ОРИГИНАЛЬНЫЕ СТАТЬИ / ORIGINAL ARTICLES

УДК 614.2
doi: https://dx.doi.org/10.22328/2413-5747-2025-11-4-20-27

RESEARCH ON THE TECHNICAL EFFICIENCY OF MEDICAL RESOURCES IN HOSPITALS OF PUBLIC HEALTH EMERGENCIES

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INTRODUCTION. The increasing demand for medical and health services from the public has brought enormous pressure to the health system, and the public health emergency will lead to an intensification of the supply-demand contradiction of medical services.

OBJECTIVE. This study aimed to evaluate and explore the factors that might affect the efficiency of medical resource allocation of hospitals in Shanghai, providing reference for the medical resource management of hospitals in the public health emergency.

MATERIALS AND METHODS. Data were obtained from the hospitals in a certain area of Shanghai from April to May, 2022. Data envelopment analysis was used to evaluate technical efficiency, pure technical efficiency, and scale efficiency. Tobit regression was applied to determine the independent factors affecting hospital efficiency.

RESULTS. A total of 214 decision-making units were included in this study. The median values of technical efficiency, pure technical efficiency, and scale efficiency of hospitals were 0.579 (interquartile range [IQR], 0.347-0.767), 0.644 (IQR, 0.487-0.883), and 0.938 (IQR, 0.905-0.953), respectively. Tobit regression analysis indicated that the higher bed-to-nurse ratio and bed capacity (at least 2000) had a negative impact on technical efficiency.

DISCUSSION. Hospitals with higher bed-to-nurse ratios tended to exhibit lower efficiency, suggesting that excessive nursing workload may hinder effective service delivery during public health emergencies. Larger bed capacity, particularly in hospitals exceeding 2000 beds, was also associated with poorer efficiency, indicating that overly large scales may limit operational responsiveness.

CONCLUSIONS. Low technical efficiency is primarily attributable to poor pure technical efficiency, which can be improved through better management and organizational practices. In addition, optimizing bed allocation and maintaining an appropriate nurse-to-bed ratio can enhance allocative efficiency in hospitals. Decision-makers should consider these findings while allocating medical resources. Meanwhile, our study can also provide reference for optimizing the allocation of medical resources in the public health emergency.

KEYWORDS: marine medicine, maritime medicine, public health emergency, Allocation efficiency, Data Envelopment Analysis, Tobit regression

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For citation: Lulu Zhang. Research on the technical efficiency of medical resources in hospitals of public health emergencies // *Marine Medicine*. 2025. Vol. 11, № 4. P. 20–27, doi: https://dx.doi.org/10.22328/2413-5747-2025-11-4-20-27; EDN: https://elibrary.ru/TXXKVS

Для цитирования: Чжан Лулу. Исследование технической эффективности распределения медицинских ресурсов в больницах в условиях чрезвычайной ситуации в области общественного здравоохранения // *Морская медицина.* 2025. Т. 11, № 4. С. 20–27, doi: https://dx.doi.org/10.22328/2413-5747-2025-11-4-20-27; EDN: https://elibrary.ru/TXXKVS

ИССЛЕДОВАНИЕ ТЕХНИЧЕСКОЙ ЭФФЕКТИВНОСТИ РАСПРЕДЕЛЕНИЯ МЕДИЦИНСКИХ РЕСУРСОВ В БОЛЬНИЦАХ В УСЛОВИЯХ ЧРЕЗВЫЧАЙНОЙ СИТУАЦИИ В ОБЛАСТИ ОБЩЕСТВЕННОГО ЗДРАВООХРАНЕНИЯ

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ВВЕДЕНИЕ Растущий спрос населения на медицинские услуги повышает нагрузку на систему здравоохранения, особенно при возникновении чрезвычайной ситуации.

ЦЕЛЬ. Изучить и оценить факторы, влияющие на эффективность распределения медицинских ресурсов в больницах Шанхая, с целью разработки рекомендаций по управлению медицинскими ресурсами в условиях чрезвычайных ситуаций.

