
Generalisability	21	Whether in China or elsewhere, conducting hospital efficiency and scale studies is urgent. Using data envelopment analysis to evaluate hospital efficiency, it enriches the research field of efficiency evaluation tool. This study confirmed that bed size is not the more the better. The finding can provide reference for other countries to improve hospital efficiency and control hospital bed size.	3 and 11
Other information			
Funding	22	None	

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

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

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Cross-sectional study of the efficiency and scale effect of county public hospitals in Shandong Province, China

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ABSTRACT

Objective: To evaluate the efficiency of county public hospitals in Shandong Province following China's new medical reform and compare the efficiency of hospitals with different bed size for improving efficiency.

Design and setting: This was a cross-sectional study on the efficiency and size of 68 county public hospitals in China in 2017.

Outcome measures: Data envelopment analysis (DEA) was used to calculate the efficiency scores of hospitals and to analyze the slack values of inefficient hospitals. The actual number of open beds, doctors, nurses and total expenditure were selected as inputs, and the total number of annual visits, discharges and total income were selected as outputs. The Kruskal-Wallis H test was employed to compare the efficiency of hospitals with different bed size. The Chi-square (χ^2) test was used to compare the returns to scale (RTS) of hospitals with different bed size.

Results: Twenty (29.41%) hospitals were efficient. There were 27 hospitals with increasing returns to scale (IRS), 23 hospitals with constant returns to scale (CRS), and 18 hospitals with decreasing returns to scale (DRS). The differences in technical efficiency (TE, P=0.248, P>0.05) and pure technical efficiency (PTE, P=0.073, P>0.05) were not statistically significant. However, the differences in scale efficiency (SE, P=0.047, P<0.05) and returns to scale (P<.001) were statistically significant. Hospitals with DRS began to appear at 885 beds.

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All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.

Conclusions: The government and hospital managers should strictly control the bed size in hospital and make hospitals resume operating in the interests of public welfare. Interventions that rationally allocate health resources and improve the efficiency of medical workers are conducive to solving redundant inputs and insufficient outputs.

Strengths and limitations of this study

The DEA accommodated multiple inputs and multiple outputs, which is in line with the characteristics of hospitals.

The DEA did not need to use a common denominator, ensuring the diversity of indicators.

This study identified the extent and source of hospital inefficiencies to help hospitals take remedial measures.

The results produced by the DEA were sensitive to measurement errors and may underestimate or overestimate the efficiency scores.

Due to the objective limitations of the data, the study included hospitals only in eastern China.

INTRODUCTION

The unreasonable allocation and utilization of resources have seriously affected the production efficiency of health services.[1] Pursuing efficiency is of vital importance to policy-makers and hospital managers.[2] Evaluating hospital efficiency can help hospital policy-makers improve inefficiencies with rational policies, and help managers to know whether medical resources are optimally allocated and fully utilized.

The focus of medical reform in China has been on hospital efficiency and quality. Prior studies held that the efficiency of hospitals needed to be further improved, and there were some problems such as the inefficient allocation of resources and the blind expansion of scale.[3 4] In 2016, the National Health Commission issued "Guidelines for Medical Institution Planning (2016-2020)", which required hospitals to strictly control the bed size. Unfortunately, there has been no significant effect. In fact, in most hospitals, the number of beds is still on the rise. The price of medical services in China is regulated by the government, and the zero-price gap policy for drugs and consumables has severely curtailed the sources of

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hospital revenue. Although it is a public hospital, government investment is insufficient to meet the needs of hospital development. The expansion of scale can attract more health resources and financial investment for hospitals, and it can also reduce the unit cost. Therefore, the benefits of hospital expansion in China are compelling. Of course, the reasons for expansion do not rule out the increase in medical demand.

Unexpectedly, the number of beds in the largest public hospital in China has reached 10000 beds. Is it the case that the more hospital beds there are, the better the hospital's efficiency? Most studies on scale efficiency have focused on analyzing the appropriate use of resources[5 6] and estimating the optimal size of hospitals.[7-9] Novosadova *et al*[10] compared the efficiency of large and small acute hospitals and gave scores in terms of technical and scale efficiency. It turned out that smaller hospitals tended to be more efficient than larger ones. Fidler *et al*[11] examined the size effect of reorganized hospitals in Austria and Estonia. Policy-makers believed that the combined large hospitals can reduce average costs and improve clinical outcomes. In contrast, employees argued that the merger neither generated economies of scale nor significantly improved quality. In short, regardless of whether hospitals are in China or elsewhere, conducting studies on hospital efficiency and scale economies is crucial to solve the optimal production size and to achieve the fair allocation of resources.[12]

