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An analysis of factors influencing technical efficiency of health expenditures in China

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Abstract

China's primary healthcare (PHC) system, together with rural healthcare services, remains the Achilles' heel in the national healthcare system. Healthcare workers, specifically village doctors, are an integral part of the healthcare system. Using the two-stage data envelopment analysis (DEA) and Tobit regression analysis, this study aims to investigate the efficiency of healthcare expenditures on medical resources and services in China, as well as determine how different types of healthcare work influence efficiency. Compared with other types of healthcare workers, village doctors exerted a prominent impact on provincial and rural efficiency at all stages and played a key role in augmenting the efficiency of healthcare expenditures on health outcomes. Besides, township health centers (THCs) and village clinics (VCs) faced administrative overstaffing, mainly involving pharmacists, other nonmedical technologists, and health administrators, which adversely affected the efficiency of healthcare expenditures. This study suggests that the higher the proportion of these non-village doctor positions (e.g., pharmacists, health administrators, and nonmedical technologists) in THCs and VCs, the lower the efficiency of China's PHC system. Overall, the priority should be enhancing the training and remuneration of village doctors and other healthcare workers in rural areas to further enhance their performance and increase the overall efficiency of China's healthcare system.

Keywords Primary healthcare, Rural health, Data envelopment analysis

Jel code C33, D61, I11, I15, J24

Introduction

The poverty that plagued China for thousands of years ended in 2020 [1]. China's rural areas are often described as "vast, populous, and thinly resourced." Despite swift urbanization in the last few decades, nearly half of the country's population still resides in rural areas. Thus, the rural healthcare system demands governmental attention. In a report, General Secretary Xi Jinping underscored the need to execute a strategy for rural revitalization, including the establishment of a national, long-term regulatory mechanism to supervise elementary medical services for the people [2]. The Ministry of Health put in immense efforts to reform the rural medical and healthcare system, which eased the burden of high medical costs, augmented the quality and management skills of healthcare workers and increased the availability of medical technology. Despite government initiatives to guarantee accessible medical services and enact a hierarchical diagnosis and treatment system nationwide, many, particularly in rural areas, still experience challenges in accessing appropriate healthcare [3–5]. Per the *China Statistical Yearbook 2022*, between 2009 and 2021, the number of township health centers (THCs) declined from 38,475 to 34,943, and the proportion of patient visits declined from 16.0%

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to 13.7% [6]. Meanwhile, the number of village clinics (VCs) declined from 632,770 to 599,292, and the proportion of patient visits declined from 28.3% to 15.8% [6]. The waning role of THCs and VCs in providing essential medical services to rural residents widened the gap between accessible resources and the surging demands for healthcare. Despite China's status as the world's largest developing country, it continues to face irregular and inadequate growth. The primary healthcare (PHC) system in China, involving rural healthcare services and PHC facilities, remains the Achilles' heel in the national healthcare system.

The disorganization of healthcare systems in attaining universal health coverage persists globally. Existing assessments indicate that with the prevailing resources and budgets, several countries could markedly amplify their progress by enhancing the efficiency of their healthcare systems, mainly through increased investments in PHC [7]. To attain this, countries should first assess their current efficiency levels and seek to embrace practices from more efficient peers, which, in turn, involves fortifying institutional frameworks and employing established best practices to replicate well-organized healthcare systems [8]. Healthcare workers consume a considerable share of healthcare expenditures. Per the *China Health Statistics Yearbook 2022*, personnel expenses account for 34.5% of the total healthcare expenditures within China's healthcare system [9]. In China, healthcare workers comprise doctors, nurses, pharmacists, medical technologists, trainees (e.g., trainee doctors, pharmacists, nurses, and technicians), nonmedical technologists (e.g., information engineers and researchers), health administrators, and village doctors. Initially, village doctors were termed "barefoot doctors," which emerged in the 1950s during the early years of the Cultural Revolution. Back then, village doctors were farmers who received minimal elementary medical and paramedical training and then worked in their rural villages to provide primary medical services, implementing a combination of both Western and Traditional Chinese remedies [10, 11]. In most rural areas of China, village doctors constitute the largest percentage of healthcare workers, averaging 36.4%, which is higher than doctors (29.1%) and nurses (17.5%) [9]. Village doctors and doctors complement each other in offering medical services, with less economically developed provinces having a higher percentage of village doctors. Quality workers can result in the sustainable performance of the healthcare system, together with the efficient use of healthcare resources to offer medical services [12, 13]. Furthermore, village doctors are essential in offering accessible healthcare services and briefly lessening resource shortages. Even the World Health Organization praised village doctors for attaining "maximum health benefits with minimum investment" [14].

Economic development in recent years has augmented public revenue, contributing to a surge in both private and public spending on healthcare. In 2009, the total healthcare expenditures in China were appraised at 1754.2 billion Chinese Yuan (¥), with government expenditures at 481.6 billion ¥ (27.5%), social expenditures at 615.5 billion ¥ (35.1%), and personal expenditures at 657.1 billion ¥ (37.4%) [15]. By 2021, these figures inflated to 7684.5 billion ¥, with government expenditures at 2067.6 billion ¥ (26.9%), social expenditures at 3496.3 billion ¥ (45.5%), and personal expenditures at 2120.6 billion ¥ (27.6%) [9]. In China, a healthcare reform was launched in 2009, and the government funding for healthcare has quadrupled since then. Although the reform intended to guarantee all citizens access to basic healthcare, inequalities persisted in medical expenditure between urban and rural residents [16]. Technical efficiency directly influences public healthcare expenditures. Enrichments in public healthcare provision could be materialized through the reallocation of resources and expanding healthcare coverage to more individuals. Guo et al. [17] indicated that local governments in eastern China should pay attention to improving their expenditure structures to remove inadequacies. Provinces in western China, however, are advised to raise government investments in healthcare to increase efficiency levels. For instance, a study in South Africa demonstrated that if inefficient provinces decreased their healthcare workforce by 6940 personnel, it could yield savings of R61 million in healthcare expenditures. Besides, extra savings could potentially be attained by further decreasing 17,000 healthcare personnel in noncore areas [18]. In China, considerable regional disparities exist in the dissemination of healthcare resources and government financial subsidies. Several cities face double challenges of insufficient healthcare resources and inadequacies [19–25]. Hence, improving the healthcare system's efficiency is an utmost necessity for the sustainable growth of healthcare services and is considered one of the vital sources of financial savings in government healthcare expenditure [26–28].

