


# BMJ Open Study of the medical service efficiency of county-level public general hospitals based on medical quality constraints: a cross-sectional study

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## ABSTRACT

**Objectives** Since the new medical reform in 2009, county-level hospitals in China have achieved rapid development, but health resource waste and shortage issues still exist.

**Design** We applied the meta-frontier and slacks-based measurement-undesirable data envelopment analysis model to measure the medical service efficiency with or without medical quality constraints of the county-level public general hospitals (CPGHs). The assessment includes four inputs, three desirable outputs and one undesirable output. We conducted the assessment via Max-DEA V.8.19 software. Moreover, we analyse the factors affecting CPGHs' medical service efficiency based on the fractional response model.

**Setting** A total of 77 sample CPGHs were selected from Shanxi province in China from 2013 to 2018.

**Results** The results of this study showed that the efficiency level of county-level public hospitals in Shanxi Province is relatively low overall (the mean value of efficiency is 0.61 without quality constraints and 0.63 under quality constraints). This showed that ignoring medical quality constraints will result in lower efficiency and lower health resource usage for high medical quality hospitals. The medical service efficiency of CPGHs differs greatly among different regions. Under the meta-frontier, the hospitals in the central region had the highest efficiency (efficiency score 0.70), followed by those in the south (efficiency score 0.63) and the hospitals in the north had the lowest efficiency (efficiency score 0.54). Factors that have larger impacts on the service efficiency of county public hospitals are the average length of hospital stay, per capita disposable income and financial subsidy income.

**Conclusions** To improve CPGHs' medical service efficiency, the government should increase investment in the northern region, and hospitals should improve the management level and allocate human resources rationally.

## BACKGROUND

In March 2009, the Chinese government started a new medical reform. Since the implementation of the medical reform, China has made great achievements in expanding medical security services.<sup>1 2</sup>

## STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This study introduced the meta-frontier and slacks-based measurement-undesirable data envelopment analysis models to measure the efficiency of the county-level public general hospitals in China. This process is advantageous to draw reliable and robust conclusions.
- ⇒ Medical quality index was set as an output indicator in this study, which means that the hospitals should not only focus on the number of patients, but also focus on the medical quality.
- ⇒ Due to data unavailability, we only selected the number of doctors, nurses, beds and machines as the input variable and did not include staff income, which is a crucial input variable.
- ⇒ Only 77 hospitals were chosen in one province, so the extrapolation of this study may be limited.

The government has vigorously developed primary medical and health services and strived to improve the fairness of the health service distribution.<sup>3</sup> However, the distribution of health resources in China is still unreasonable, and health resources are scarce.<sup>4</sup> High-quality medical resources are mainly concentrated in cities, leading to a significant medical quality gap between urban and rural hospitals.<sup>5–7</sup> Additionally, patients prefer to choose urban hospitals, which leads to the idleness of rural hospital resources.<sup>8</sup> Health resource waste and shortage issues have seriously restricted the service ability of medical and health institutions and led to low medical efficiency.<sup>9</sup> To solve these problems and improve the quality of medical services, the government has implemented a series of reforms in rural hospitals.<sup>1 10</sup> China's urban and rural medical system is mainly composed of urban tertiary hospitals, urban community hospitals, county-level hospitals and township health centres.<sup>11</sup> Among them, county-level

public general hospitals (CPGHs) act as a link between China's urban and rural medical systems, and they are the leaders of rural health institutions.<sup>12–14</sup> Their medical services have a wide range of radiation and cover a large population.<sup>9</sup> However, county-level hospitals also have problems such as shortages of human resources, low levels of medical services and uneven distributions of resources.<sup>14–16</sup> For example, Wu and Lam noted that the quality of human resources in primary hospitals is not high and the medical service level is poor.<sup>17</sup> Pan and Shallcross found that the average resource levels of county-level hospitals in western China were lower than those in other regions.<sup>18</sup> Therefore, it is very important to improve the usage rate of primary health resources and the medical efficiency of county-level hospitals.

In recent years, many scholars have studied the medical efficiency of CPGHs in China. Li *et al* measured the medical efficiency of 12 CPGHs in Anhui Province and found that it has declined year by year; additionally, the medical reform effect of CPGHs was not significant.<sup>19</sup> Wang *et al* analysed the medical efficiency of 127 CPGHs in China and found that the efficiency of CPGHs still has considerable room for improvement.<sup>20</sup> Jiang *et al* conducted a study of 1105 CPGHs in China and noted that although medical reform has increased the scale of hospitals, it has not improved the medical efficiency of CPGHs.<sup>9</sup> Other scholars' studies have also shown that the medical efficiency of CPGHs has room for improvement.<sup>12 21 22</sup> However, in the evaluation of medical efficiency, researchers are most likely to ignore the indicators of medical quality, which lead to some high-efficiency hospitals with low medical quality.<sup>23 24</sup> At present, medical quality indicators such as mortality rate, infection rate and adverse events are often selected as undesirable indicators in hospitals efficiency evaluation.<sup>25–27</sup> In slacks-based measurement-undesirable (SBM-undesirable) data envelopment analysis (DEA) model, medical quality indicators can be regarded as undesirable indicators. For example, SBM-undesirable DEA model was used by Monzeli *et al* to measure the emergency departments, which indicated that the undesirable output can determine the hospitals' efficiency.<sup>28</sup> Lu used the SBM-undesirable DEA model to measure 77 county-level medical efficiency in China.<sup>29</sup> This model is widely used in the field of medical service efficiency evaluation in recent years.