General hospitals are pioneers in the reform of county public hospitals and are also the primary carrier for the government to provide basic medical services to residents living in counties. Shandong Province, located in eastern China, is one of the major coastal provinces. It is also a populous province. At the end of 2017, the total residential population reached more than 100 million. Shandong Province took the lead in starting a comprehensive reform of county public hospitals, which played an exemplary role for the country as a whole. Therefore, taking county public general hospitals in Shandong Province as a sample for evaluating the efficiency and exploring scale effect of county public hospitals is representative. We anticipate that this study will provide a reference for other regions in regard to efficiency evaluation and scale development.

METHODS

Sample and variable selection

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The data set was collected from the health statistics information reporting system of the Hospital Management Research Institute of Qingdao University and was provided by 71 county public hospitals from March to June 2018. First, DEA premised on the selection of similar decision making units (DMUs), so the sample was composed of the county public general hospitals. Second, all no variables in the sample hospitals should include missing or abnormal values. Third, this study selected counties with one and only one general hospital. Two hospitals were removed for missing data. Another hospital was removed because the district it belonged to was merged. As a result, 68 hospitals were eventually identified for research under the above requirements.

The study selected seven input and output variables that fit the characteristics of hospital efficiency. The actual number of open beds, the number of doctors, the number of nurses, and total expenditure were used as inputs, to represent material, human and financial resources. The total number of annual visits, the number of discharges, and total income were used as outputs to represent the quantity, quality and benefits of medical services. The variables were determined under the guidance of previous empirical studies.[13-17] The calculation process was implemented by means of DEAP 2.1 software. The specific indicators are explained in Table 1.

Table 1 Definition of the inputs and outputs

Category	Variable	Definition
Inputs	Actual number of open beds	The number of beds actually opened at the end of the year.
	Number of doctors	The number of practising (assistant) physicians.
	Number of nurses	The number of qualified nurse practitioners.
	Total expenditure	The expenses incurred by the hospital at the end of the year.
Outputs	Total number of annual visits	The number of visits, counted by the number of registrations.
	Number of discharges	The number of all discharged patients after hospitalization.
	Total income	The total income earned by the hospital at the end of the year.

Efficiency evaluation methods

Currently, the evaluation of hospital efficiency focuses on the use of economic models.[18 19] Stochastic frontier analysis (SFA) and the technique for order preference by similarity to an ideal solution (TOPSIS) are also commonly used in efficiency evaluation.[20 21] SFA is limited to evaluating the objects of multiple inputs and single output. Although absolute efficiency can be measured, the ability to distinguish allocation efficiency from technical efficiency is

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weak.[6] With the TOPSIS method, the weight of the indexes is subjective, which may affect the accuracy of the results.[21] International studies have shown that data envelopment analysis is an important tool in evaluating hospital efficiency.[22-24] DEA is a mature and advanced non-parametric method that compensates for the shortcomings of the above methods. It can solve problems with multiple inputs and multiple outputs. Not only can efficiency be evaluated and ranked, but the source of inefficient decision making units and the extent of improvement can also be further tracked.[13 19]

Data envelopment analysis

Data envelopment analysis is an evaluation method that was first proposed by the famous American operations researcher A.Charnes and scholar W.W.Cooper[22 25] in 1978, based on the concept and connotation of relative efficiency.[26] CCR and BCC are the most commonly used models.[2] In this paper, a two-stage DEA was used to conduct research using the CCR and BCC models of the output-oriented model. The output-oriented model involves how to increase or maximize output without changing the proportion of input.[17 22] Based on the assumption of constant returns to scale (CRS), Charnes extended and developed the CCR model, which is mainly used to measure the TE score of DMUs.[27] A score equal to 1 indicates that the DMU is efficient. A score of less than 1 indicates that the DMU is inefficient.

$$(D_{CCR})\begin{cases} \max \phi \\ \sum_{j=1}^{n} x_j \lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j \lambda_j \ge \phi y_0 \\ \lambda j \ge 0,\ j = 1,2,\cdots,n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0,\ y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0},\ y_0 = y_{j0}, 1 \le j_0 \le n$$

The scholars then developed the BCC model based on variable return to scale (VRS) to separate pure technical efficiency (PTE) from scale efficiency (SE).[28] The BCC model mainly measures the PTE and SE of the DMU.[29] The BCC model is an extension of the CCR model.