This study focuses on examining the efficiency of healthcare expenditures on medical resources and services in China. The data envelopment analysis (DEA) is an established nonparametric model that is widely used for determining the technical efficiency of medical resources and allocation of healthcare expenditures [29, 30], as observed in studies conducted in the United States [31], Spain [32], China [33, 34] and Hong Kong [35]. The two-stage DEA model comprises two sub-decision-making units (DMUs), where inputs or outputs

can be shared among different activities and stages in many scenarios [36–39]. Several recent studies have used two-stage DEA models to measure resource efficiency for decreasing healthcare expenditures and enhancing healthcare services [40, 41]. In real cases of the healthcare system, inputs to the first stage are shared by the two stages. Shared inputs have been explored in the DEA literature, such as Chen et al. [42], Wang et al. [43], and Avilés-Sacoto et al. [44]. Likewise, Tobit regression has been used to examine additional factors that influence efficiency [45–47]. Hence, this study used the two-stage DEA and Tobit regression analysis to investigate the efficiency of healthcare expenditures on medical resources and services, as well as determine the impact of healthcare workers on this efficiency.

Analytical framework

Healthcare system and rural revitalization

Rural revitalization is an integral part of the Chinese government's 2021–2025 work plan [48], which it seeks to attain by integrating the accomplishments of poverty alleviation in rural areas. In the context of an aging population and mounting healthcare service demands, PHC institutions play a vital role in averting outbreaks like COVID-19, monitoring diseases, and promoting health [49]. Rural healthcare workers have played a crucial role in offering tiered, timely, and convenient medical services to rural residents. Village doctors, considered frontline health guardians, know their fellow villagers well and play an essential role in promptly referring critically ill patients to higher-tier medical institutions [10, 50].

Health and poverty are entwined [51]. Enhancing residents' health directly enhances the nation's overall quality of life and contributes to poverty eradication [52]. Besides, poverty reduction helps in decreasing malnutrition, thereby raising health standards [51, 53]. A fundamental regional healthcare system is crucial in lessening the financial burden on rural residents and mitigating their "illness because of poverty" concern.

Investment in healthcare resources and services

Healthcare resources comprise human, material, and financial resources, and they can be classified into tangible and intangible categories. While tangible healthcare resources comprise human and material resources, intangible healthcare resources comprise science, technology, education, information, and policies [54, 55] This study focuses on tangible healthcare resources and delves deeper into the technical efficiency of healthcare expenditures in China, along with the effect of healthcare workers on that efficiency. Healthcare expenditures are classified into three main types—governmental, social, and individual expenditures [9]. Government expenditures denote funds allocated by various government levels for medical resources and services, medical insurance subsidies, and administrative management. Social healthcare expenditures denote funds invested in healthcare by nongovernmental sectors, comprising social medical insurance, premiums for commercial health insurance, social donations, and administrative fees for public services. Social healthcare expenditures complement government healthcare expenditures to cooperatively promote the expansion of the national healthcare system. Individual expenditure signifies direct expenses paid by urban and rural residents while receiving various medical and healthcare services. Since the 2009 medical reform in China, the government has amplified expenditure on the healthcare system [56]. Lately, some concerns have been raised about the rapid upsurge in total healthcare costs, which could raise the burden on the government and insurance institutions, thereby necessitating proper regulation. Compared with urban areas, however, investment in rural healthcare has been sluggish in recent years [9], and the rural healthcare infrastructure and service system remain the weakest in the entire healthcare system.

Owing to the limited availability of financial and human resources for healthcare, cost containment must be considered in the delivery of healthcare. The government should spend the healthcare budget where it counts the most and maximize its return. In China, the majority of patients tend to select tertiary hospitals to pursue medical assistance [57]. Therefore, by wasting considerable time on treating common diseases, doctors in tertiary hospitals are wasting medical resources and raising the cost for the entire society and individuals [58]. Thus, the government should construct a hierarchical medical system, improving the allocation of healthcare expenditures and resources. In real cases of the healthcare system, inputs to the first stage are shared by the two stages. Some of the funds used in the first stage to procure beds, medical facilities, and personnel can instead be used to provide the second-stage medical services. Figure 1 represents an analytical framework for healthcare workers on the impacts of medical resource efficiency and the involved elements in the analysis.

Materials and methods

Data sources and description

The data in this study were obtained from the *China Statistical Yearbook,* the *China Health Statistical Yearbook,* and the *China Rural Statistical Yearbook* in 2021 and 2022, which were published in Chinese by the Chinese Central Government [6, 9, 59]. In China, rural healthcare facilities are defined as THCs and VCs. As no THCs and VCs exist in Beijing and Shanghai, only 29 provinces were

