



# Evaluation of Medical Service Efficiency in Township Hospitals Based on DEA-Malmquist Model

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## ABSTRACT

This article takes the township hospitals in 29 provinces in China as the research objects, using the DEA-Malmquist model to analyze the input-output efficiency of medical services in them, aiming to understand the changes in the efficiency of medical services in township hospitals in China. The results display that overall level of medical service efficiency of township hospitals in 29 provinces in China is not high, the value of pure technical efficiency is low, and only 10 provinces have comprehensive efficiency equal to 1, as well as the number of provinces that is technically effective is relatively small. Although the total factor productivity index of 29 provinces displayed an overall upward trend from 2011 to 2020, the change in total factor productivity efficiency during the 10-year period was not stable. Provinces with a total factor productivity index greater than 1 accounted for 75.86%, indicating that the medical service efficiency of township hospitals in most provinces has improved from 2011 to 2020. The medical services of township hospitals have excess input and insufficient output. It is indispensable to rationally arrange the resource allocation of township hospitals and enhance their own and external technical efficiency.

**Keywords:** Township hospitals, Medical services, Efficiency evaluation, DEA-Malmquist model

## 1. INTRODUCTION

Medical care is intimately related to the people and is also the key to improving people's livelihood. China's total health expenditure, government health expenditure, social health expenditure and personal health expenditure all show a trend of increasing year by year, which demonstrates that my country attaches great importance to and supports medical services. With the advancement of science and technology, the growth of the economy and the continuous improvement of people's life, with the joint efforts of the government, people from all walks of life and the masses, China's medical and health service industry has developed rapidly, hence China has basically established a comprehensive coverage in the medical and health service system, so that the people put forward more requirements and have more expectations for medical and health services.

According to the China Statistical Yearbook 2020, the population of villages and towns in China accounts for 36.10% of the total population. A total of 35,365 township hospitals were built in China, accounting for 3.46% of the total number of medical institutions.

Township hospitals are part of primary medical institutions. With the development of medical and health services in China in recent years, township hospitals can also bring great medical services and health care to rural residents.

23.81% of the total population is 60 years old and above in villages and towns in China. These residents are relatively older and less educated, and they are in the age group where diseases are more frequent. As can be seen from Fig.1 and Fig.2. In case of physical discomfort, they usually choose to seek medical treatment nearby, township hospitals are their best choice and also the priority place for local township residents to get medical treatment. Statistics show that 51.9% of township residents choose to seek medical treatment in township hospitals.

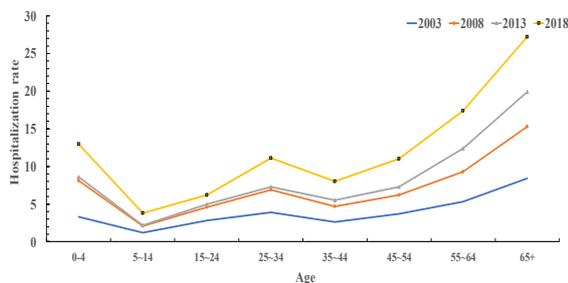


Figure 1: Hospitalization rates of residents in different age groups.

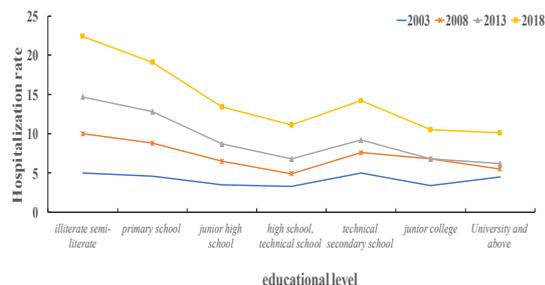


Figure 2: Hospitalization rates of residents with different educational levels.

It can be seen that township residents have a great demand for township hospitals. However, China's medical resources are also limited, and the medical and health system is relatively complex and huge, which leads to unbalanced and differentiated resource allocation. In view of this, the medical service efficiency of township hospitals in 29 provinces in China was studied to explore the differences and causes of the medical service performance of township health hospitals in different provinces, and provide scientific support for improving the medical service efficiency of township hospitals.