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$$(D_{BCC})\begin{cases} \min \phi \\ \sum_{j=1}^{n} x_j\lambda_j \le x_0 \\ \sum_{j=1}^{n} y_j\lambda_j \ge \phi y_0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \ge 0,\ j = 1,2,\cdots n \end{cases}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0, y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0,$$
$$x_0 = x_{j0}, y_0 = y_{j0}, 1 \le j_0 \le n$$

Statistical methods

This study defined the size of hospitals based on the actual number of open beds. The sample hospitals were divided into four groups: 500 beds and below, 501-1000 beds, 1001-1500 beds and 1501 beds and above. The Kruskal-Wallis H non-parametric test was used to compare the efficiency of hospitals with different bed size. Efficiency included technical efficiency, pure technical efficiency, and scale efficiency. The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed size. Statistical analysis was performed using SPSS 25.0.

RESULTS

Description of the inputs and outputs

Table 2 is a descriptive summary of the inputs and outputs of the 68 sample hospitals. The data indicated that the average number of open beds per hospital was 991.0 in 2017. The average number of doctors and nurses per hospital was 352.7 and 529.3 respectively. With an average of 527,816.1 visits per hospital per year, the efficiency of the hospitals is commendable.

Table 2 Descriptive statistics of inputs and outputs

Indicators	Minimum	Maximum	Average	SD
Inputs				
Actual number of open beds	185.0	2220.0	991.0	373.6
Number of doctors	101.0	670.0	352.7	126.3
Number of nurses	149.0	971.0	529.3	191.5
Total expenditure (ten thousand)	8184.0	90030.0	41587.8	17910.3
Outputs				
Total number of annual visits	87116.0	1511751.0	527816.1	257916.2
Number of discharges	8689.0	99565.0	43127.6	17099.7

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Total income (ten thousand)	8133.3	91991.0	42958.6	18356.4

Hospital efficiency scores from the DEA

Table 3 showes the distribution of the efficiency scores for the sample hospitals. Only 20 (29.41%) hospitals were 100% efficient in technical efficiency, and 48 (70.59%) hospitals were inefficient. The pure technical efficiency of 26 (38.24%) hospitals was efficient, while the remaining 42 (61.76%) were inefficient. All hospitals had scale efficiency scores above 0.900, but only 23 (33.82%) were fully efficient. The efficiency score of all sample hospitals are shown in Appendix 1.

Table 3 Distribution of the efficiency scores for the sample hospitals

Efficiency \ Scoring range	1.000	0.999-0.900	0.899-0.800	0.799-0.700
Technical efficiency	20 (29.41%)	32 (47.06%)	15 (22.06%)	1 (1.47%)
Pure technical efficiency	26 (38.24%)	30 (44.12%)	11 (16.18%)	1 (1.47%)
Scale efficiency	23 (33.82%)	45 (66.18%)	0 (0.00%)	0 (0.00%)

Slack value of the inputs and outputs of inefficient hospitals

This study analyzed the slack values of 48 inefficient hospitals. In other words, the differences between the actual value and the ideal value of the variables were calculated. Taking hospital H16 as an example, the actual number of doctors was 38.8 more than the ideal number. As shown in Table 4, hospital H16 needs to increase the total number of visits by 15%, the number of discharges by 6% and total income by 6% to make full use of its current resources.

Table 4 The slack value of the inputs and outputs of hospital H16

DMU	Related indicators	Inputs				Outputs		
		Beds	Doctors	Nurses	Expenditure	Visits	Discharges	Income
H16	Actual value	717.0	300.0	344.0	27508.0	418402.0	35536.0	28743.0
	Ideal value	717.0	261.2	344.0	27508.0	479793.2	37800.8	30574.8
	Slack value	0.00	38.8	0.00	0.00	-61391.2	-2264.8	-1831.8
	Change ratio	0%	13%	0%	0%	-15%	-6%	-6%

Differences in TE，PTE and SE among hospitals with different bed size

There were no significant differences in TE (P=0.248, P>0.05) and PTE (P=0.073, P>0.05) among the four comparison groups. However, the difference in SE was statistically significant (P=0.047, P<0.05). See Table 5 for details.