МАТЕРИАЛЫ И МЕТОДЫ. Получены данные из больниц одного из районов Шанхая в период с апреля по май 2022 года. Для оценки технической эффективности, чистой технической эффективности и масштабной эффективности использовался анализ оболочки данных (DEA). Для определения независимых факторов, влияющих на эффективность работы больниц, был применен регрессионный анализ Тобита.

РЕЗУЛЬТАТЫ. В исследование включено 214 единиц принятия решений (DMU). Медианные значения технической эффективности, чистой технической эффективности и масштабной эффективности больниц составили 0,579 (интерквартильный размах [IQR], 0,347–0,767), 0,644 (IQR, 0,487–0,883) и 0,938 (IQR, 0,905–0,953) соответственно. Регрессионный анализ Тобита показал, что более высокое соотношение коек к медицинскому персоналу и количество коек (⩾2000) отрицательно влияют на техническую эффективность.

ОБСУЖДЕНИЕ. Высокое соотношение числа коек к медицинскому персоналу связано с повышенной нагрузкой на медсестер, что снижает операционную эффективность больниц в условиях чрезвычайных ситуаций в области общественного здравоохранения. Размер больницы, особенно если количество коек превышает 2000, также приводит к снижению эффективности, что объясняется ограничением гибкости управленческих возможностей больницы.

ЗАКЛЮЧЕНИЕ. Низкий уровень технической эффективности в основном является результатом неудовлетворительных показателей чистой технической эффективности, что можно улучшить за счет оптимизации управления и организации. Эффективность распределения ресурсов в больницах может быть повышена путем оптимизации количества коек и соответствующего соотношения коек к медицинскому персоналу. Результаты исследования следует учитывать лицам, принимающим решения, при распределении медицинских ресурсов. Кроме того, данное исследование может служить ориентиром для оптимизации распределения медицинских ресурсов в условиях чрезвычайных ситуаций в области общественного здравоохранения.

КЛЮЧЕВЫЕ СЛОВА: морская медицина, чрезвычайная ситуация в области общественного здравоохранения, эффективность распределения, анализ оболочки данных, регрессия Тобита

Introduction. Since the reform and opening up, China's economic development has achieved universally recognized achievements, and the enormous economic achievements have significantly increased the total amount of China's health resources. However, there is also a contradiction between the growing health demand of the people and the insufficient supply of health resources, which would be intensified by the public health emergency. Reasonably allocating limited medical and health resources has become a huge challenge for hospital management, which has made determining the reasonable allocation of medical resource an important issue and highlights the necessity to evaluate the performance and efficiency hospital resource utilization.

Data Envelopment Analysis (DEA), a non-parametric linear programming method, has been widely used to assess hospital efficiency according to input and output indicators [1, 2]. With this method, the efficient production frontier is calculated by constructing a linear programming model based on the actual inputs and outputs of decision-making units (DMU). Only DMU located on the frontier are considered to be effective. With the method of DEA, we conducted this study to evaluate the efficiency of hospitals in the public health emergency and to explore its influencing factors, providing reference for emergency management of medical resource.

Materials and methods

Data sources

The data was obtained from hospitals one district in a certain area of Shanghai from April 2022 to May 2022. Data included the number of medical workers, bed capacity, number of hospitalized patients, type of hospital, doctor-to-nurse ratio, and bed-to-nurse ratio. Personal identification information was not collected, conforming to the principles of the Declaration of Helsinki revised in 2013 [3].

Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric mathematical method widely used in various fields to calculate efficiency [4]. The most classic DEA models are the CCR model, a constant returns to scale (CRS) model proposed by Charnes in 1978 [4], and the BCC model, a variable returns to scale (VRS) model proposed by Banker in 1984 [5]. The BCC model was selected to evaluate the technical efficiency (TE) of the hospital. TE can be decomposed into pure technical efficiency (PTE) and scale efficiency (SE) as follows: TE = PTE × SE. PTE represents the level of management and organization, and SE indicates the ability to choose an optimal scale size [6, 7]. The efficiency value ranges from 0 to 1, with higher scores indicating greater efficiency. An input-oriented DEA model was adopted in the analysis. In this study, one day at each hospital was regarded as a unit of analysis. For example, X hospital provided medical service for ten days, meaning that ten DMUs were involved in the analysis. In this study, there were 214 DMUs, representing the operation of the selected hospitals.