Domestic scholars have conducted many studies on the efficiency evaluation of medical institutions, which can be roughly divided into the efficiency evaluation research of township health institutions, primary medical and health institutions, hospitals and overall health institutions. A recent research used entropy weight TOPSIS to comprehensively evaluate the basic public health services of township hospitals in 27 townships in Guangzhou, and concluded that the development of public health services in each township hospital in Guangzhou was unbalanced and has two levels of differentiation [1]. Two recent articles have both studied the service efficiency of township hospitals under the model of county medical community, study showed that the model of county medical community could promote the scale efficiency of township hospitals, however did not a negative impact on the technical efficiency of township hospitals. The improvement of pure technical efficiency is not obvious, and concluded that the overall efficiency of medical services in township hospitals is low [2] [3]. Many scholars have studied the efficiency of township hospitals in different regions, different

townships in the same region and a certain province [4] [5] [6]. DEA-Tobit two-stage method was used to evaluate the technical efficiency of community health service centers in 31 provinces, analyzed the factors affecting the technical efficiency of community health service centers [7]. The study used DEA and RSR comprehensive evaluation methods to reach the conclusion that the comprehensive efficiency of primary medical and health institutions in China is not high and there are differences in different provinces [8]. A article conducted a comparative study on medical efficiency of hospitals and primary medical and health institutions by comprehensively applying Malmquist index method, and also analyzed the influencing factors of total factor productivity changes [9]. A recent study used the bootstrap-DEA method to research the operating efficiency of public hospitals in Shanxi Province. Combined with the panel data of 4 years, the results displayed that the total factor productivity index and technological progress index of public hospitals in Shanxi Province increased, while the technical efficiency index decreased [10]. Some scholars have used DEA, DEA-Malmquist and DEA-SFS methods to evaluate the efficiency of medical services efficiency of TCM hospitals in China [11] [12] [13]. A study evaluated and analyzed the allocation efficiency of health resources in Shaanxi province with DEA method [14]. Scholars use DEA, two-stage DEA, three-stage DEA and four-stage DEA-Malmquist method to evaluate the efficiency of China's health care service system [15] [16] [17].

Through previous literature review, it is discovered that the research on township hospitals mainly focuses on the problem-countermeasure level, current situation research, resource allocation, talent team construction, cost control and standardization research. There are many researches on the service efficiency of medical institutions at different levels, however few scholars have conducted research on the evaluation of medical service efficiency in township hospitals across the country. In view of this, this paper uses the DEA-Malmquist method to comprehensively evaluate the medical service efficiency of township health hospitals in 29 provinces in China, in order to explore the differences and causes of medical service performance of township hospitals in different provinces and regions, and to provide a scientific basis for improving the medical service performance of township hospitals.

## 2. DATA SOURCES AND SELECTION OF INDICATORS

### 2.1 Data Sources

The data used in this article are all from the "China Health and Family Planning Statistical Yearbook" and "China County Statistical Yearbook", and Data related to

medical services in township hospitals in 29 provinces of China from 2011 to 2020 were selected.

### 2.2 Selection of Indicators

According to the literature review and related theories, combined with the availability of data. The investment indexes selected in this article are the number of township hospitals and hospital beds, which can represent the capital investment of township hospitals; as the health technicians in each city account for more than 80% of the staff in township hospitals, the correlation

coefficient between health technicians and health personnel is as high as 99.78%. Therefore, health technicians are selected as the labor input of township hospitals.

Township hospitals provide integrated services of diagnosis and treatment and hospitalization, so starting from diagnosis and treatment-inpatient services, the number of patients treated, number of people hospitalized, number of discharged patients, and average hospitalization days were selected as output indexes, as shown in Table 1.

Table 1: Composition of input and output index of medical services in township hospital.

Index	Indicator	Explanation
Input index	Number of health techs $X_1$	Includes occupational physicians, physician assistants, registered nurses, pharmacists, technicians and others
	Number of township hospitals $X_2$	Including the number of township hospitals and central hospitals
	Number of hospital beds $X_3$	The number of hospital beds inherent in the hospital at the end of the year
Output index	Number of people treated $Y_1$	Refers to the total number of patients treated during the reporting period, including outpatient and emergency visits
	Number of people hospitalized $Y_2$	The number of patients admitted to the hospital
	Number of discharged patients $Y_3$	The number of inpatients discharged during the reporting period
	Average hospitalization days $Y_4$	Average length of stay for hospitalized patients during the reporting period

### 3. METHOD

The DEA model is suitable for evaluating the relative effectiveness of multi-input and multi-output decision units. However, only using the DEA model for efficiency evaluation can only measure the efficiency evaluation value of each DMU in the same period, while the Malmquist index model can dynamically analyze the service efficiency level of each DMU in different periods of township hospitals.