Table 5 Statistical analysis results of the efficiency of hospitals with different bed size

Efficiency	Bed size	$\bar{X}$±S	χ^2 value	P value
Technical	≤500 beds	0.965±0.049	4.131	0.248

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efficiency	501-1000 beds	0.927±0.064		
	1001-1500 beds	0.957±0.045		
	≥1501 beds	0.930±0.046		
Pure technical efficiency	≤500 beds	0.983±0.031	6.954	0.073
	501-1000 beds	0.934±0.060		
	1001-1500 beds	0.967±0.041		
	≥1501 beds	0.979±0.037		
Scale efficiency	≤500 beds	0.989±0.022	10.321	0.047
	501-1000 beds	0.992±0.011		
	1001-1500 beds	0.989±0.013		
	≥1501 beds	0.951±0.032		

Differences in returns to scale among hospitals with different bed size

The findings in Table 6 suggested that the difference in the returns to scale of hospitals with different bed size was significant (*P*<.001). Twenty-three hospitals with the scale efficiency score equal to 1 were constant returns to scale. This means that these hospitals not only have the optimal bed size, but also have the lowest operation costs, additionally, their inputs and outputs were in balance. The inefficient hospitals were divided into two categories: increasing returns to scale and decreasing returns to scale. The 27 hospitals with IRS had insufficient inputs and needed to expand their scale to achieve better efficiency. The 18 hospitals with DRS had redundant inputs and needed to scale down and optimize their allocation of resources.

Table 6 Statistical analysis results of the returns to scale of hospitals with different bed sizes

Bed size \ Returns to scale	IRS	CRS	DRS	Total	χ^2 value	*P* value
≤500 beds	2 (50%)	2 (50%)	0 (0%)	4 (100%)	32.023	<.001
501-1000 beds	23 (63.89%)	11 (30.56%)	2 (5.56%)	36 (100%)		
1001-1500 beds	2 (8.70%)	9 (39.13%)	12 (52.17%)	23 (100%)		
≥1501 beds	0 (0%)	1 (20%)	4 (80%)	5 (100%)		
Total	27	23	18	68		

A scatter plot was produced to highlight the relationship between bed size, scale efficiency and returns to scale. As depicted in Figure 1, with the increase in the number of hospital beds, the scale efficiency of hospitals approximately first increased and then decreased. It was obvious that only one hospital was efficient in the ≥1501 beds group, and the remaining four hospitals were not only inefficient, but also had a low scale efficiency score.

In addition, hospitals with DRS began to appear at 885 beds. A large number of hospitals in the 1001-1500 beds and ≥1501 beds groups were already in DRS. Of the 11 hospitals with

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more than 1300 beds, 9 (81.8%) were DRS. When the bed size exceeded 1100 beds, there were no longer hospitals with IRS. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.

Figure 1 Scatter plot of the relationship between bed size and scale efficiency and returns to scale

DISCUSSION

An increasing number of countries have been using DEA to evaluate hospital efficiency.[2 14 18 30] The findings indicated that 48 sample hospitals were inefficient. That was, more than 70% of hospitals had problems of excessive inputs or insufficient outputs, which was consistent with the results of many experts.[1 31 32] Cheng *et al*[31] suggested that only 8.8% of the 114 county hospitals in Henan Province, China, were defined as technically efficient, and proposed that the efficiency needed to be improved. Our study found that the outputs of inefficient hospitals had higher slack values, largely because of underutilized resources. In the research on the equity and efficiency of health resource allocation in mainland China, Zhang *et al*[33] pointed out that many provinces in China had problems of idle and underutilized health resources. This may be due to the inefficient use of resources by medical staff. It may also be because county hospitals are limited by their own service capabilities, resulting in a loss of patients, which makes resources idle and difficult to use efficiently in turn.

The blind expansion of bed size is a common problem in Chinese hospitals.[34] In theory, due to economies of scale, more beds should result in higher efficiency score. However, the results did not prove that the scale difference in hospital technical efficiency was significant. This may be because the effect of bed size on technical efficiency is not obvious or the difference depends on the combined effect of size and other factors. As a public welfare undertaking led by the government, the development of hospitals cannot be separated from the support of the government. In recent years, the government has reduced the supply of resources to hospitals with DRS by imposing reasonable controls on hospital construction and the purchase of large equipments.[35] Asmild *et al*[36] used DEA to study the optimal size of hospitals, especially the relationship between efficiency and size, and indicated that different hospitals had different efficiencies that depended on location, the population served, and the policies which provincial governments wish to implement.