In this study, we used the SBM-undersirable DEA model to measure the medical efficiency of CPGHs. Moreover, considering the inconsistencies in the internal and external environment of the CPGHs area, traditional DEA model can not capture the heterogeneity among CPGHs in different area. To solve this problem, we introduced the meta-frontier DEA model,<sup>30</sup> which is a mature DEA model to solve heterogeneity, to measure the heterogeneity of CPGHs in different areas. Therefore, we combined the meta-frontier DEA and SBM-undersirable model to measure the efficiency of the CPGHs.

## METHODS

### Data sources

The data are mainly from the 2013–2018 Shanxi (a province with a population of 37 million in China) Statistical Yearbook and China Health Statistics Yearbook. Overall, 77 CPGHs in Shanxi Province were selected.<sup>31</sup> The data excluded other types of hospitals, such as traditional Chinese medical hospitals, maternal and child healthcare hospitals and other medical institutions, so they met the homogeneity requirement of the DEA method.

### Meta-frontier and group frontier DEA models

The meta-frontier DEA model was first proposed by Battese and Rao.<sup>32</sup> The meta-frontier refers to the potential technical level of all decision making units (DMUs), and the group frontier refers to the actual technical level of each DMU. The difference between them is the different technology sets to which they refer.

According to the meta-frontier DEA model of Battese *et al*,<sup>33</sup> we took the unexpected output into account. In this case, the technology set ( $T^{\text{meta}}$ ) includes all technically feasible input–output combinations:

$$T^{\text{meta}} = \left\{ \begin{array}{l} (x, y, b) : x \geq 0, y \geq 0, b \geq 0; \\ x \text{ can produce } (y, b) \end{array} \right\} \quad (1)$$

In the above formulation,  $x$  is the input vector,  $y$  is the expected output vector and  $b$  is the unexpected output vector. That is, to obtain a certain output  $P^{\text{meta}}(y, b)$ , the input ( $x$ ) must be satisfied under the given technological condition ( $T^{\text{meta}}$ ). The production possibility set (meta-frontier) is as follows:

$$P^{\text{meta}}(x) = \{(y, b) : (x, y, b) \in T^{\text{meta}}\} \quad (2)$$

Therefore, the technical efficiency function of the meta-frontier from the perspective of the output can be expressed as follows:

$$TE^{\text{meta}}(x, y, b) = \inf_{\beta} \{\beta > 0 : (y/\beta) \in P^{\text{meta}}(y, b)\} \quad (3)$$

According to the different levels of economic development, Shanxi Province is divided into three groups: Northern Shanxi, Central Shanxi and Southern Shanxi ( $h=1, 2, 3$ ). The group technology set is:

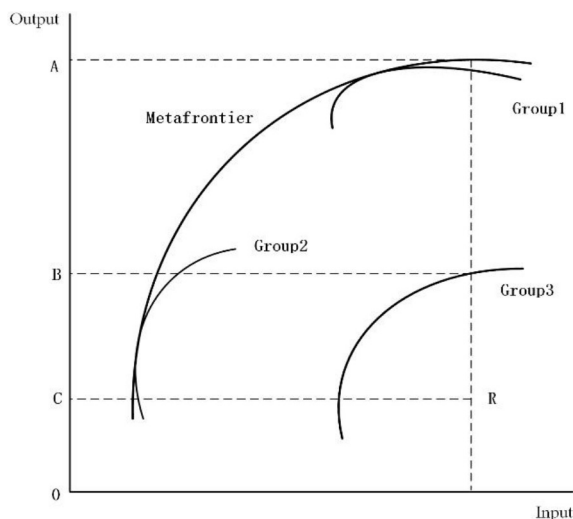
$$T^h = \{(x_h, y_h, b_h) : x_h \geq 0, y_h \geq 0, b_h \geq 0; x_h \rightarrow (y_h, b_h)\}, \\ h = 1, 2, 3 \quad (4)$$

The production set is as follows:

$$P^h(x_h) = \{(y_h, b_h) : (x_h, y_h, b_h) \in T^h\}, \\ h = 1, 2, 3 \quad (5)$$

The group technical efficiency ( $h=1, 2, 3$ ) can be expressed as:

$$TE^h(x_h, y_h, b_h) = \inf_{\beta} \{\beta > 0 : (y_h/\beta) \in P^h(y_h, b_h)\}, \\ h = 1, 2, 3 \quad (6)$$



**Figure 1** Schematic diagram of common frontier and group frontier. ‘Meta-frontier’ is formed by the efficiency frontier of 77 county-level public general hospitals group1, 2, 3 represents the sample hospitals.

Meta-frontier technology is the envelope curve of the group frontier technology. So:  $T^m = \{T^1 \cup T^2 \cup T^3\}$ .

### Technology gap ratio

The technology gap ratio (TGR)<sup>33</sup> can be expressed by the meta-frontier and group technology efficiency functions (the results are shown in figure 1):

$$TGR^h(x_h, y_h, b_h) = \frac{TE^{meta}(x, y, b)}{TE^h(x_h, y_h, b_h)}, \quad (7)$$

$h = 1, 2, 3$

Take R Hospital located in group3 as an example, then

$$\begin{aligned} TE^{meta}(R) &= \frac{OC}{OA}; TE^h(R) = \frac{OC}{OB}; TGR^h(R) \\ &= \frac{TE^{meta}}{TE^h} = \frac{OC/OA}{OC/OB} = \frac{OB}{OA} \end{aligned} \quad (8)$$

If the TGR is less than 1 or there are obvious differences between the mean values of  $TE^{meta}$  and  $TE^h$ , it is necessary to divide the CPGHs into different groups. In contrast, if the TGR is close to 1 or there are no obvious differences between the mean values of  $TE^{meta}$  and  $TE^h$ , there is no need to divide the CPGHs into different groups.