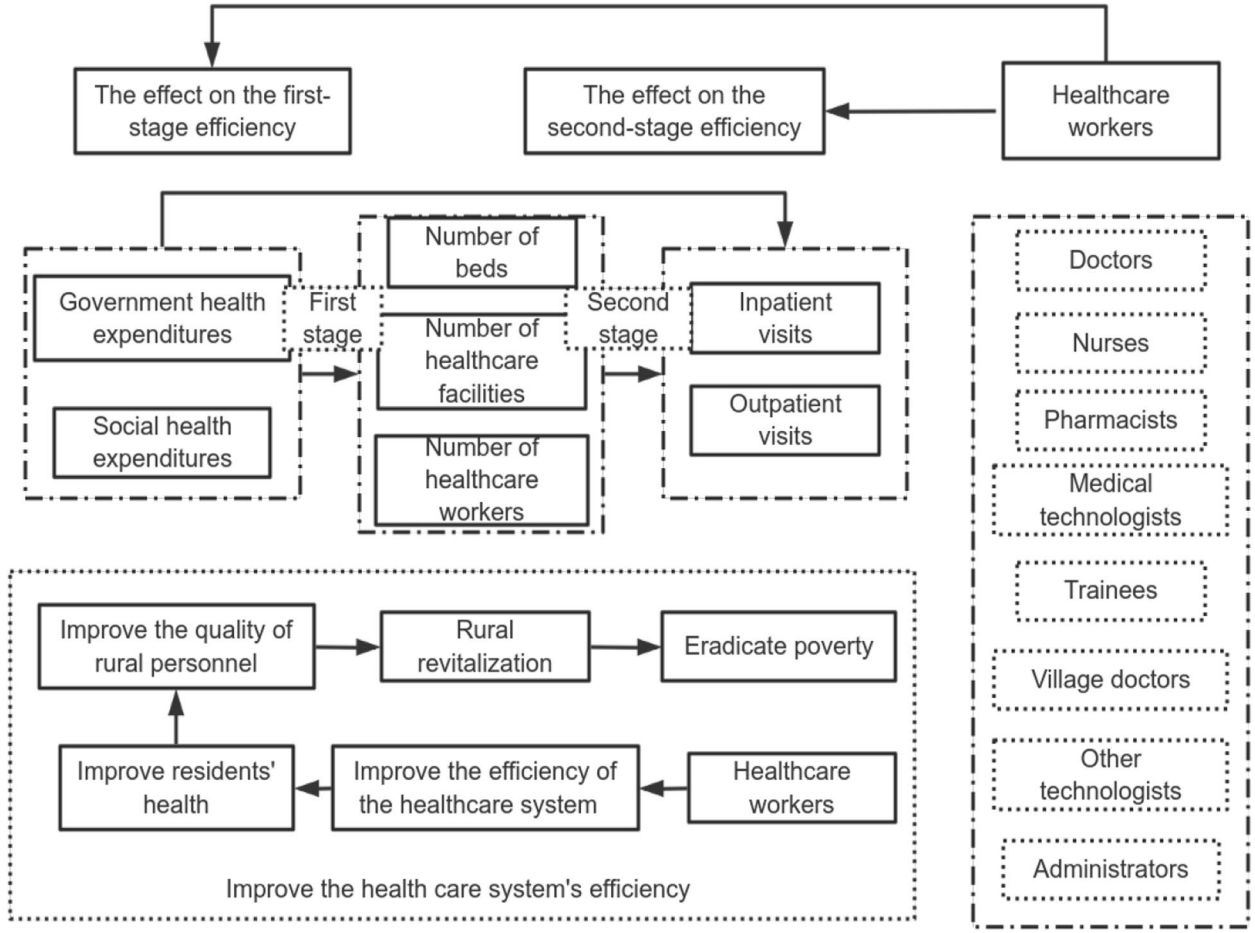

Fig. 1 Analytical framework

chosen to assess the efficiency of rural health resources. However, all 31 provinces were selected for the efficiency analysis of the entire province.

Input and output variables

Healthcare efficiency signifies the effective allocation of healthcare expenditures and resources to maximize health benefits while minimizing investment. To assess healthcare efficiency, prior empirical research usually considered input and output variables like fixed assets, hospital beds, healthcare personnel, and public healthcare expenditures [13, 24, 31, 45, 49]. This study focused on examining the efficiency of healthcare expenditures. We selected government healthcare expenditure (x_1) and social healthcare expenditure (x_2) as the initial input. Meanwhile, three intermediate products (medical resources), including the number of beds, the number of healthcare facilities, and the number of healthcare workers, were obtained by using the healthcare expenditures. The final outputs (medical service) focused on this study were the number of outpatient and inpatient visits. Notably, variables of intermediate and final outputs were together called "health outcomes." Table 1 presents the selection of variables.

Healthcare expenditures were classified into two stages. In the first stage, healthcare expenditures are used to generate beds, medical facilities, and personnel, which are denoted as intermediate outputs. Rather than being

Table 1 Two-stage data envelopment analysis (DEA) model variables

Initial inputs	Intermediate outputs	Final outputs
Government healthcare expenditures	Number of beds	Inpatient visits
Social healthcare expenditures	Number of healthcare facilities	Outpatient visits
	Number of healthcare workers	

instantly utilized by the first subprocess, healthcare expenditures are first allocated to both subprocesses. Then, the intermediate outputs generated by the first subprocess are used by the second subprocess, which focuses on offering medical services. Our data limitation allowed us to only focus on the healthcare expenditure in a given year. Notably, in China, the use of single-year data on healthcare expenditure could be a valid depiction of long-term healthcare expenditure. Per the *China Statistical Yearbook* during 2012–2022, over the past decade, the ranking of each province by the percentage of healthcare resource investment to GDP did not exhibit noteworthy deviations, suggesting that using data from a single year can, to a certain extent, depict and grasp the differences in healthcare expenditures across provinces.

Independent variables

Healthcare workers assumedly influenced the efficiency of a healthcare system. In the Tobit regression analysis, efficiency scores were used as dependent variables, while independent variables comprised doctors (x_1), nurses (x_2), pharmacists (x_3), medical technologists (x_4), trainees (e.g., interns and practice nurses; x_5), village doctors (x_6), other nonmedical technologists (x_7) and health administrators (x_8). As efficiency scores ranged from 0 to 1, for sustaining data consistency, we used the percentage of each type of healthcare worker instead.

Correlation analysis of input and output variables

Table 2 presents the correlation analysis results of healthcare expenditures and rural health resources. In every case, $P<0.05$ suggested a positive correlation between the variables. The Pearson correlation between beds and inpatient visits was 0.968 (96.8%). As evidenced by strong correlation coefficients of 0.948 with outpatient visits and 0.947 with the number of beds, healthcare workers play a vital and positive role in healthcare services. Besides, the correlation coefficient between government healthcare expenditures and other indicators surpassed that of social healthcare expenditures with these indicators, suggesting that government healthcare expenditures play a foremost role in guiding the allocation of medical resources.

Two-stage DEA model with shared input

To estimate the efficiency of rural and provincial medical resources in China, we used an output-oriented two-stage DEA model with shared inputs. The theoretical basis for this model can be traced back to the rudimentary work of Charnes et al. [60] and Banker et al. [61] in the field of DEA. Subsequently, models were developed to assess efficiency in multi-stage processes and models with shared inputs [37, 41, 62]. We used the formula referring to Kao and Hwang [38] and Chen et al. [39].

Figure 2 demonstrates the two-stage DEA model with shared input. Among n DMUs, each used m inputs $X_{ij}(i = 1,2,\ldots,m)$ to generate q intermediate products Z_{pj} ($p=1,2,\ldots,q$) and s final outputs Y_{rj} ($r=1,2,\ldots,s$). The first subprocess did not occupy the initial system input but was allocated to the two subprocesses in a ratio of a_i and $(1-a_i)$, respectively. Next, intermediate products by the subprocess in stage 1 were utilized by the subprocess in stage 2. The overall efficiency was deconstructed in the product of the efficiencies of the two sub-DMUs.