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The difference in PTE was not significant. It can be speculated that the siphon effect of scale on medical technology and equipment had been alleviated. In the future, regardless of the size of the hospital, medical technology and equipment will gradually achieve fairness and homogeneity. This will be a good vision for future hospital development. The hospitals scored higher on PTE, with an average score of 0.951. Shandong Province and other areas of China have given strong support and attention to the investment and renewal of medical equipment, the strengthening of hospital information systerms,[37] and the connection of internet hospitals. Excluding the impact of scale factors, hospitals have produced better improvements in efficiency through pure technology.

This study found that the bed size will affect the SE and RTS of hospitals. Below a critical range, an increase in the number of beds can lead to an increase in efficiency, but beyond the threshold, the increase will result in a decrease in efficiency. The findings indicated that hospitals with DRS began to appear at 885 beds. A large number of hospitals in the 1001-1500 beds and ≥1501 beds groups were already in DRS. However, Dong[38] stated that the vast majority of county hospitals in Hubei Province had more than 335 beds, and were generally in a state of DRS. The results of Dong's study and our study were quite different. Over time, the difference may be related to different factors such as the population base of different provinces and the release of medical service demand due to the expansion of China's medical insurance coverage.

Internationally, several articles focused on evaluating the benefits of hospital scale in business and economics journals showed that the IRS appeared in hospitals with 300 and 600 beds. [39 40] Banker *et al*[41] observed that the increasing returns to scale could be exploited up to a capacity of approximately 200 beds. Our study concluded that IRS should be controlled below 1100 beds. The scale effect of all sample hospitals with more than 1100 beds was already saturated, and some hospitals even had a negative scale effect. Research undertaken in the USA and the United Kingdom indicated that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds.[12 42] Weaver *et al*[9] in a research which is about the scale economies of 654 Vietnamese public hospitals, concluded that economies of scale depend on the type of hospital, as well as the number of beds and outputs. Specifically, when the average number of beds was 516, the Vietnamese Central General

Hospitals were in CRS. China is a country with a large population, and its demand for medical services is higher than that of other countries. The health sector has been implementing a hierarchical diagnosis and treatment model, and striving to make the county hospital visit rate 90% by 2020. The interval of beds for IRS in county public hospitals may be broader than that in other countries.

Limitations

This study evaluated the efficiency of county public hospitals in Shandong Province following the new medical reform, and explored the influence of scale on hospital efficiency. It provided a reference for the government and hospitals to reasonably control bed size, and it offered a warning to hospitals with regard to blindly expanding. However, the study has several limitations. First, the sample hospitals were selected from Shandong Province in eastern China, while hospitals located in central and western areas were excluded. Second, the data in this study covered only 2017, and cannot form panel data, leading to a lack of longitudinal analysis and comparison. Bias adjustments of efficiency scores were not carried out due to limitation of the DEA approach. We will continue to track the efficiency of county public hospitals in Shandong Province in the next study.

CONCLUSIONS

This study evaluated and compared the efficiency of 68 county public hospitals in Shandong Province using DEA. These hospitals had higher efficiency scores, but most hospitals had problems of an unreasonable allocation and inadequate utilization of health resources. Hospitals should mobilize the enthusiasm of medical staff and continuously improve human efficiency. The synergy between human efficiency and pure technical efficiency will lead to higher efficiency in hospitals.

This study further demonstrated that the blind expansion of bed size did not lead to greater hospital efficiency. County public hospitals should avoid blindly expanding their scale and should take various effective measures to improve their efficiency. County public hospitals, as the main providers of services to county residents, should accurately locate the service contents based on the functions of hospitals, the types of residents' medical needs and the structure of the population they serve. We hope that this study will provide a reference for

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other regions to evaluate efficiency and control scale.

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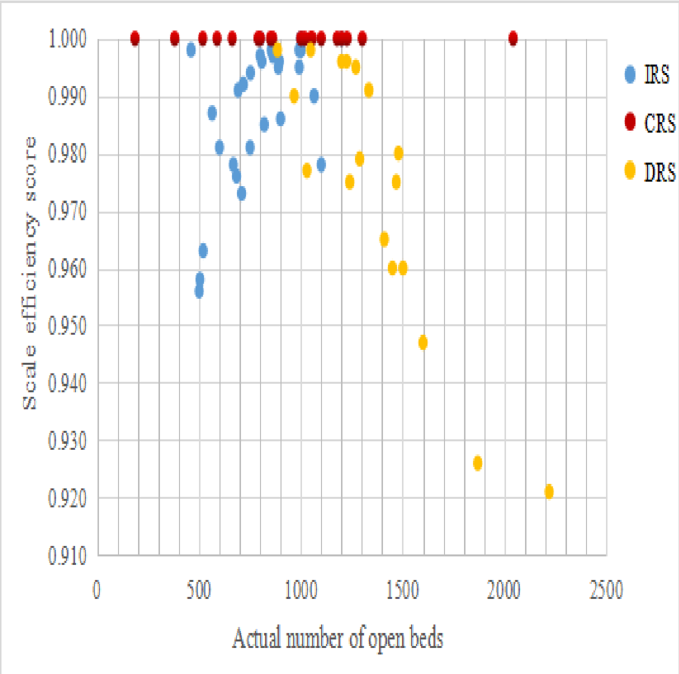