### SBM-undesirable DEA model

The SBM-undesirable DEA model<sup>34</sup> of unexpected output is used to construct the efficiency measurement model under the meta-frontier and group frontier conditions, and the formula is:

$$\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s} \left( \sum_{r=1}^{s_1} \frac{s_r^g}{y_{r0}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}} \right)}$$

Subject to

$$\begin{aligned} x_0 &= X\lambda + S^- \\ y_0^g &= Y\lambda - S^g \\ y_0^b &= Y\lambda + S^b \end{aligned}$$

$$L \leq e\lambda \leq U$$

$$S^-, S^g, S^b, \lambda \geq 0 \quad (9)$$

In the above formulation,  $X$ ,  $Y$  and  $B$  represent the input and output vectors of different CPGHs each year. The meta-frontier represents 77 county regions, and the group frontier represents different groups in the 77 county regions;  $s^-$ ,  $s^y$  and  $s^b$  are slack variables related to the input, expected output and unexpected output, respectively;  $r$  represents the  $r$ th DMU; and  $r^0$  represents the DMU to be assessed. The objective function  $\rho^*$  decreases with  $s_b^- (\forall h)$ ,  $s_r^y (\forall r)$  and  $s_r^b (\forall r)$ , where  $0 < \rho^* \leq 1$ .

Because the data are from multiple years, homogeneity for each CPGH and statistical relations should be considered. Therefore, we adopted the global reference model proposed by Pastor and Lovell<sup>35</sup> to calculate the Malmquist index. This model can solve the comparability problem caused by considering different frontiers in efficiency evaluation.

### Disease complexity adjustment for discharged patients

Since the disease complexity varies from hospital to hospital, it is unfair to simply input the approximate number of discharged patients into the input–output index. For example, hospitals with high technology levels are likely to treat patients with complicated conditions, and these hospitals will take more time to treat such a patient than to treat a patient with a mild illness. Hospitals with low technology levels can supply health services to patients with mild illness or light symptoms as a result of their limited technical capacities, and patients with severe illness may prefer directly seeking health services at high-level hospitals. Thus, 1000 patients in hospital-A will all have difficult and complicated diseases, and those in hospital-B will have mild diseases. However, when performing efficiency evaluation research, if a quantity of units 1000 is input without considering the complexity of the disease, it would be unfair to hospitals with high technical levels. However, the Romer index (RCI) index can be used to adjust the number of discharged patients according to the average length of stay and bed usage rate.<sup>36</sup> Given the poor quality of the patient records in county-level hospitals, we select the RCI index, which provides a reference for efficiency evaluation in underdeveloped areas. The specific adjustment methods were as follows:

$$RCI_i = ALoS_i \times (OCC_i / OCC_s) \quad (10)$$

In the above formula,  $ALoS_i$  refers to the average length of stay in the  $i$ th hospital,  $OCC_i$  refers to the bed usage rate of the  $i$ th hospital and  $OCC_s$  refers to the average bed usage rate of all evaluated hospitals. Therefore, the average length of stay will be adjusted upward for hospitals with higher bed usage rates than the average. The actual number of discharged patients (P) was adjusted based on the RCI of each hospital, and finally, the number of discharged patients (EP) adjusted according to the RCI index was obtained. The formula is as follows:

$$EP = P \times (RCI_i / RCI_s) \quad (11)$$

### Fractional response model

The regression equation is:

$$\begin{aligned} \text{EFFICIENCY}_{it} = & \beta_0 + \beta_1 \ln \text{INCOME}_{it} + \beta_2 \ln \text{POPULATION}_{it} \\ & + \beta_3 \ln \text{SUBIDY}_{it} + \beta_4 \ln \text{DAY}_{it} + \beta_5 \text{BEDRATIO}_{it} \\ & + \beta_6 \text{STAFFRATIO}_{it} + \varepsilon_{it} \end{aligned} \quad (12)$$

where  $\text{EFFICIENCY}_{it}$  represents the service efficiency of the hospital  $i$  in year  $t$ ,  $\beta_0$  is a constant term.  $\text{INCOME}_{it}$  and  $\text{POPULATION}_{it}$  represent the per capita disposable income and residents population of the district (county) where the hospital  $i$  is located in year  $t$ , respectively;  $\text{SUBIDY}_{it}$ ,  $\text{DAY}_{it}$ ,  $\text{BEDRATIO}_{it}$  and  $\text{STAFFRATIO}_{it}$  represent the subsidy, average length of hospital stay, hospital bed usage rate and the proportion of health technicians, respectively.  $\varepsilon_{it}$  is the error term. This paper uses Stata V.16.0 software for data processing and regression.

To examine the factors that influence the service efficiency of public hospitals, this paper uses the panel Tobit model with right-side restriction for regression. One of the defects of the Tobit model is that it has a strong dependence on distribution and is sensitive to the problem of heteroscedasticity. If the error term does not follow the normal distribution or has a heteroscedasticity issue, the estimation will be inconsistent.<sup>37</sup> In addition, there are some problems in using the Tobit model to analyse the factors of hospital efficiency.<sup>38</sup> In fact, the hospital efficiency in this paper is a natural consequence of the way DEA is defined, and the hospital efficiency measured according to the non-oriented energy-based model (EBM) model is inherently between 0 and 1, which is not because of the Tobit model that set the efficiency greater than 1 to the value of 1.