Selection of study variables

Two input variables and one output variable were selected based on data availability, and previous studies have focused on hospital efficiency [2, 8, 9]. As input variables, the number of medical workers and open beds was chosen for efficiency evaluation. In terms of the output variables, the number of hospitalized patients was selected to measure the production of health services provided by the hospitals (Table 1).

Several factors that might affect the efficiency score, such as the stage, the type of hospital, number of open beds, doctor-to-nurse ratio, and bed-to-nurse ratio, were assessed by Tobit regression analysis (Table 1).

Data analysis

Continuous variables not normally distributed are presented as median (IQR), and categorical variables as frequency (%). DEA was used to calculate the TE, PTE, and SE. The non-parametric Kruskal-Wallis test was used to explore the group differences because of the skewed distribution of the efficiency scores. As efficiency scores were censored variables ranging from 0 to 1, Tobit regression was applied to determine the independent factors affecting the TE, PTE, and SE of hospitals [10, 11]. The results of the Tobit regression were reported as estimates and 95% confidence interval (CI). The following variables were assessed by Tobit regression: the stage, hospital type (non-tertiary or tertiary hospital), bed capacity (< 2000 or ⩾ 2000), doctor-to-nurse ratio, and bed-to-nurse ratio. Z-score method was applied to normalize the doctor-to-nurse and bed-to-nurse ratios to improve data comparability [12].

Table 1

Definitions of variables included in the analysis

Таблица 1

Определения переменных, включенных в анализ

Variables	Explanation
Input variables	
Medical workers	Number of doctors and nurses per day in each hospital
Beds	Number of open beds per day in each hospital
Output variables	
Hospitalized patients	Number of patients per day receiving treatment in each hospital
Control variables	
Stage	Rising stage and descending stage
Source	Non-tertiary hospital and tertiary hospital
Bed capacity	Number of open beds (< 2000 and ⩾ 2000)
Doctor-to-nurse ratio	Doctor-to-nurse ratio of each hospital
Bed-to-nurse ratio	Bed-to-nurse ratio of each hospital

All statistical analyses were performed using STATA version 16.0 (StataCorp, College Station, TX, USA) and the DEAP analysis software (version 2.1). Statistical significance was set at $p < 0.05$ on two-tailed testing.

Results

Descriptive statistics of the input, output, and control variables

In total, 214 DMUs were included in this study (Table 2). These DMUs deployed a median of 144 (IQR, 57-189) medical workers and a median of 1140 (IQR, 350-1700) bed capacity, which produced a median of 537.5 (IQR, 204-1012) hospitalized patients. The median doctor-to-nurse and bed-to-nurse ratios were 0.24 (IQR, 0.24-0.43) and 10.17 (IQR, 8.75-13.60), respectively. The majority of DMUs were in the descending stage, and approximately 26% were in the rising stage. According to the bed capacity of the hospitals, 177 DMUs (82.71%) were classified as hospitals with < 2000 beds, and 37 DMUs (17.29%) were classified as hospitals with ⩾ 2000 beds. There were 130 DMUs (60.75%) belonging to non-tertiary hospitals, and 84 (39.25%) DMUs belonging to tertiary hospitals.

Efficiency scores

As shown in Table 3, the median TE, PTE, and SE of these hospitals were 0.579 (IQR, 0.347-0.767), 0.644 (IQR, 0.487-0.883), and 0.938 (IQR, 0.905-0.953), respectively. These results indicated that the low level of PTE contributed to the low TE score, which could be improved through better management and organization. Compared with the descending stage, the median TE in the rising stage was significantly higher, reaching 0.820 (IQR, 0.702-0.887). This trend was also observed for PTE, which was 0.895 (IQR, 0.777-0.984) and 0.552 (IQR, 0.392-0.756), respectively. The median TE of hospitals managed by medical assistance teams from non-tertiary and tertiary hospitals was 0.595 (IQR, 0.315-0.765) and 0.552 (IQR, 0.387-0.744), respectively. Regarding bed capacity, all efficiency scores of hospitals