Figure 1 Scatter plot of the relationship between bed size and scale efficiency and returns to scale

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Appendix 1.

The efficiency scores of all sample hospitals

DMU	Bed size	TE	PTE	SE	RTS
H1	185	1.000	1.000	1.000	-
H2	380	1.000	1.000	1.000	-
H3	460	0.964	0.996	0.998	irs
H4	500	0.896	0.937	0.956	irs
H5	504	0.878	0.917	0.958	irs
H6	518	1.000	1.000	1.000	-
H7	520	0.963	1.000	0.963	irs
H8	564	0.902	0.914	0.987	irs
H9	588	1.000	1.000	1.000	-
H10	600	0.864	0.881	0.981	irs
H11	662	1.000	1.000	1.000	-
H12	668	0.905	0.925	0.978	irs
H13	684	0.868	0.890	0.976	irs
H14	692	0.977	0.985	0.991	irs
H15	709	0.706	0.726	0.972	irs
H16	717	0.932	0.940	0.992	irs
H17	750	0.853	0.870	0.981	irs
H18	752	0.862	0.867	0.994	irs
H19	790	1.000	1.000	1.000	-
H20	800	0.954	0.957	0.997	irs
H21	800	1.000	1.000	1.000	-
H22	800	1.000	1.000	1.000	-
H23	808	0.907	0.910	0.996	irs
H24	820	0.829	0.841	0.985	irs
H25	850	1.000	1.000	1.000	-
H26	854	0.925	0.926	0.998	irs
H27	862	0.903	0.906	0.997	irs
H28	862	1.000	1.000	1.000	-
H29	885	0.887	0.889	0.998	drs
H30	889	0.900	0.905	0.995	irs
H31	894	0.935	0.939	0.996	irs
H32	900	0.919	0.932	0.986	irs
H33	967	0.934	0.944	0.990	drs
H34	991	0.951	0.953	0.998	irs
H35	992	0.866	0.871	0.995	irs
H36	1000	0.942	0.944	0.998	irs
H37	1000	0.886	0.886	1.000	-
H38	1000	0.975	0.978	0.998	irs
H39	1000	0.946	0.946	1.000	-

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H40	1000	1.000	1.000	1.000	-
H41	1018	1.000	1.000	1.000	-
H42	1030	0.875	0.896	0.977	drs
H43	1048	0.971	0.973	0.998	drs
H44	1050	1.000	1.000	1.000	-
H45	1055	0.884	0.884	1.000	-
H46	1065	0.889	0.898	0.990	irs
H47	1100	0.977	1.000	0.977	irs
H48	1100	1.000	1.000	1.000	-
H49	1178	1.000	1.000	1.000	-
H50	1200	1.000	1.000	1.000	-
H51	1200	0.911	0.915	0.996	drs
H52	1200	1.000	1.000	1.000	-
H53	1225	0.936	0.940	0.996	drs
H54	1227	1.000	1.000	1.000	-
H55	1240	0.975	1.000	0.975	drs
H56	1270	0.976	0.981	0.995	drs
H57	1289	0.898	0.918	0.979	drs
H58	1302	1.000	1.000	1.000	-
H59	1334	0.991	1.000	0.991	drs
H60	1410	0.927	0.960	0.965	drs
H61	1450	0.960	1.000	0.96	drs
H62	1469	0.921	0.944	0.975	drs
H63	1480	0.916	0.934	0.980	drs
H64	1502	0.877	0.914	0.960	drs
H65	1600	0.943	0.996	0.947	drs
H66	1869	0.910	0.983	0.926	drs
H67	2043	1.000	1.000	1.000	-
H68	2220	0.921	1.000	0.921	drs