Papke and Wooldridge<sup>39</sup> proposed the fractional response model (FRM) in 1996, which overcomes many of the limitations of linear and non-linear econometric models when studying bounded data. Ramalho *et al*<sup>40</sup> further developed the FRM. The FRM is a non-linear model using the quasi-maximum likelihood estimation (QMLE). Compared with the Tobit model, the QMLE is asymptotically efficient and consistent because the FRM does not require distributional or heteroskedasticity assumptions on the DEA score.<sup>41</sup> In addition, the advantages of the FRM are that it allows a non-linear relationship between hospital efficiency and its determinants, allows error terms to have autocorrelation, and does not allow the efficiency score to fall outside 0–1, which are in line with the research content of this paper. To this end, this paper uses the FRM for robustness testing. The specification is:

$$E(y_i | x_i) = G(x_i \beta) \quad (13)$$

where the subscript  $i$  represents hospital,  $x_i$  are the factors and  $\beta$  is the parameter to be estimated.  $G(\eta) = \exp(\eta) / [1 + \exp(\eta)]$  represents a probability

distribution function in the form of logit whose domain is all real numbers and whose range is (0, 1).

Referring to Papke and Wooldridge,<sup>39</sup> the log-likelihood equation can be estimated by QMLE:

$$l_i(\beta) = y_i \ln [G(x_i \beta)] + (1 - y_i) \ln [1 - G(x_i \beta)] \quad (14)$$

Finally, maximise equation (15) to obtain the value of  $\beta$  in equation (13).

$$\max_{\beta} \sum_{i=1}^{269} l_i(\beta) \quad (15)$$

### Patient and public involvement

No patient involved.

## RESULTS AND ANALYSIS

### Variable selection

The variables were selected according to previous empirical research and the literature.<sup>7 9 12 19–22</sup> Input variables usually include labour and capital.<sup>42</sup> In our study, the numbers of registered doctors and registered nurses were used to represent the elements of human resources as input variables. Beds and equipment valued above 10 000 yuan were used as capital elements. The total visits, the number of discharged patients (EP) adjusted by the RCI and the number of operations were used as output variables. At present, all critically ill patients in counties in China go to urban tertiary hospitals, so there are almost no death cases.<sup>43</sup> Therefore, in this study, the number of adverse events was used to replace the unexpected output variable as a quality index.<sup>27</sup> The descriptive statistics of the input–output indicators are shown in [table 1](#).

The variables for FRM, the dependent variable is the service efficiency of public hospitals. As for the independent variables, according to the existing literature and the consideration of data availability and sample size, the following six types of factors affecting the service efficiency of county-level public hospitals were selected for analysis, including (1) external factors: per capita disposable income of residents (county-level economic factor), number of usual residents (county-level population factor); (2) internal factors: financial subsidy income (hospital-level financial factor), the proportion of health technicians (human resource factor), hospital bed usage rate (equipment implementation factor), average length of hospital stay (service delivery factor). The summary of variables for FRM is shown in [table 2](#).

### Test and analysis of the TGR

Under a quality constraint, a mean value comparison test of the obtained TGR was performed, as shown in [table 3](#). Assuming that the mean value was 1 and the significance level was 95%, the results showed that the average TGR of each group was less than 1. After performing calculations, from 2013 to 2018, the mean value of the hospital TGR in the southern group was at the highest level, close to 1, reaching 0.93, followed by that of the central group of 0.91, and finally that of the northern group at only 0.63.

**Table 1** Descriptive statistics

Input/output	Variable	Mean	SD	Min	Max
Input variables	doctor	95.232	42.017	18	278
	nurse	117.985	71.658	9	390
	bed	250.217	125.748	80	790
	machine	226.736	145.973	35	831
Desirable output variables	treatment	95 432.120	58 710.450	16 351	292 534
	EP	9607.892	6610.737	756.4231	32 707.7
	operations	1470.729	1189.186	81	7926
Undesirable output variables	adverse events	68.712	38.462	10	200

The sample size in the model was 462.

This result indicated that the southern group was closest to the meta-frontier of technology in county-level public general hospitals, followed by the central group and the northern group. Obviously, both the overall TGR and the regional TGR values were significantly different from the assumed mean value of 1. Therefore, the heterogeneity of the division of public hospitals in Shanxi Province was very obvious, and this finding agreed on the conditions of the DEA meta-frontier model; thus, the meta-frontier model could be suitably applied to analyse the results.

After calculating the efficiency of county-level general hospitals in Shanxi Province under meta-frontier and group frontier conditions, the temporal trends of the technology gaps in the north, central and southern regions under the quality constraint were further compared. The results are shown in [figure 2](#).

[Figure 2](#) shows that the mean value of the TGR in the southern and central regions of Shanxi Province was high, while that in the northern region was the lowest, indicating that the central and southern regions provide better hospital management and medical levels as a whole than did the northern region; additionally, they are closer to the technological frontier. The mean value of the TGR in the central and southern regions fluctuated at a high level and remained in a basically stable state, but the mean value of the TGR in the northern region considerably changed. Except for a slight increase in the mean

TGR in 2016, other years experienced a downward trend, which indicated that the medical level in the northern region decreased and that different frontiers influenced the efficiency of county-level public general hospitals in different regions of Shanxi Province.

#### Time series analysis of the technical efficiency of hospitals

[Figure 3A,B](#) shows the trend of the average comprehensive efficiency of sample hospitals in Shanxi Province and in three major regions from 2013 to 2018 under the meta-frontier and group frontier, respectively. Taking the meta-frontier in [figure 3A](#) as a reference, the overall average medical service efficiency of county-level public general hospitals was more than 0.6, and the medical service efficiency in each region was relatively stable each year; notably, the efficiency in the northern region displayed a slow downward trend. Referring to [figure 3B](#), the overall average efficiency for the group frontier was approximately 0.75, the southern region was relatively stable, and the trends in the northern and central regions involved inverted U-shaped curves in the early stage; however, all the regions experienced a significant increase in 2018.