With a little notation modification, we also defined v_i^1,v_i^2 ,w_p^1,w_p^2 and u_r as the weights of the first-stage inputs, second-stage inputs, intermediate outputs, intermediate inputs, and final outputs, respectively. The input in the first stage was $\sum_{i=1}^{m} v_i^1 a_i X_{ik}$, while the intermediate product was

Table 2 Correlation coefficient of input and output variables

Input–output correlation		Government healthcare expenditures	Social healthcare expenditures	Beds	Health facilities	Healthcare workers	Inpatient visits
Social healthcare expenditures	Pearson correlation	0.895**					
	significance	0.000					
Beds	Pearson correlation	0.795**	0.577**				
	significance	0.000	0.001				
Healthcare facilities	Pearson correlation	0.672**	0.462*	0.873**			
	significance	0.000	0.012	0.000			
Healthcare workers	Pearson correlation	0.843**	0.655**	0.947**	0.892**		
	significance	0.000	0.000	0.000	0.000		
Inpatient visits	Pearson correlation	0.728**	0.497**	0.968**	0.776**	0.862**	
	significance	0.000	0.006	0.000	0.000	0.000	
Outpatient visits	Pearson correlation	0.872**	0.745**	0.839**	0.818**	0.948**	0.728**
	significance	0.000	0.000	0.000	0.000	0.000	0.000

**Significance at the 5% statistical level

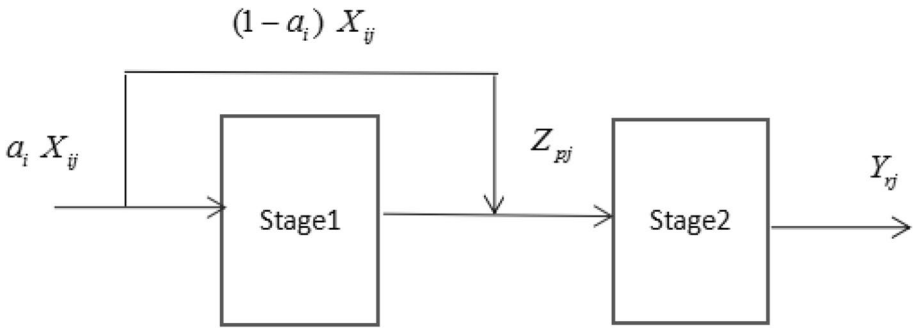

Fig. 2 Two-stage data envelopment analysis (DEA) model with shared input

$\sum_{p=1}^{q} w_p^1 Z_{pk} - \mu_k^1$. Meanwhile, the joint input in the second stage was $\sum_{i=1}^{m} v_i^2(1-a_i)X_{ik} + \sum_{p=1}^{q} w_p^2 Z_{pk}$, the final outputs were $\sum_{r=1}^{s} u_r Y_{rk} - \mu_k^2$, and combination outputs were $\sum_{p=1}^{q} w_p^1 Z_{pk} - u_k^1 + \sum_{r=1}^{s} u_r Y_{rk} - u_k^2$. Given below is the general two-stage model with shared inputs that assesses DMU efficiencies:

$$s.t\begin{cases} \max \frac{\sum_{p=1}^{q} w_p^1 Z_{pk} - \mu_k^1}{\sum_{i=1}^{m} v_i^1 a_i X_{ik}} \\ \frac{\sum_{p=1}^{q} w_p^1 Z_{pj} - \mu_k^1}{\sum_{i=1}^{m} v_i^1 a_i X_{ij}} \le 1, j = 1,2,\ldots,n \\ 1 \ge a_i > 0;\ v_i^1 \ge 0;\ w_p^1 \ge 0, i = 1,2,\ldots,m \end{cases} \tag{1}$$

$$s.t\begin{cases} \max \frac{\sum_{r=1}^{s} u_r Y_{rk} - \mu_k^2}{\sum_{i=1}^{m} v_i^2(1-a_i)X_{ik} + \sum_{p=1}^{q} w_p^2 Z_{pk}} \\ \frac{\sum_{r=1}^{s} u_r Y_{rk} - \mu_k^2}{\sum_{i=1}^{m} v_i^2(1-a_i)X_{ik} + \sum_{p=1}^{q} w_p^2 Z_{pk}} \le 1, j = 1,2,\ldots,n \\ 1 \ge a_i > 0;\ v_i^2 \ge 0;\ w_p^2 \ge 0, i = 1,2,\ldots,m \end{cases} \tag{2}$$

$$\overline{E}_k = \max \frac{\sum_{p=1}^{q} w_p^1 Z_{pk} + \sum_{r=1}^{s} u_r Y_{rk} - \mu_k^1 - \mu_k^2}{\sum_{i=1}^{m} v_i^1 a_i X_{ik} + \sum_{i=1}^{m} v_i^2(1-a_i)X_{ik} + \sum_{p=1}^{q} w_p^2 Z_{pk}} \tag{3}$$

The efficiency of the first and second processes are:

$$\begin{aligned} \overline{E}_k^1 &= \frac{\sum_{p=1}^{q} w_p^1 Z_{pk} - \mu_k^1}{\sum_{i=1}^{m} v_i^1 a_i X_{ik}} \\ \overline{E}_k^2 &= \frac{\sum_{r=1}^{s} u_r Y_{rk} - \mu_k^2}{\sum_{i=1}^{m} v_i^2(1-a_i)X_{ik} + \sum_{p=1}^{q} w_p^2 Z_{pk}} \end{aligned} \tag{4}$$

Perhaps, it might not portray the correlation between the two stages if the input weights of the subprocesses in stage 1 did not equate to the output weights of the subprocesses in stage 2. Thus, we supposed that $v_i^1 = v_i^2$ and $w_p^1 = w_p^2$. In addition, we used DEA evaluation to assess the efficiency from the viewpoint of the most beneficial DMU. Accordingly, the optimal allocation ratio of input resources might differ from true values in this study. To ensure that both stages are allocated a specific amount of the shared inputs, the lower and upper bounds should be restricted to given intervals and generally determined by the users [63]. Herein, we focused on the percentage of investment in the first stage; based on the minimum value other than 0 was 0.359, and 0.35 was considered the lower bounds in the first stage. Notably, all programming calculations were performed using Matlab (v. R2018b, The Mathworks Inc., Natick, MA, USA).