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

	Item No.	Recommendation	Page No.
Title and abstract	1	(*a*) A Study on the Efficiency and Scale Effect of County Public Hospitals in Shandong Province, China	1
		(*b*) Data envelopment analysis (DEA) was used to calculate the efficiency scores of hospitals. Kruskal-Wallis H and Chi-square (χ2) test were employed to compare the efficiency and returns to scale (RTS) of hospitals with different bed sizes respectively. The study found that the difference of scale efficiency (SE, P=0.047, P<0.05) and returns to scale (RTS, P<0.001) were statistically significant. The findings indicated that hospitals with DRS began to appear at 885 beds. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.	1
Introduction			
Background/rationale	2	The unreasonable allocation and utilization of health resources and the blind explosion of hospital scale have seriously affected the production efficiency of health services. In 2016, with regard to the healthcare sector, the "Guiding Principles for the Planning of Medical Institutions (2016-2020)" were issued; these principles required hospitals to strictly control the bed size. Unfortunately, there has been no significant effect. In fact, in most hospitals, the number of beds is still on the rise. Novosadova et al10 compared the efficiency of large and small acute hospitals and gave scores in terms of technical and scale efficiency. It turned out that smaller hospitals tend to be more efficient than larger ones. Regardless of whether hospitals are in China or elsewhere, conducting studies on hospital efficiency and scale economies is crucial to address the question of the optimal productive size and to manage a fair allocation of resources. In 2015, the comprehensive reform of county public hospitals was fully rolled out in China. The status of hospital efficiency after the reform needs to be evaluated. The relationship between efficiency and bed size is also of great interest to managers. Based on efficiency theory and production theory, data envelopment analysis is used to analyze the efficiency of hospitals and the scale effect of efficiency from	2-3

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		the inputs and outputs.	
Objectives	3	To evaluate the efficiency of county public hospitals in Shandong Province after the new medical reform in China and to explore the scale effect.	3
Methods			
Study design	4	The study selected seven input and output variables that fit the characteristics of hospital efficiency. The main purpose of the study was to use DEA-CCR and DEA-BBC to evaluate the efficiency of county level public hospitals, and to compare the efficiency of hospitals with different bed size groups. Efficiency included technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). The Kruskal-Wallis H non-parametric test was used to compare the efficiency of hospitals with different bed size. Efficiency included technical efficiency, pure technical efficiency, and scale efficiency. The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed size.	4-6
Setting	5	The data set was collected from the health statistics information reporting system of the Hospital Management Research Institute of Qingdao University and was provided by 71 county public hospitals. The data collection time is from March to June 2018. It is mainly provided by the statisticians of each hospital to the Institute of Hospital Management of Qingdao University through electronic data sheets, and then all the data is consolidated by the Hospital Management Institute.	4
Participants	6	Participants came from 68 county public general hospitals. First, DEA premised on the selection of similar decision-making units; thus, the sample consists of county public general hospitals. Second, all no variables in the sample hospitals should include missing or abnormal values. Third, this study selected counties with one and only one general hospital. Therefore, combining the above requirements, the study finally identified 68 hospitals.	4
Variables	7	Variables included 4 inputs and 3 outputs.The study used the actual number of open beds, the number of doctors, the number of nurses, and the total expenditure as inputs, representing the investment in three aspects of human, financial and material resources. The total number of annual visits, the number of	4

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		discharges, and the total income were used as outputs to represent the quantity, quality and benefits of medical services. Seven variables were applied to the DEA model to calculate efficiency. We also used the actual number of open beds to explore the impact of bed size on hospital efficiency.	
Data sources/ measurement	8*	The data related to the variables are reported personally by the participating hospitals and derived from the Shandong Province Statistical Yearbook of Health. Actual number of open beds measured by the number of beds actually opened at the end of the year. The number of doctors referred to the number of practising (assistant) physicians. The number of nurses referred to the number of qualified nurse practitioners. Total expenditure calculated by the expenses incurred by the hospital at the end of the year. Total number of annual visits measured by the number of visits counted by the number of registrations. Number of discharges measured by the number of all discharges patients after hospitalization.Total income calculated by the total income earned by the hospital at the end of the year.	4
Bias	9	Bias adjustments of efficiency scores were not carried out due to limitation of Coelli ' s basic DEA approach.	11
Study size	10	Sixty-eight county public general hospitals met the research objectives and inclusion criteria. The sample size is therefore determined.	4
Quantitative variables	11	The sample hospitals are divided into four groups: 500 beds and below, 501-1000 beds, 1001-1500 beds and 1501 beds and above. The difference of hospital efficiency in different bed size was compared by grouping.	6
Statistical methods	12	(a) Kruskal-Wallis H test was used to compare the efficiency of hospitals with different bed sizes.	6
		(b) The Chi-square (χ^2) test was used to compare the differences in the returns to scale of hospitals with different bed sizes.	6
		(c) Study removed samples with missing data or abnormal values.	4
Results			