[Figure 3C,D](#) shows the trend of the average comprehensive efficiency of the sample hospitals in Shanxi Province and in three major regions under the meta-frontier and the group frontier conditions, respectively, based on the quality constraints from 2013 to 2018. Taking the common

**Table 2** Summary of variables for fractional response model

Variable name	Variable	Definition
Hospital service efficiency	EFFICIENCY	Service efficiency of each county-level public hospital calculated according to the non-oriented EBM (Energy-Based Model) model
Per capita disposable income (yuan)	INCOME	Per capita disposable income of usual residents
Resident population (person)	POPULATION	Population of usual residents
Financial subsidy income (10 000 yuan)	SUBSIDY	Financial subsidy received by hospitals
Average length of hospital stay	DAY	$\frac{\text{Number of days that beds are occupied by dischargers}}{\text{Number of people discharged}}$
Usage rate hospital bed	BEDRATIO	$\frac{\text{Number of days that beds are actually occupied}}{\text{Number of days that beds are available}}$
Proportion of health technicians	STAFFRATIO	$\frac{\text{Number of Inspection Technician and Imaging Technician}}{\text{Number of employees}}$

**Table 3** Comparative test results of the mean value of the technology gap among county-level public general hospitals in northern, central and southern Shanxi Province from 2013 to 2018

Region	Mean TGR	t	P value
North	0.62649	-17.2815	0.000
Central	0.907907	-8.9249	0.000
South	0.9328708	-6.9778	0.000
Entire	0.8494894	-15.6809	0.000

TGR, technology gap ratio.

frontier in [figure 3C](#) as a reference, the overall average medical service efficiency of county-level public general hospitals was approximately 0.63, and the medical service efficiency trend in various regions displayed an inverted U-shaped curve in each year; that is, it fluctuated and rose from 2013 to 2016 and then dropped rapidly after 2016. Regarding [figure 3D](#), the overall average efficiency under the group frontier was approximately 0.75, and the medical service efficiency trend in the northern region displayed a U-shaped curve that fluctuated and decreased from 2013 to 2016 and then rose slowly after 2016. Moreover, the efficiency trends in the central and southern regions were the same as those for the meta-frontier.

#### Analysis of the differences in hospital technical efficiency

The distribution of the service efficiency of public general hospitals in Shanxi Province is shown in [figure 4](#). Graph A shows the distribution of hospital efficiency without quality constraints, and graph B presents the distribution of hospital efficiency under quality constraints. In terms of location, the peak position of the distribution curve in [figure 4B](#) moves to the right compared with that in [figure 4A](#), indicating an overall efficiency improvement. The kurtosis of the distribution curve for the central

and southern regions in [figure 4B](#) is greater than that in [figure 4A](#), indicating that the distribution of the efficiency was more concentrated in B. The northern distribution curve in [figure 4A](#) displays an obvious bimodal state, indicating that the efficiency distribution was somewhat scattered. Therefore, quality constraints were very important in the hospital efficiency evaluation. A lack of quality constraints would lead to certain deviations in the evaluation results, and the results would not comprehensively reflect the actual operation status of the medical system.

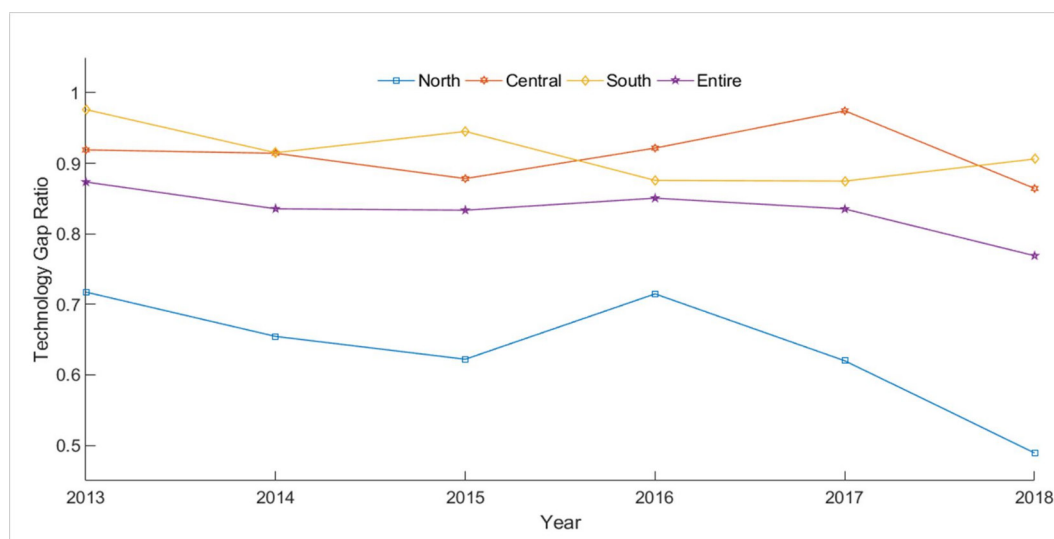
An analysis of the hospital efficiency distribution in [figure 4B](#) was performed. First, for the location, the distribution curves of the hospital efficiency density in the northern, southern and central regions sequentially moved to the right. The distribution curves of the southern and central regions were closely interlaced, indicating that the hospital efficiency levels in the southern and central regions are similar and significantly higher than the level in the northern region.