Tobit regression

Besides the selected input and output variables, external factors like healthcare workers considerably influence the efficiency of the healthcare system. Thus, regression analysis was used to identify other factors that influence efficiency. As the efficiency value was a censored variable, based on prior research, Tobit regression was primarily used together with DEA research. Tobit regression was first proposed by Tobit and the standard form is as follows [64]:

$$\begin{aligned} y^* &= \alpha + \beta x_i + \mu_i \\ y^* &= y_i \ if\ y^* > 0 \\ y^* &= 0 \ if\ y^* \le 0. \end{aligned} \tag{5}$$

where y^* denotes the potential dependent variable; α denotes the constant term; x_i denotes the impact factor; β denotes the coefficient vector; μ_i denotes the error term. Then, we supposed that different types of healthcare

workers markedly influenced the efficiency of health resources. Thus, the following regression equations were formulated:

$$\begin{aligned}\theta_1 &= a_1x_{1j} + a_2x_{2j} + a_3x_{3j} + a_4x_{4j} + a_5x_{5j} + a_6x_{6j} + a_7x_{7j} + a_8x_{8j} + \mu_j(j = 1,2,\ldots,29)\\ \theta_2 &= \beta_1x_{1t} + \beta_2x_{2t} + \beta_3x_{3t} + \beta_4x_{4t} + \beta_5x_{5t} + \beta_6x_{6t} + \beta_7x_{7t} + \beta_8x_{8t} + \varepsilon_t(t = 1,2,\ldots,31)\end{aligned} \quad (6)$$

where θ_1 denotes the efficiency scores in the rural areas of the province; θ_2 denotes the efficiency scores in the entire province; j denotes the 29 provinces without Shanghai and Beijing; t denotes the 31 provinces including Shanghai and Beijing; x_{ij} denotes the variables of influencing factors on efficiency; a_i,β_i denotes the regression coefficient; and μ_i and ε_t denote the normally distributed error terms.

Results

Healthcare expenditures on rural medical resources and services

Optimal allocation of healthcare expenditures for rural medical resources and services

Table 3 explains the efficiency and optimal allocation of healthcare expenditures for the rural healthcare system in the first stage. First, in high-efficiency provinces, such as Hunan, Jiangxi, Tibet, Henan, and Ningxia, the initial stage of optimal allocation of healthcare expenditures ($\alpha^1_{\text{Government}}$ and α^1_{Social}) in rural medical resources was comparatively low, suggesting that these provinces could prioritize surging healthcare expenditures in the second stage. Second, provinces like Shandong, Guizhou, Heilongjiang, and Guangdong were considered fairly inefficient, and the optimal allocation of healthcare expenditures ($\alpha^1_{\text{Government}}$ and α^1_{Social}) in the first stage was equal to or very close to 1, suggesting that both government and society should prioritize surging healthcare expenditures in the first stage to enhance the overall efficiency of these provinces, particularly toward augmenting medical resources. Third, the distribution of government and social healthcare expenditures in the first stage exhibited inconsistency. For instance, in Guangxi and Hubei, the share of government healthcare expenditures ($\alpha^1_{\text{Government}}$) was 0.391 and 0.350, respectively, whereas the share of social healthcare expenditures (α^1_{Social}) was consistently 1.000. This finding suggested a need for governments to assign additional healthcare funds toward the second stage (medical services), whereas social healthcare expenditures should prioritize the first stage (medical resources). Conversely, provinces like Shanxi, Jilin, and Inner Mongolia displayed the opposite trend.

Efficiency of healthcare expenditures on rural medical resources and services

Figure 3 demonstrates the efficiency of healthcare expenditures on rural medical resources and services. First, provinces like Hunan, Jiangxi, Tibet, Henan, and Ningxia were leading on the efficiency frontier. Conversely, provinces like Sichuan, Hebei, and Zhejiang attained maximum efficiency mainly in the second stage only. Besides, provinces with higher overall efficiency values displayed higher efficiency values in their substages.

Second, in Chongqing, Hubei, Jiangsu, Zhejiang, and Guangdong, the efficiency of healthcare expenditures assigned to rural medical resources (first stage) was

Table 3 Healthcare expenditures on rural medical resources and services

Province	$\overline{E}_k$	$\overline{E}^1_k$	$\overline{E}^2_k$	$\alpha^1_{\text{Government}}$	α^1_{Social}
Hunan	1.000	1.000	1.000	0.541	0.568
Jiangxi	1.000	1.000	1.000	0.544	0.502
Tibet	1.000	1.000	1.000	0.789	0.564
Henan	1.000	1.000	1.000	0.821	0.447
Ningxia	1.000	0.999	1.000	0.350	0.406
Sichuan	0.988	0.956	1.000	0.350	0.350
Hebei	0.981	0.950	1.000	0.581	1.000
Guangxi	0.959	0.966	0.954	0.391	1.000
Shandong	0.932	0.971	0.894	0.890	0.988
Chongqing	0.899	0.794	0.998	0.677	1.000
Hubei	0.895	0.735	0.989	0.350	1.000
Hainan	0.872	0.842	0.887	0.350	0.368
Qinghai	0.871	0.801	0.947	0.592	0.350
Guizhou	0.830	0.941	0.701	1.000	1.000
Yunnan	0.800	0.776	0.829	1.000	0.823
Gansu	0.796	0.774	0.815	1.000	0.470
Anhui	0.779	0.711	0.850	0.631	1.000
Jiangsu	0.759	0.627	0.917	0.796	1.000
Sinkiang	0.750	0.701	0.803	0.684	1.000
Shaanxi	0.726	0.793	0.656	0.803	0.895
Zhejiang	0.719	0.438	1.000	0.621	1.000
Liaoning	0.710	0.715	0.704	0.803	1.000
Shanxi	0.697	0.901	0.474	1.000	0.350
Fujian	0.692	0.652	0.740	0.796	0.999
Heilongjiang	0.677	0.690	0.653	1.000	1.000
Jilin	0.588	0.612	0.549	1.000	0.350
Inner Mongolia	0.575	0.597	0.530	1.000	0.350
Guangdong	0.548	0.377	0.907	0.890	0.950
Tianjin	0.478	0.414	0.553	0.571	0.905
Mean	0.811	0.784	0.840	0.718	0.746