Table 2

Descriptive statistics of the inputs, outputs, and control variables

Таблица 2

Описательная статистика входных, выходных и контрольных переменных

	N (%)	Input variables		Output variables		
		Medical workers	Bed capacity	Hospitalized patients	D-N ratio	B-N ratio
Stage						
Rising stage	55 (25.70%)	144 (57, 189)	1140 (350, 1705)	877 (292, 1134)	0.24 (0.24, 0.54)	12.59 (8.75, 17.35)
Descending stage	159 (74.30%)	144 (57, 256)	1140 (350, 1700)	408 (167, 850)	0.24 (0.19, 0.43)	10.17 (8.68, 13.60)
Source						
Non-tertiary hospital	130 (60.75%)	62 (57, 144)	680 (350, 1180)	284.5 (147, 614)	0.43 (0.24, 0.54)	10.17 (8.75, 17.35)
Tertiary hospital	84 (39.25%)	256 (161, 256)	1700 (1140, 1705)	892.5 (620.5, 1339.5)	0.19 (0.19, 0.24)	8.68 (5.53, 12.59)
Bed capacity						
< 2000	177 (82.71%)	144 (57, 161)	1140 (350, 1180)	430 (176, 865)	0.24 (0.24, 0.42)	10.17 (8.75, 12.63)
⩾ 2000	37 (17.29%)	363 (189, 363)	2718 (2134, 2718)	1121 (403, 1567)	0.16 (0.16, 0.54)	8.68 (8.68, 17.35)
Total	214 (100%)	144 (57, 189)	1140 (350, 1700)	537.5 (204, 1012)	0.24 (0.24, 0.43)	10.17 (8.75, 13.60)

Abbreviations: D-N ratio, doctor-to-nurse ratio; B-N ratio, bed-to-nurse ratio
Сокращения: соотношение врачей и медсестер (D-N); соотношение койко-мест и медсестер (B-N)

Table 3

Summary of the efficiency scores according to the stage, source, and bed capacity

Таблица 3

Сводные данные по показателям эффективности в зависимости от стадии, источника и вместимости коек

	TE	*p* value	PTE	*p* value	SE	*p* value
Stage		< 0.001		< 0.001		0.737
Rising stage	0.820 (0.702, 0.887)		0.895 (0.777, 0.984)		0.937 (0.933, 0.946)	
Descending stage	0.497 (0.267, 0.636)		0.552 (0.392, 0.756)		0.939 (0.901, 0.956)	
Source		0.652		0.004		0.345
Non-tertiary hospital	0.595 (0.315, 0.765)		0.738 (0.491, 0.929)		0.940 (0.799, 0.970)	
Tertiary hospital	0.552 (0.387, 0.744)		0.587 (0.412, 0.796)		0.938 (0.934, 0.943)	
Bed capacity		0.002		< 0.001		0.010
< 2000	0.598 (0.381, 0.775)		0.694 (0.491, 0.895)		0.940 (0.933, 0.956)	
⩾ 2000	0.417 (0.139, 0.607)		0.456 (0.145, 0.681)		0.922 (0.901, 0.937)	
Total	0.579 (0.347, 0.767)		0.644 (0.487, 0.883)		0.938 (0.905, 0.953)	

Abbreviations: TE, technical efficiency; PTE, pure technical efficiency; SE, scale efficiency

Сокращения: TE — техническая эффективность; PTE — чистая техническая эффективность; SE — эффективность масштаба

with < 2000 beds were significantly higher than those with ⩾ 2000 beds.