Second, the distribution curve of the efficiency density in northern hospitals peaks, and the distribution curves of the efficiency density for the central and southern hospitals displays broad kurtosis.

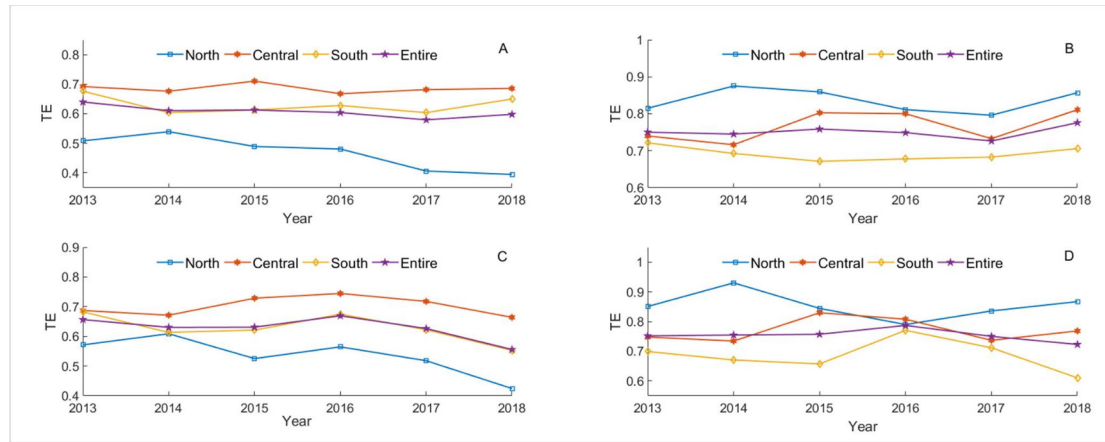
Finally, in terms of shape, the distribution curve of the efficiency density for northern hospitals is bimodal, and those for the central and southern hospitals are unimodal, suggesting that most hospitals in the central and southern regions have little difference in medical level, while the medical level of northern hospitals is polarised; this relation reflects the concept of ‘the strong get stronger, and the weak get weaker’ (Matthew’s effect).

#### Analysis of the changes in hospital technical efficiency rankings

To show the changes in efficiency among the sample hospitals before and after the implementation of quality constraints, the comprehensive efficiency values of sample hospitals



**Figure 2** The technology gap ratios in northern, central and southern Shanxi Province from 2013 to 2018 under the quality constrain. —□— According to the north. —◇— According to the central. —◇— According to the south. —★— According to the entire.



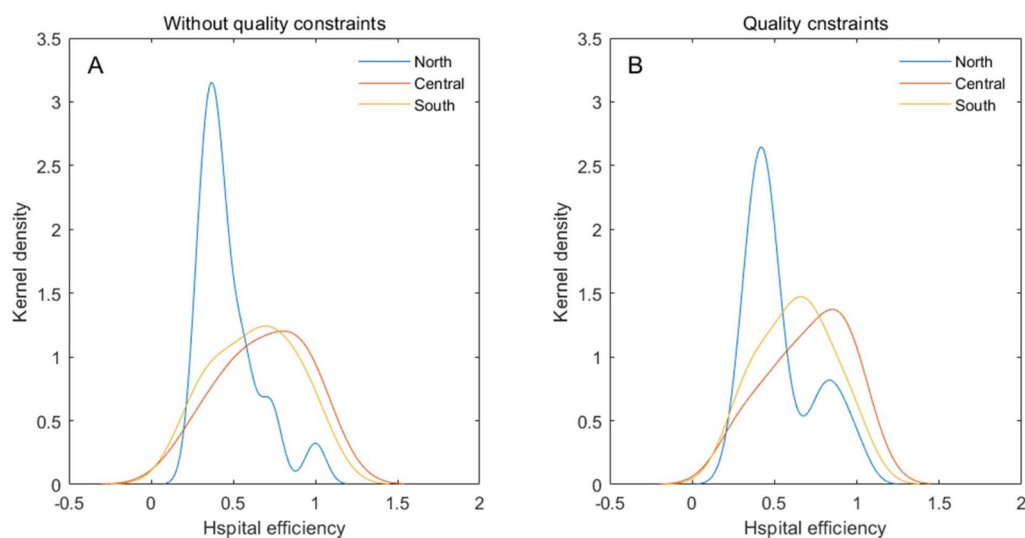
**Figure 3** Efficiency changes of county-level public general hospitals in northern, central and southern Shanxi Province from 2013 to 2018. — According to the north. — According to the central. — According to the south. — According to the entire.

under the two constraint conditions were ranked, and the changes in hospital rankings were compared. The results are shown in figure 5. In the northern region, the ranking of hospital 17 increased the fastest, and the rankings of hospitals 6 and 13 decreased most obviously. In the central region, the ranking of hospital 24 increased the fastest, and the ranking of hospital 29 decreased the most. In the southern region, the ranking of hospital 71 increased the fastest, and the ranking of hospital 67 decreased the most.