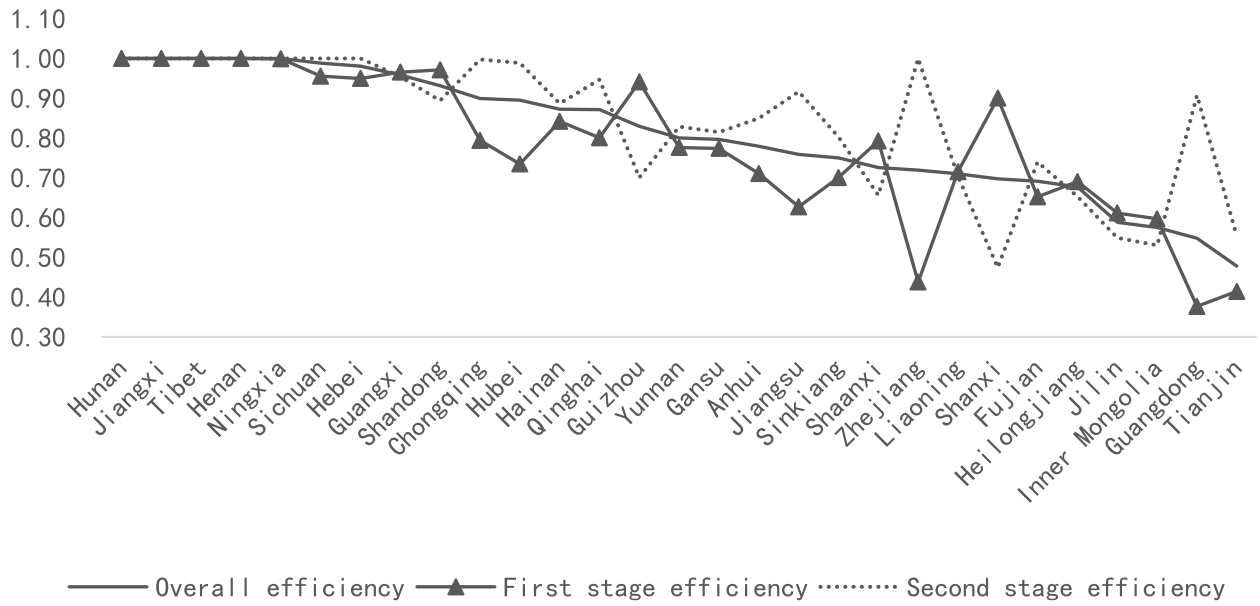

Fig. 3 The efficiency of healthcare expenditures on rural medical resources and services

markedly lower than those assigned to medical services (second stage), suggesting that while these provinces attained higher final outputs in terms of medical services, investments in medical resources were less efficient. However, provinces like Guizhou, Shaanxi, and Shanxi displayed the opposite trend, suggesting a need for these provinces to enhance the efficiency of healthcare expenditures in the second stage, using both government and social health funds to boost the production of medical services.

Healthcare expenditures on provincial medical resources and services

Optimal allocation of healthcare expenditures for provincial medical resources and services

Table 4 presents the efficiency and optimal allocation of healthcare expenditures in the provincial healthcare system, emphasizing disparities between investments in the entire province and those explicitly in rural areas. Regarding government healthcare expenditures assigned to medical resources ($\alpha^1_{\text{Government}}$), only Inner Mongolia presented an optimal ratio of 1; however, in Yunnan, Gansu, Shanxi, Heilongjiang, Jilin, and Inner Mongolia, the optimal ratio was 1 in rural areas. This finding suggested that Inner Mongolia should focus on raising provincial investment in government healthcare expenditures in the first stage, whereas other provinces should focus on increasing investments predominantly in rural areas. In contrast, provinces like Shandong, Hebei, Sichuan, Liaoning, Zhejiang, Guangxi, Jiangsu, and Heilongjiang displayed lower ratios for the entire province. Precisely, Sichuan and Guangxi exhibited lower ratios both in rural areas and for the entire province. Regarding social healthcare expenditures assigned to medical resources (α^1_{Social}), several provinces, including Chongqing, Heilongjiang, Shaanxi, Xinjiang, Shanxi, Jilin, Inner Mongolia, Tianjin, and Beijing, had a ratio of 1, indicating that investing social healthcare expenditures in the first stage can successfully augment provincial efficiency in medical resources.

Efficiency of healthcare expenditures on provincial medical resources and services

Figure 4 presents the efficiency of healthcare expenditures on provincial medical resources and services in descending order of overall efficiency. Provinces like Tibet, Jiangxi, Guizhou, Ningxia, Henan, and Hunan were recognized as efficient. However, Liaoning and Shanxi attained maximum efficiency solely in the first stage, while Zhejiang, Hubei, and Chongqing attained maximum efficiency only in the second stage. Besides, economically developed provinces like Tianjin, Beijing, and Shanghai displayed the lowest overall efficiency. Besides the efficient provinces, in most regions, second-stage efficiency surpassed that of the first stage, suggesting that healthcare expenditure investments did not fully augment medical resources relative to their effect on medical services. Furthermore, the lower efficiency noted in the first stage subsequently reduced overall efficiency.

In addition, consistent efficiency rankings emerged when comparing provincial and rural efficiency of healthcare expenditures on medical resources and