In view of this, this article uses the DEA-Malmquist evaluation model to analyze and research the efficiency of medical services in township hospitals in 29 provinces in China from 2011 to 2020, making up for the shortcomings of the traditional DEA evaluation model and making the efficiency evaluation more scientific and reliable.

#### 3.1 Principle of CCR-BCC Model

The  $BC^2$  model under  $VRS$  condition was selected. Its linear programming was as follows: Suppose there are  $m$  DMU in the model, each DMU has  $n$  inputs and  $s$  outputs,  $x_{ij}$  represents the  $j$ -th input of the  $i$ -th DMU,  $x_{ij} \geq 0$ ;  $y_{ir}$  is the  $r$ -th output of the  $i$ -th DMU,  $y_{ir} \geq 0$ ;  $v_j$  and  $u_r$  are the weights of input and output respectively.

$$(p_1) \begin{cases} \max(u^T y_0 + \mu_0) = V_p \\ s.t. \begin{cases} w^T x_i - \mu y_i - \mu_0 \geq 0, i = 1, 2, \dots, m \\ w^T x_0 = 1 \\ w \geq 0, \mu \geq 0 \end{cases} \end{cases} \quad (1)$$

Its dual plan is:

$$(p_2) \begin{cases} \min \theta = V_D \\ s.t. \sum_{i=1}^m x_i \lambda_i \leq \theta x_0 \\ \sum_{i=1}^m y_i \lambda_i \geq y_0 \\ \sum_{i=1}^m \lambda_i = 1 \\ \lambda_i \geq 0, i = 1, 2, \dots, m \end{cases} \quad (2)$$

If (1) has the optimal solution  $w_0, u_0$ , satisfying:  $V_p = \mu_0^T y_0 + \mu_0^0 = 1$ , the DUM is called weakly efficient; if (1) has the optimal solution  $w_0, u_0$ , satisfying:  $V_p = \mu_0^T y_0 + \mu_0^0 = 1$ , and satisfying  $w_0 > 0, u_0 > 0$ , the DUM is said to be effective.

### 3.2 Principle of Malmquist Exponential Model

$x'_i$  represents the input index of the  $i$ -th DUM in the  $t$  period,  $y'_i$  represents the output index of the  $i$ -th DUM in the  $t$  period. In the case of variable returns to scale, the change formula of productivity from period  $t$  to period  $t+1$  is:

$$M(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{D_v^t(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} \times \frac{D_v^{t+1}(x^t, y^t)}{D_v^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad (3)$$

Where  $D_v^t(x^t, y^t)$  is the distance function of  $(x^t, y^t)$  at time  $t$ , where  $D_v^{t+1}(x^t, y^t)$  is the distance function of  $(x^t, y^t)$  at time  $t+1$ , where  $D_v^t(x^{t+1}, y^{t+1})$  is the distance function of  $(x^{t+1}, y^{t+1})$  at time  $t$ , where  $D_v^{t+1}(x^{t+1}, y^{t+1})$  is the distance function of  $(x^{t+1}, y^{t+1})$  at time  $t+1$ .

## 4. RESEARCH ANALYSIS

### 4.1 Evaluation of Medical Service Efficiency in Township Hospitals by DEA

In terms of investment indicators, in 2020, there are 1,267,426 health technicians, 35,762 township hospitals, and 1,390,325 hospital beds in township hospitals in China. Sichuan Province ranks first, with 96,516 health technicians. There are 4,283 township hospitals with 134,987 hospital beds; In terms of output indicators, in 2020, a total of 1095162704 patients were treated in township hospitals in China, of which 114,634,044 were diagnosed in Henan Province, accounting for 10.48% of the total number of patients. Sichuan Province had the highest number of people hospitalized and discharged patients, These two indicators both accounting for 12.58% of the total.