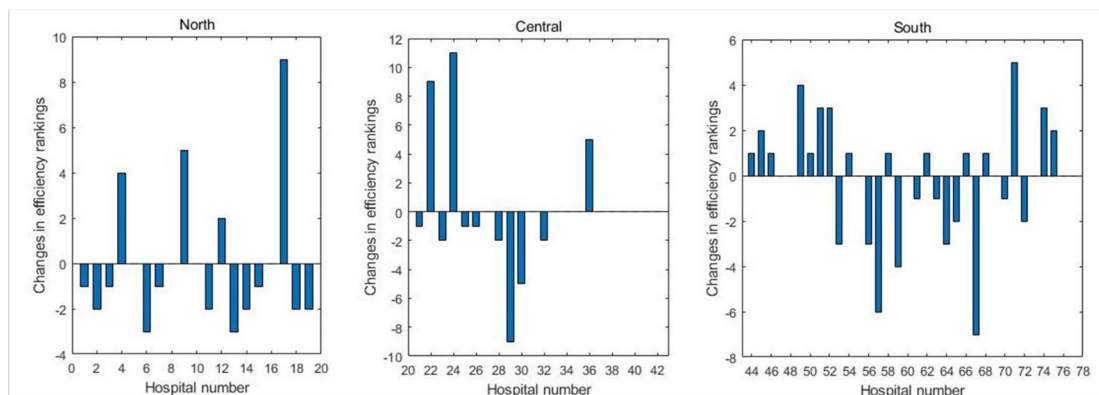
By analysing the unexpected outputs of adverse events at hospitals, it was found that the changes in efficiency rankings were related to the unexpected outputs of adverse events; notably, the efficiency ranking increased when the unexpected output level was low, and the ranking decreased when the unexpected output level was high. For example, the average unexpected output of hospitals in the northern region was  $-14.35$ , and that of hospital 17, with a medical quality higher than that of most hospitals, was  $-3.38$ . However, the average unexpected outputs of hospitals 6 and 13 were  $-23.78$  and  $-31.08$ , respectively, and the corresponding

medical quality was lower than that of other hospitals. Additionally, the average unexpected output values of hospitals in the central and southern regions were  $-15.3$  and  $-19.22$ , respectively, and the average unexpected output values of hospitals 24 and 71 were only  $-3.09$  and  $-3.49$ , respectively. Moreover, the average unexpected output values of hospitals 29 and 67 were  $-23.99$  and  $-57.25$ , respectively.

The Spearman rank correlation test was used to determine whether there was a correlation between the hospital efficiency values under the two different constraints. The significance level was 1%. The results showed that there was a positive correlation between the efficiency values of sample hospitals under the two constraints. According to the results, the three regions were different: the southern region had the highest similarity, with a correlation coefficient of 0.9673, and the greatest difference was observed in the northern region, with a correlation coefficient of 0.8452.



**Figure 4** Distribution of the service efficiency of county-level public general hospitals in Shanxi Province. — According to the north. — According to the central. — According to the south.



**Figure 5** Changes in the efficiency ranking of county-level public general hospitals in Shanxi Province before and after the implementation of quality constraints.

### Analysis of factors affecting public hospital efficiency

The result on factors affecting public hospital efficiency based on the FRM is shown in [table 4](#).

We can find that the coefficient of per capita income is positive and significant, that is, the improvement of residents' per capita disposable income can improve the service efficiency of county public hospitals; population factor negatively impacts public hospital efficiency when the fixed effects are not controlled. After controlling for the fixed effects, the coefficient is significantly positive, that is, the resident population in the county where the hospital is located is positively correlated with the service efficiency of county public hospitals; The effect of financial subsidy income on the service efficiency of county public hospitals is significantly positive; the coefficient for the average length of hospital stay is the largest and significantly negative; and the proportion of health technicians has a significant positive impact on the service efficiency of public hospitals.

### DISCUSSION

This paper used the meta-frontier model and SBM-undesirable model to calculate the efficiency of county-level public hospitals in Shanxi Province from 2013 to 2018. Then, we evaluated the reform effect and resource usage rate of county hospitals and explored the influence of medical quality on hospital efficiency. Moreover, we analyse the factors affecting public hospital efficiency based on the FRM.

The results of this study showed that the efficiency level of county-level public hospitals in Shanxi Province is relatively low overall (the mean value of efficiency is 0.61 without quality constraints and 0.63 under quality constraints). In other studies, the average efficiency of county hospitals in Chongqing was 0.83,<sup>12</sup> in Anhui Province was 0.956<sup>19</sup> and in China, as a mean value, was 0.7,<sup>20</sup> suggesting that the efficiency of county-level hospitals in Shanxi Province is obviously low; additionally, the usage rate of existing resources is relatively low, and the

**Table 4** Regression result of the FRM

	(1) FRM-logit	(2) FRM-logit
Constant	-63.1201 (57.5153)	174.6323** (69.2530)
ln INCOME	23.9425*** (8.0147)	57.9482*** (9.1432)
ln POPULATION	11.7407** (4.8335)	18.0447*** (4.9030)
ln SUBSIDY	18.2966*** (2.1988)	13.6022*** (2.1659)
ln DAY	-53.1396*** (8.9505)	-53.4437*** (8.9724)
BEDRATIO	1.8526*** (0.1080)	1.8717*** (0.1104)
STAFFRATIO	4.3761*** (1.1724)	3.9982*** (1.1333)
Wald test	570.78 (0.0000)	758.54 (0.0000)
Time fixed effect	No	Yes
County fixed effect	No	Yes
Hospital category effect	No	Yes
Observations	1430	1430

The data in parentheses after each coefficient is the SD. To facilitate comparison with the Tobit model, both coefficients and SD are multiplied by 100. In the Wald test, the values on the left side of the parentheses are the values of  $\chi^2$  distribution, and the values in the parentheses are the corresponding p values. \*\*\*, \*\* and \* represent 1%, 5% and 10% significance levels, respectively. FRM, fractional response model.



technology used is inefficient. To improve the efficiency level of county-level hospitals, in addition to increasing investments to alleviate resource shortages, it is necessary to improve the usage efficiency of resources, such as improving hospital management, rationally allocating human resources, and optimising capital investments.<sup>44</sup>