Tobit regression analysis

The efficiency scores were significantly affected by the stage in the Tobit regression analysis. Compared with the rising stage, descending stage was associated with significantly lower TE (-0.317, 95% CI: -0.387, -0.247; $p < 0.001$) (Figure 1), PTE (-0.295, 95% CI: -0.365, -0.225; $p < 0.001$) (Figure 2), and SE (-0.106, 95% CI: -0.170, -0.041; $p = 0.002$) (Figure 3). Regarding the hospital type, tertiary hospitals (0.195, 95%: 0.112, 0.279; $p < 0.001$) strengthened PTE remarkably but had no impact on TE (0.044, 95% CI: -0.039, 0.127; $p = 0.299$) and SE (-0.051, 95% CI: -0.128, 0.026; $p = 0.190$). Compared with hospitals with < 2000 bed capacity, those with ⩾ 2000 weakened TE (-0.149, 95%: -0.230, -0.068; $p < 0.001$) and PTE (-0.352, 95% CI: -0.435, -0.269; $p < 0.001$). D-N ratio did not affect TE (0.039, 95% CI: -0.006, 0.084; $p = 0.092$) but was significantly associated with higher PTE (0.134, 95% CI: 0.088, 0.180; $p < 0.001$) and lower SE (-0.050, 95% CI: -0.092, -0.008; $p = 0.020$). Moreover, the B-N ratio had a negative impact on TE (-0.047, 95% CI: -0.084, -0.008; $p = 0.017$) and SE (-0.078, 95% CI: -0.113, -0.043; $p < 0.001$), and a positive impact on PTE (0.148, 95% CI: 0.093, 0.202; $p < 0.001$).

Discussion. One challenge in fighting against the public health emergencies is rationally allocating limited medical resources to improve the efficiency. DEA-Tobit analysis was conducted to evaluate the efficiency of hospitals the public health emergency. We found that a low level of PTE led to poor TE, significantly affected by the bed-to-nurse ratio, bed capacity, and stage.

The bed-to-nurse ratio, widely applied to measure nursing workload, is a crucial determinant of efficiency. A previous study showed that the bed-to-nurse ratio was positively associated with the TE of county hospitals [13], while another study indicated that efficient units were associated with a lower bed-to-nurse ratio in intensive care units [14]. A higher bed-to-nurse ratio, indicating a high-intensity nursing workload, might

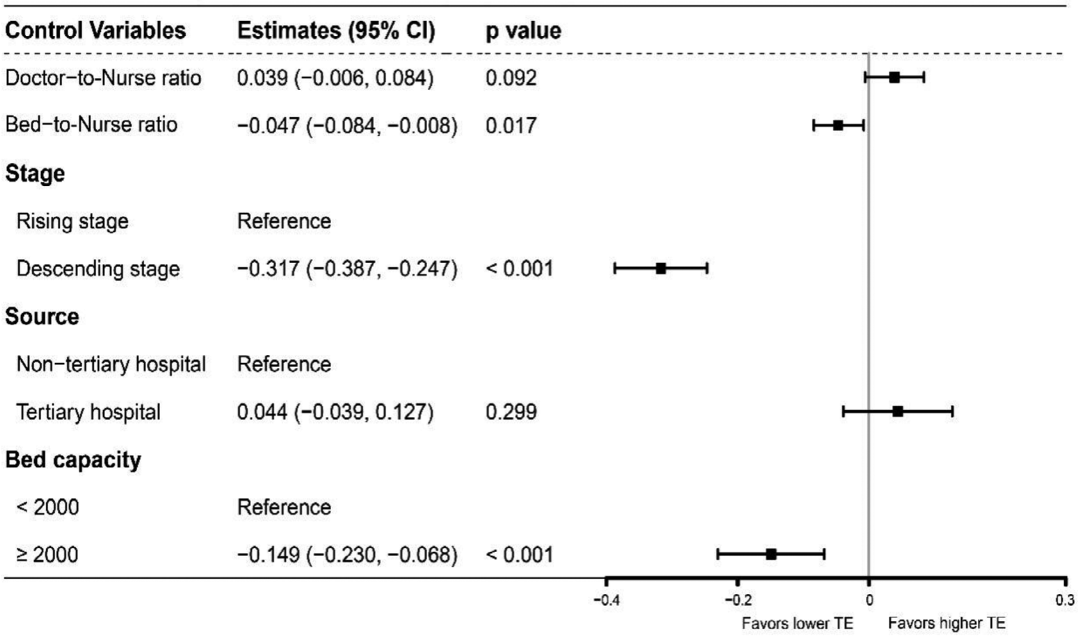

Fig. 1. Factors affecting the technical efficiency of hospitals
Рис. 1. Факторы, влияющие на техническую эффективность больниц