DEAP 2.1 was used to analyze the input and output data of township hospitals in 29 provinces in China in 2020. The static analysis of medical service efficiency of township hospitals in 29 provinces was based on DEA

evaluation model. And the result shows that the comprehensive efficiency, pure technical efficiency and scale efficiency of medical services in township hospitals in Tianjin, Jiangsu, Zhejiang, Henan, Hubei, Guangxi, Chongqing, Sichuan, Qinghai and Ningxia are all 1, that is, these 10 provinces are effective units; their return to scale remains unchanged, signifying that the medical investment of township hospitals in these 10 provinces has been fully utilized; Hunan, Hainan and Tibet Autonomous Region are effective in pure technical efficiency. However, in terms of scale efficiency, it is not effective and belongs to the relatively weak effective provinces. While Hunan and Hainan have diminishing returns to scale, the results illustrate that in the construction of medical services in township hospitals, Hunan and Hainan provinces should focus on improving the quality of medical services in township hospitals, instead of just focusing on increasing the number and size of township hospitals; the increasing returns to scale in the Tibet Autonomous Region indicate that the input scale of medical services in township hospitals in the Tibet Autonomous Region is relatively large, and the input is higher than the output of medical services in township hospitals. Although the pure technical efficiency of the Tibet Autonomous Region is effective, its scale benefit is the lowest in the studied provinces, and the scale return is only 0.699, indicating that the Tibet Autonomous Region should maintain the existing medical and health technical level on the basis of rationally adjusting the scale of township hospitals, as shown in Table 2.

Table 2: Evaluation and composition of medical service efficiency of township hospitals in 2020.

Province	crste	vrste	scale	Returns to scale
Tianjin	1	1	1	-
Hebei	0.615	0.615	0.999	drs
Shanxi	0.549	0.644	0.852	drs
Inner Mongolia	0.436	0.446	0.978	drs
Liaoning	0.621	0.714	0.87	drs
Jilin	0.375	0.423	0.886	drs
Heilongjiang	0.438	0.446	0.981	irs
Jiangsu	1	1	1	-
Zhejiang	1	1	1	-
Anhui	0.806	0.812	0.992	irs
Fujian	0.697	0.704	0.99	irs
Jiangxi	0.81	0.814	0.996	irs
Shandong	0.803	0.935	0.859	drs
Henan	1	1	1	-

Hubei	1	1	1	-
Hunan	0.906	1	0.906	drs
Guangdong	0.874	0.879	0.994	irs
Guangxi	1	1	1	-
Hainan	0.733	1	0.733	drs
Chongqing	1	1	1	-
Sichuan	1	1	1	-
Guizhou	0.752	0.763	0.985	irs
Yunnan	0.857	0.876	0.977	drs
Tibet	0.699	1	0.699	irs
Shaanxi	0.466	0.481	0.971	drs
Gansu	0.678	0.688	0.986	irs
Qinghai	1	1	1	-
Ningxia	1	1	1	-
Xinjiang	0.848	0.849	0.999	irs
Average	0.792	0.831	0.954	

The pure technical efficiency of Inner Mongolia and Heilongjiang is the lowest, the pure technical efficiency of Inner Mongolia Autonomous Region is 0.446, the scale efficiency is 0.978, and the scale returns are decreasing. Table 3 shows the projection results of the Inner Mongolia Autonomous Region, which displays that the three inputs of the Inner Mongolia Autonomous Region all have redundancy, that is, the inputs of "health technicians", "number of township hospitals", and "number of hospital beds" all have different extents of excess. The redundant values of the input indicators are 10969.977, 696.53 and 11903.12, respectively. Except for effective and weakly effective provinces, the rest of the provinces all have redundant investment, indicating that the investment scale of township hospitals should be reasonably allocated.

Table 3: Projection results of Inner Mongolia Autonomous Region.

Index	Original value	Radial movement	Slack movement	Projected value
Y <sub>1</sub>	9744792	0.000	0.000	9744792
Y <sub>2</sub>	202764	0.000	348	203112
Y <sub>3</sub>	202368	0.000	0.000	202368
Y <sub>4</sub>	6.9	0.000	0.000	6.9
X <sub>1</sub>	19797	-10970	0.000	8827
X <sub>2</sub>	1257	-697	-303	257
X <sub>3</sub>	21481	-11903	-1313	8265

### 4.2 Malmquist Index Analysis of Medical Service Efficiency in Township Hospitals

The relevant data of township hospitals from 2011 to 2020 was selected to analyze the efficiency of medical service. From 2011 to 2020, the technical efficiency index, technological progress index, pure technical efficiency index and total factor productivity index are all greater than 1. However, the total factor productivity index was less than 1 in 2015-2016, 2018-2019 and 2019-2020, the total factor productivity index of other years was greater than 1, indicating that the overall efficiency of medical service of township hospitals shows an upward trend. The total factor productivity index was 1.019 between 2011 and 2020, showing that the efficiency of medical service of township hospitals increased by 1.9 percentage points. Among them, the changes of the technological progress index and the total factor productivity index are roughly consistent, that is, the change of technological progress has a high correlation with the comprehensive evaluation of medical service resources in township hospitals. Although the total factor productivity index of 29 provinces displayed an overall upward trend from 2011 to 2020, the change in total factor productivity efficiency during the 10-year period was not stable. as shown in Table 4 and Fig.3.