The results showed that the efficiency of county-level public hospitals in Shanxi Province did not improve and even declined in some areas from 2013 to 2018 (figure 2C). Although the reform of county-level hospitals was initiated in 2012, the effect was not remarkable, as also noted by Jiang *et al.*<sup>9</sup> Moreover, the study found that there were regional differences in the efficiency of county-level public hospitals in Shanxi Province. The efficiency level of county-level public hospitals in the central and southern regions of Shanxi Province was high, while the efficiency level in the northern region was comparatively low (figure 2A,C); these trends were also reflected by the TGR distribution in each region (figure 1), which indicated that the county-level hospitals in the northern region were far from the technological frontier. Therefore, increasing the resource inputs for hospitals in the northern region of the province should be prioritised to improve their medical levels. Additionally, the population and economic level in northern Shanxi Province are lower than those in the central and southern regions<sup>45</sup>; thus, hospital efficiency may be related to the economic environment and population.

This study also showed that quality constraints had an important impact on hospital efficiency evaluation (figures 3 and 4). Neglecting medical quality output could lead to underestimates of the hospital efficiency level. This finding could potentially be attributed to the fact that medical quality is often related to hospital management and human resources.<sup>46</sup> With improvements in hospital management and medical treatment ability, medical quality will also increase, as will the corresponding hospital efficiency. Improving the quality of medical services is often the goal of public hospitals,<sup>47</sup> but many hospitals begin to expand blindly, resulting in inefficiency.<sup>20 41 48</sup> Pang and Wang<sup>49</sup> noted that improperly scaled expansion can lead to technical efficiency in the short term but not in the long term. Therefore, to improve the medical quality level, increasing the technological capacity and improving management are steps.

For the factors that influence public hospital efficiency, first, when the per capita disposable income of residents is high, people may pay more attention to their health, and have more requirements for the service and technical level of the hospital. Accordingly, health services will be used more rationally. Second, the more resident population in the region, the greater the intensity of the demand for medical services, and the hospital will continuously improve its medical service to meet the demand, thus making the hospital service more efficient. The reason for the low level of significance level is that: on the one hand, the resident population is the macro-level data, which has little impact on the efficiency of the micro-level

hospital; on the other hand, the mobility of people seeking medical treatment is high, so the population of the area where the hospital is located has limited effect on the efficiency of the local hospital. Third, if the government increases the financial investment in the hospital, it will help the hospital to introduce high-tech equipment and improve the hospital's infrastructure construction capacity, etc. Thus it will prompt the hospital to realise the rational allocation of resources under the guidance of the government's policy of increasing the corresponding investment. As a result, the hospital achieves more efficient health service, improving the efficiency of hospital services. Fourth, the average length of hospital stay is an important factor affecting the service efficiency of public hospitals, and a longer length of hospital stay will reduce the service efficiency level of the hospital. This may be because a longer length of hospital stay means hospitals are not treating patients in a timely manner or have to deal with more severe cases, making hospital services less efficient. Fifth, the bed usage rate reflects the vacant beds in the hospital. The higher the hospital bed usage rate, the more patients can be provided with hospital-stay services at the same time, thereby increasing the hospital-stay service output and improving the hospital's service efficiency. Sixth, for the positive impact of the proportion of health technicians, the reason may be that the higher the proportion of health technicians, the higher the level of medical service, and the further improvement of the service efficiency of the hospital.

#### Limitations and suggestions for future research

This study evaluated the efficiency of county public hospitals in Shanxi Province and explored the influence of scale on hospital efficiency. It provided a reference for the government and hospitals to reasonably allocate health resources. However, we believe that our research can be improved and extended in a number of directions. First, the study has only 77 hospitals were chosen in one province, so the extrapolation of this study may be limited. Future studies can be conducted and include CPGHs in other provinces, which are divided by region. Second, we did not include the staff salary as the input variable, mainly due to data limitations. However, further analysis focusing on the staff salary variable is also necessary given that we are studying public hospitals' efficiency, the salary paid to employees by the government is an important input indicator for evaluating public hospitals' efficiency.

#### CONCLUSION

This showed that after the implementation of county-level public hospital reform, the efficiency level of county-level public hospitals in Shanxi Province did not improve but remained low. Notably, the usage rate of resources was low, and the reform effect was not obvious. There are differences in the efficiency of county-level hospitals in different regions, with the highest efficiency in the central region, the second-highest level in the southern region

and the lowest level in the northern region. To improve the efficiency of hospitals, support to the northern region should be strengthened, hospital management should be improved, and health human resources should be rationally allocated.

The results also indicated that quality factors have a significant impact on hospital efficiency evaluation. The keys to improving the level of medical quality are to improve the proportion of technical personnel and the level of hospital management. The expansion of county-level hospitals should consider the economic level and service area in the region to avoid expansion and blind investment, potentially resulting in wasted resources.

According to the FRM regression results, it is concluded that the factors that have larger impacts on the service efficiency of county public hospitals are the average length of hospital stay, per capita disposable income and financial subsidy income. Shortening the average hospital stay can improve hospital efficiency. In areas with higher per capita disposable income of residents, the service efficiency of county-level public hospitals is higher. And the increase in subsidy has a positive effect on the improvement of hospital service efficiency. In addition, the county population, bed usage rate and the proportion of health technicians also have significant impacts on hospital service efficiency. The higher the population, the higher the hospital efficiency. Increasing the bed usage rate and the proportion of health technicians will also promote hospital service efficiency. However, only 77 hospitals in one province were selected for this study, so the extrapolation from this study may be limited.

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