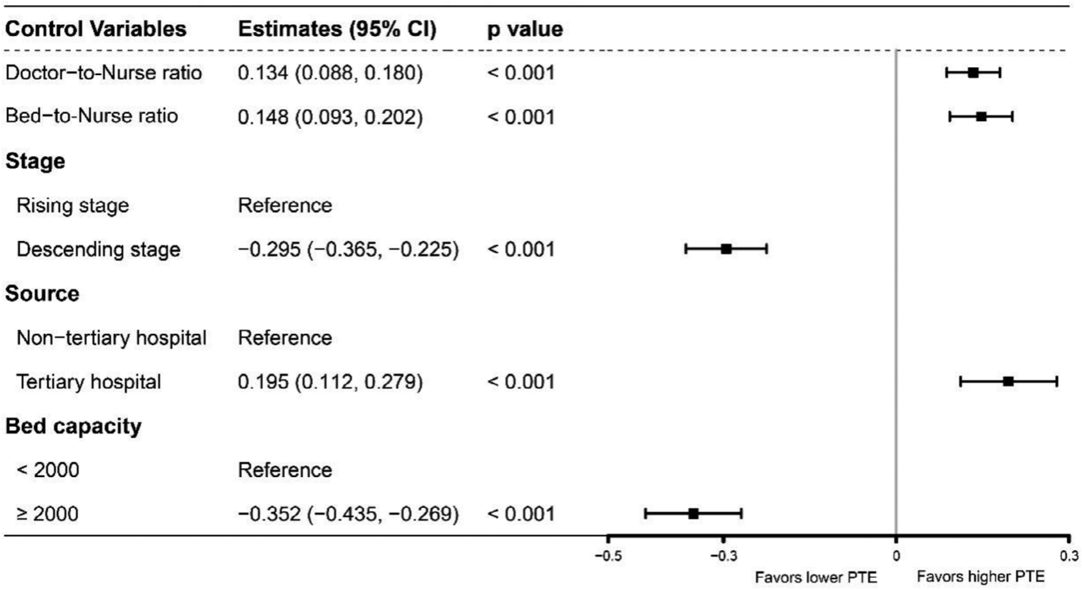

Fig. 2. Factors affecting the pure technical efficiency of hospitals
Рис. 2. Факторы, влияющие на чисто техническую эффективность больниц

lead to physical and mental fatigue, which is an independent risk factor for efficient nursing practice [15, 16]. Therefore, an optimized nursing workforce allocation should be developed to improve the efficiency of hospitals.

The bed capacity is another important factor that affects efficiency. A previous study showed that maternal and child health hospitals with at least 200 beds positively affected efficiency [17]. However, another study demonstrated that efficiency scores declined as bed capacity was more than 618 in county hospitals [13]. These contradictions indicated that the hospitals' SE might be reciprocal U-shaped, which means that the efficiency declined as bed capacity was beyond the optimum scale [18]. Small hospital scale was unfavourable to the full release of its potential, while it was difficult for huge hospitals to manage efficiently. This study also showed that hospitals with more than 2000 beds displayed poorer effi-