Table 4: Malmquist index of service efficiency of township health hospital from 2011 to 2020.

Year	effch	techch	pech	sech	tfpch
2011-2012	1.059	1.087	1.086	0.976	1.151
2012-2013	1.002	1.064	0.983	1.02	1.066
2013-2014	0.964	1.076	0.976	0.987	1.037
2014-2015	1.076	0.935	1.049	1.026	1.006
2015-2016	0.991	0.963	1.015	0.976	0.955
2016-2017	0.991	1.032	0.992	0.999	1.023
2017-2018	0.97	1.073	0.96	1.011	1.041
2018-2019	1.014	0.978	1.018	0.997	0.992
2019-2020	1.001	0.918	1.024	0.977	0.919
Average	1.007	1.012	1.011	0.996	1.019

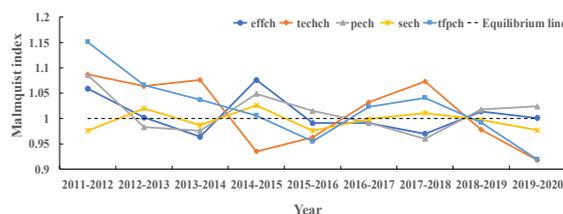


Figure 3: Trend of Malmquist index of township hospitals from 2011 to 2020.

From 2011 to 2020, the total factor productivity index of service efficiency of township hospitals was less than 1 in Tianjin, Jiangsu, Zhejiang, Henan, Hubei, Guangxi and Chongqing among 29 provinces. Except for these seven provinces, the total factor productivity index of

other provinces is greater than 1, indicating that the medical service efficiency of township hospitals in these provinces has improved during 2011-2020. The technical efficiency index, pure technical efficiency index and scale efficiency index of Tianjin, Jiangsu, Zhejiang, Guangxi and Chongqing are all 1, and the technological progress index is all less than 1, indicating that the main reason for the decline of medical service efficiency of township hospitals in these five provinces is the negative effect of technological change. The pure technical efficiency index of Henan Province and Hubei Province is equal to 1, while the other indexes are all less than 1, indicating that the factors affecting the medical service efficiency of township hospitals in Henan Province and Hubei Province are technology and the scale of health centers, as shown in Table 5.

Table 5: Malmquist index of medical service efficiency of township health hospital during 2011-2020.

Province	effch	techch	pech	sech	tfpch
Tianjin	1.000	0.989	1.000	1.000	0.989
Hebei	1.019	1.011	1.042	0.978	1.03
Shanxi	0.989	1.022	1.05	0.942	1.011
Inner Mongolia	1.018	1.029	1.017	1.001	1.048
Liaoning	1.002	1.027	1.006	0.996	1.03
Jilin	1.016	1.018	1.003	1.013	1.034
Heilongjiang	1.013	1.037	1.012	1.002	1.051
Jiangsu	1.000	0.973	1.000	1.000	0.973
Zhejiang	1.000	0.977	1.000	1.000	0.977
Anhui	0.999	1.011	0.998	1.001	1.009
Fujian	1.03	1.009	1.029	1.001	1.039
Jiangxi	1.024	1.036	1.023	1.000	1.06
Shandong	1.025	0.985	1.008	1.017	1.009
Henan	0.996	0.977	1.000	0.996	0.973
Hubei	0.996	0.977	1.000	0.996	0.973
Hunan	0.997	1.005	1.000	0.997	1.003
Guangdong	1.015	1.006	1.014	1.001	1.021
Guangxi	1.000	0.999	1.000	1.000	0.999
Hainan	1.026	0.999	0.993	1.034	1.025
Chongqing	1.000	0.989	1.000	1.000	0.989
Sichuan	0.992	1.022	1.000	0.992	1.013
Guizhou	1.032	1.043	1.03	1.002	1.076
Yunnan	1.017	1.011	1.015	1.003	1.029
Tibet	1.024	1.03	1.000	1.024	1.056
Shaanxi	1.002	1.037	1.062	0.944	1.039
Gansu	0.983	1.035	1.017	0.967	1.018
Qinghai	1.000	1.048	1.000	1.000	1.048