Table 4 Healthcare expenditures on provincial medical resources and services

Province	$\overline{E}_k$	$\overline{E}_k^1$	$\overline{E}_k^2$	$\alpha^1_{\text{Government}}$	α^1_{Social}
Tibet	1.000	1.000	1.000	0.745	0.550
Jiangxi	1.000	1.000	1.000	0.496	0.442
Guizhou	1.000	1.000	1.000	0.577	0.447
Ningxia	1.000	1.000	1.000	0.636	0.683
Henan	1.000	1.000	1.000	0.677	0.400
Hunan	1.000	1.000	1.000	0.420	0.789
Shandong	0.991	0.990	0.992	0.350	0.799
Hebei	0.978	0.969	0.981	0.350	0.539
Qinghai	0.974	0.975	0.973	0.607	0.366
Sichuan	0.970	0.909	0.996	0.350	0.822
Liaoning	0.968	1.000	0.957	0.350	0.999
Zhejiang	0.961	0.853	1.000	0.350	0.350
Guangxi	0.949	0.844	0.990	0.359	0.350
Hubei	0.948	0.853	1.000	0.451	0.557
Yunnan	0.928	0.857	0.963	0.430	0.454
Chongqing	0.915	0.831	1.000	0.709	1.000
Jiangsu	0.902	0.797	0.940	0.350	0.996
Gansu	0.898	0.889	0.905	0.845	0.521
Hainan	0.893	0.882	0.899	0.510	0.350
Heilongjiang	0.888	0.931	0.864	0.350	1.000
Shaanxi	0.874	0.863	0.884	0.597	1.000
Anhui	0.870	0.792	0.924	0.471	0.829
Sinkiang	0.849	0.759	0.959	0.774	1.000
Shanxi	0.824	1.000	0.639	0.924	1.000
Guangdong	0.818	0.669	0.950	0.883	0.350
Fujian	0.793	0.724	0.850	0.695	0.496
Jilin	0.776	0.808	0.735	0.907	1.000
Inner Mongolia	0.772	0.834	0.687	1.000	1.000
Tianjin	0.754	0.635	0.926	0.798	1.000
Shanghai	0.662	0.477	0.951	0.798	0.979
Beijing	0.610	0.575	0.665	0.863	1.000
Mean	0.896	0.862	0.924	0.601	0.712

services. Provinces like Hunan, Tibet, Jiangxi, Henan, and Ningxia illustrated maximum efficiency, while Guangdong, Fujian, Jilin, Inner Mongolia, and Tianjin displayed inefficient resource utilization. Typically, second-stage efficiency exceeded that of the first stage, and the efficiency of medical resources in rural areas markedly influenced provincial efficiency. Therefore, inefficient provinces should prioritize continuous supervision of healthcare funds and medical resource utilization, particularly in rural areas.

Impact of healthcare workers on efficiency in rural areas

In this study, we used the overall efficiency, first-stage efficiency, and second-stage efficiency as dependent variables in the three models, respectively. Besides, healthcare workers in THCs and VCs across China (excluding Beijing and Shanghai) were considered independent variables. Table 5 presents the Tobit regression results.

Only village doctors (x_6) were statistically significant ($P<0.05$) and positively correlated with efficiency in the overall efficiency model and first-stage efficiency model, suggesting that higher proportions of village doctors positively influenced overall efficiency and the efficiency of medical resource utilization in the first stage.

In the second-stage efficiency model, supplementary variables emerged as significant; besides village doctors, doctors (x_1) and health administrators (x_8) were also significant. Remarkably, health administrators (x_8) adversely influenced second-stage efficiency, indicating that a higher proportion of health administrators correlated with lower efficiency in providing medical services (second stage). Of note, the magnitude of the coefficient for health administrators (x_8) was markedly higher in absolute terms than doctors (x_1) and village doctors (x_6), emphasizing its substantial effect on decreasing second-stage efficiency.

These findings suggested that improving the distribution of healthcare workers, especially increasing the percentage of village doctors while supervising the percentage of health administrators, could augment the overall efficiency of healthcare delivery in rural areas.

Impact of healthcare workers on efficiency in the whole province

Regarding the entire province in China, doctors and nurses constitute the core healthcare workforce, accounting for 29.9% and 34.3%, respectively, of all healthcare workers. Conversely, village doctors constituted a smaller percentage, averaging 6.5%, with Tibet displaying the highest percentage (30.6%) and Zhejiang the lowest (1%). These differences underscore regional inequalities in healthcare workforce conformation across provinces. Table 6 presents the effect of healthcare workers on efficiency at the provincial level, showing that the factors influencing provincial efficiency vary marginally from those influencing efficiency in rural areas.

Except for pharmacists (x_3), medical technologists (x_4), and trainees (x_5), all other types of healthcare workers in the overall efficiency model were statistically significant ($P<0.05$). Besides, doctors (x_1, coefficient: 1.769), nurses (x_2, coefficient: 1.386), and village doctors (x_6,

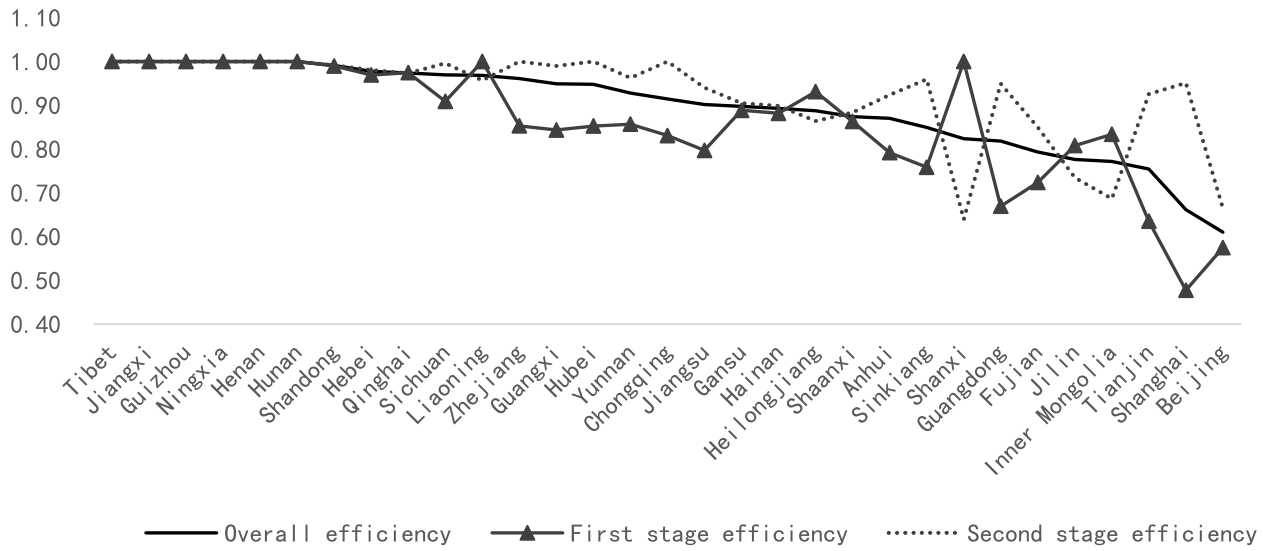

Fig. 4 The efficiency of healthcare expenditures on provincial medical resources and services