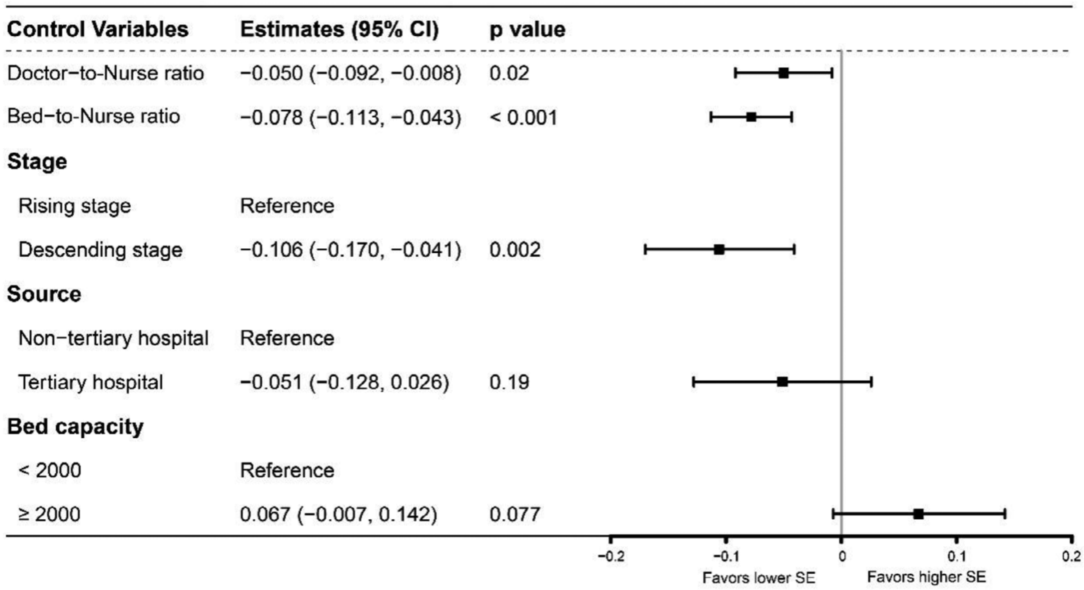

Fig. 3. Factors affecting the scale efficiency of hospitals
Рис. 3. Факторы, влияющие на масштабную эффективность больниц

ciency than their smaller counterparts. However, we did not define the optimal size of hospitals in our study. Further research should be conducted to determine the optimized bed capacity of hospitals to improve medical resource utilization.

Tobit regression analysis showed that the stage of the public health emergency was significantly associated with efficiency. Compared to the rising stage, hospitals were less efficient during the declining stage. This could be partly explained by the declining number of newly infected cases, which made the original medical resources relatively redundant, while it might also be related to the fact that the long-lasting, high-intensity work exhausted the medical staff. Similar results also existed in a previous study that evaluated the efficiency of medical rapid response teams after the 2010 Yushu earthquake [19]. To improve utilization efficiency, it was advised to adjust the allocation of medical resources dynamically according to the process of the public health emergency.

The hospital type had no significant impact on TE and SE in our study. However, the tertiary hospitals strengthened the PTE significantly compared with non-tertiary hospitals. The tertiary hospitals had no significant technical advantages over non-tertiary hospitals, and the hospital type was not the determinant of TE in hospitals.

This study applied DEA and Tobit regression to comprehensively evaluate hospitals' efficiency in the public health emergency and determine its influencing factors. However, this study has some limitations. First, the hospitals included in this study were located in specific regions in Shanghai. It suggests caution in applying these results in other regions, and future studies including hospitals from multiple regions should be conducted to verify our findings. Second, owing to limited data availability, a limited number of variables were included in the analysis to evaluate efficiency, which cannot comprehensively reflect hospital activity. Further research incorporating more significant information is preferable for in-depth analysis.

Conclusions. It is crucial to assess hospital efficiency and optimize medical resource allocation in the public health emergency, which is beneficial for alleviating pressure on healthcare systems. In our study, the TE of hospitals can be attributed to poor PTE, which highlights the pressing need for better management and organization. The efficiency of hospitals was significantly affected by bed capacity, bed-to-nurse ratio, and emergency stage, which decision-makers should consider while allocating medical resources.

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Author contribution. Author according to the ICMJE criteria participated in the development of the concept of the article.
Вклад автора. Автор подтверждает соответствие своего авторства, согласно международным критериям ICMJE.

Disclosure. The authors declare that they have no competing interests.
Потенциальный конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Funding. The study was carried out without additional funding.
Финансирование. Исследование проведено без дополнительного финансирования.

Поступила/*Received: 10.10.2025*
Принята к печати/*Accepted: 15.12.2025*
Опубликована/*Published: 30.12.2025*

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