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Participants	13*	(a) Participants included 71 county public general hospitals, but 68 hospitals that passed the audit and participated in the final analysis.	4
		(b) Two hospitals were removed for missing data. Another hospital was removed because the district it belonged to was merged.	4
Descriptive data	14*	(a) The participants were county public general hospitals in Shandong Province, which mainly provide medical services to residents in the county.	4
		(b) A sample hospital without the number of nurse. Another sample hospital without the number of beds. The district to which the third sample hospital belongs was merged. Therefore, the three hospitals was removed.	4
Outcome data	15*	The data indicate that the average number of open beds per hospital was 991.0 in 2017. The average number of doctors and nurses per hospital was 352.7 and 529.3 respectively. With an average of 527,816.1 visits per hospital per year, the efficiency of the hospitals was commendable.	6
		Only 20 (29.41%) hospitals which technical efficiency calculated to be 100% efficient, and 48 (70.59%) hospitals were inefficient.	7
		The difference of the technical efficiency (P=0.248, P>0.05) and the pure technical efficiency (P=0.073, P>0.05) were not statistically significant. The difference of scale efficiency (P=0.047, P<0.05) and returns to scale (P<0.001) were statistically significant.	7-8
Main results	16	(*a*) Most of county public hospitals in Shandong Province were inefficient and had problems of excessive inputs or insufficient outputs.	7
		(*b*) Bed size had an impact on hospital scale efficiency and returns to scale.	8
		(*c*) With more than 885 beds, hospitals were beginning to enter the decreasing returns to scale. When the bed size exceeded 1100, there were no longer hospitals with IRS. All sample hospitals with more than 1100 beds were already saturated, and some hospitals even had a negative scale effect.	8

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Other analyses	17	None	
Discussion			
Key results	18	The efficiency of county public hospitals needs to be improved. Bed size above a certain threshold will lead to decreasing returns to scale .	9
Limitations	19	First, the sample hospitals were selected from Shandong Province in eastern China, while hospitals located in central and western areas were excluded. Second, the data in this study cover only 2017, and cannot form panel data, leading to a lack of longitudinal analysis and comparison.	11
Interpretation	20	There is still room for improvement of hospital efficiency in China, which is consistent with numerous studies. For example, Zhaohui Cheng, et al suggested that only 8.8% of the 114 sample hospitals in Henan Province in China were defined as technically efficient. In addition, When the number of beds exceeds 885, the returns to scale of the hospital began to move into the DRS. However, Siping Dong stated that the vast majority of county hospitals in Hubei Province had more than 335 beds, which was generally in a state of DRS. This may be related to different factors such as the population base of different provinces and the release of medical service demand due to the expansion of China's medical insurance coverage. Internationally, several articles in business and economics journals focused on evaluating the benefits of hospital scale have shown that the IRS appears in hospitals with 300 and 600 beds. Banker RD observed that increasing returns to scale could be exploited up to a capacity of approximately 200 beds. Our study concluded that IRS should be controlled below 1100 beds. The scale effect of all sample hospitals with more than 1100 beds was already saturated, and some hospitals even had a negative scale effect. Research undertaken in the USA and the United Kingdom indicated that diseconomies of scale can be expected to occur below approximately 200 beds and above 600 beds. Weaver M and Deolalikar A concluded that economies of scale depend on the type of hospital, as well as the number of beds and outputs in research on the scale economies of 654 Vietnamese public hospitals. China is a country with a large population, and its demand for medical services is higher than that of	9

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		other countries. The health sector has been implementing a hierarchical diagnosis and treatment model, and striving to make the county hospital visit rate 90% by 2020. The interval of beds for IRS in county public hospitals may be broader than that in other countries.	
Generalisability	21	Whether in China or elsewhere, conducting hospital efficiency and scale studies is urgent. Using data envelopment analysis to evaluate hospital efficiency, it enriches the research field of efficiency evaluation tool. This study confirmed that bed size is not the more the better. The finding can provide reference for other countries to improve hospital efficiency and control hospital bed size.	3 and 11
Other information			
Funding	22	None	

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

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

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