Ningxia	1.000	1.027	1.000	1.000	1.027
Xinjiang	0.988	1.03	0.999	0.989	1.018

### 4.3 Distribution of Medical Service Efficiency of Township Hospitals

31.03% of the medical service efficiency of township hospitals in 29 provinces in China are in the state of increasing returns to scale. and 34.48% of the provinces are in a state of constant scale efficiency and diminishing scale return. The proportion of provinces in the three efficiency indicators is similar, and provinces where the technology is available is less than half of the total, indicating that there are still insufficient medical services in township hospitals in China. The total factor productivity index is greater than 1, accounting for 75.86%, that is, the medical service efficiency of township hospitals in most provinces has improved from 2011 to 2020, as shown in Table 6.

Table 6: Distribution of medical service efficiency in township hospital.

The efficiency of state	Number of provinces	Proportion
Increasing returns to scale	9	31.03%
Constant returns to scale	10	34.48%
Decreasing returns to scale	10	34.48%
The tfpch greater than 1	22	75.86%
The tfpch less than 1	7	24.14%

## 5. CONCLUSIONS

### 5.1 Overall Benefits of Medical Services in Township Hospitals in Various Provinces Are General

According to DEA analysis, there are only 10 provinces with constant and relatively scale return, three provinces are in a weakly effective state, as well as the number of technically effective provinces is relatively small, indicating that provinces can improve medical service efficiency by improving the efficiency of township hospitals. The medical service efficiency of the township hospitals in the remaining 16 provinces is in an ineffective state. The mean values of comprehensive efficiency, pure technical efficiency and scale efficiency are 0.792, 0.831 and 0.954 respectively. The comprehensive efficiency value is the lowest, and the technical efficiency has also needed to be improved.

According to the analysis of the Malmquist index model, from the mean value, except the scale efficiency index value is less than 1, the other efficiency index values are greater than 1. The overall total factor production index from 2011 to 2020, the overall total factor productivity index is 1.019, showing a trend of decline, rise and decline. Although the medical service efficiency of township hospitals increased by 1.9 percentage points, the efficiency changes during the period were unstable, and there was a downward trend in efficiency in the middle, and the efficiency index of technological progress showed a downward trend. The data showed that the total factor productivity index of 22 provinces is greater than 1, that is, the medical service efficiency of township hospitals in most provinces has improved from 2011 to 2020.

### ***5.2 Phenomenon of Redundant Input and Insufficient Output of Medical Services***

The phenomenon of redundant investment in township hospitals in relatively ineffective provinces, that is, "health technicians", "number of township hospitals" and "number of hospital beds" all have different degrees of redundancy, indicating that the investment utilization rate of township hospitals is not high. Which will inevitably lead to insufficient output. According to statistics for 2020, the utilization rate of hospital beds in township hospitals in China is only 50.4%, and half of the hospital beds are not used reasonably. Blindly increasing the investment in medical resources has not increased the benefits. It can be seen that the township hospitals in each province should further do a good job in the allocation of investment resources and improve the management efficiency of the township hospitals.

The proportion of township population in most provinces is between 30%-40%, there are 10 provinces account for 40%-50% in China, the population of towns and townships in Xizang accounted for the largest proportion, accounting for 64.4%; with the exception of Xizang, Qinghai, and Ningxia, the proportion of the population aged 65 and over in other provinces exceeds 10%. The residents living in towns are mostly middle-aged and elderly people and teenagers, most of the middle-aged and elderly people are in the high incidence period of circulatory system diseases and nervous system diseases. Therefore, each province should reasonably allocate the proportion of medical staff and medical resources according to the actual local situation, taking into account the population distribution, age composition, disease prevalence rate, economic situation and other factors of each province. Township hospitals should also keep up with the era of smart Internet and actively explore new medical models.

### ***5.3 Shortcomings of the Article***

This paper only selects the cross-sectional data from 2011 to 2020 to use the DEA-Malmquist model to evaluate the efficiency of medical services in China's township hospitals. There are other models can be used, such as three-stage DEA and four-stage DEA, and a more perfect model will be used for efficiency research in future research.

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