Table 5 Impact of healthcare workers on efficiency in rural areas

Variable	Model 1		Model 2		Model 3	
	Overall efficiency		First-stage efficiency		Second-stage efficiency	
	Coefficient	*P*	Coefficient	*P*	Coefficient	*P*
Doctors (x_1)	0.450	0.281	0.038	0.935	0.862	0.047
Nurses (x_2)	0.597	0.426	0.398	0.631	0.751	0.337
Pharmacists (x_3)	1.201	0.763	0.577	0.896	2.905	0.484
Medical technologists (x_4)	4.321	0.393	6.956	0.213	1.272	0.809
Trainees (x_5)	0.540	0.594	0.067	0.952	1.118	0.290
Village doctors (x_6)	1.020	0.000	1.282	0.000	0.719	0.000
Nonmedical technologists (x_7)	5.213	0.206	4.668	0.304	6.115	0.155
Health administrators (x_8)	−5.318	0.099	−2.899	0.415	−8.548	0.011

Table 6 Impact of healthcare workers on provincial efficiency

Variable	Model 1		Model 2		Model 3	
	Overall efficiency		First-stage efficiency		Second-stage efficiency	
	Coefficient	*P*	Coefficient	*P*	Coefficient	*P*
Doctors (x_1)	1.769	0.002	2.282	0.003	0.906	0.222
Nurses (x_2)	1.386	0.003	1.018	0.113	1.365	0.027
Pharmacists (x_3)	−3.851	0.122	−6.966	0.039	−1.204	0.711
Medical technologists (x_4)	2.192	0.566	5.139	0.321	3.354	0.502
Trainees (x_5)	0.908	0.210	0.269	0.785	1.050	0.268
Village doctors (x_6)	1.470	0.000	1.677	0.000	1.191	0.000
Nonmedical technologists (x_7)	−3.514	0.038	−5.012	0.029	−0.637	0.773
Health administrators (x_8)	−2.568	0.030	−2.024	0.208	−1.869	0.227

coefficient: 1.470) positively affected efficiency. However, nonmedical technologists (x_7, coefficient: −3.514) and health administrators (x_8, coefficient: −2.568) exerted an adverse impact. In addition, pharmacists (x_3) exerted a significant negative impact on first-stage efficiency, which could be attributed to historical policies where pharmacy profits subsidized medical services. Furthermore, only nurses (x_2) and village doctors (x_6) positively influenced second-stage efficiency. In contrast to rural areas, doctors (x_1) and health administrators (x_8) did not influence provincial second-stage efficiency.

Discussion

Chinese provinces have varied healthcare expenditures owing to variances in economic growth and regional attributes [65]. Typically, economically developed provinces, such as Guangdong, Jiangsu, and Zhejiang, assign considerable government healthcare expenditures; despite not being on the efficiency frontier, these provinces can invest profoundly in constructing medical facilities, upgrading infrastructure, and augmenting healthcare services [66–68]. Conversely, provinces in central and western China, including Guizhou, Yunnan, Gansu, Hunan, Tibet, Ningxia, Qinghai, and Xinjiang, tend to have lower government healthcare expenditures [9], which often poses challenges like inadequate healthcare resources and unfinished service coverage in certain areas. Besides, although Tibet and Ningxia were recognized as efficient, attaining an efficiency score of 1 in both rural and provincial contexts, this is mainly attributable to their relatively lower total healthcare expenditure than other provinces. Moreover, provinces with a higher proportion of rural areas, including Hunan, Jiangxi, Henan, and Sichuan, had a comparatively low initial-stage optimal allocation of healthcare expenditures although the efficiency of healthcare expenditures on rural medical resources and services was positioned on the efficiency frontier. This advocates that these provinces should focus on surging healthcare expenditures for medical services. Overall, these differences in healthcare expenditures accentuate the diverse socioeconomic landscapes across China's provinces, emphasizing the discrepancies in resource allocation and varying priorities in healthcare investment among economically advanced, central/western, and highly concentrated rural areas.

Meanwhile, economically developed provinces, including Tianjin, Beijing, and Shanghai, display the lowest overall efficiency in healthcare, perhaps, because the concentration of prestigious hospitals causes the appearance of inefficiency in these regions. This disparity is evident in the overloading of prestigious hospitals and the low utilization rates of some PHC facilities [69]. Moreover, it reveals problems in scheduling appointments with specialists, although some general practitioners have available appointment slots. Furthermore, these hospitals prioritize scientific research to advance medical technology. However, this study did not measure the effect of medical technology advancements on the efficiency of healthcare expenditures.

Considering the impact factors on efficiency, village doctors play a pivotal role in augmenting healthcare expenditure efficiency and warrant further discussion. Healthcare workers in rural China often lack higher education and adequate experience. Moreover, there is a shortage of personnel at the higher levels of the professional hierarchy. In THCs, healthcare workers with a bachelor's degree only accounted for 15%, and the main educational level comprised degrees from junior colleges (accounting for 43.0%). In VCs, healthcare workers with technical secondary school education accounted for 90.6% [9]. Compared with their counterparts in provincial healthcare settings, rural healthcare workers typically hold lower professional titles. Precisely, among provincial healthcare workers, 8.9% hold senior titles, 19.8% hold intermediate titles, and 62.3% hold junior titles [9]. In THCs, these numbers are 3.2% for senior titles, 13.9% for intermediate titles, and 72.7% for junior titles. In VCs, only 0.7% of healthcare workers hold intermediate or senior titles, and 50.6% do not hold any professional title at all [9]. Despite their accessibility, rural healthcare workers often offer a temporary solution to resource scarcities; however, their low educational attainment and lack of experienced professionals signify substantial bottlenecks in offering superior medical services and augmenting management activities in rural areas. This limitation hampers their capability to diagnose new diseases and perform fundamental medical procedures efficiently. Furthermore, the lower skill level and scarcity of talent among rural healthcare workers create a downward spiral, causing less efficient use of healthcare expenditures.

Figure 5 presents the shifting downward trend in the number of THCs and VCs from 1990 to 2021. As of the end of 2021, there were 34,943 THCs and 599,292 VCs, depicting cuts of 919 and 9536, respectively, compared with the previous year [9]. The sharp decline in VCs happened particularly in 2003, whereas THCs witnessed a noteworthy surge in 1993, partly because of the merger of administrative villages or institutions. Several studies have reported THCs and VCs to be in poor condition. One study reported that the THCs and VCs located in rich areas had higher levels of human resources and additional fixed assets than those in impoverished areas [70]. Although China's National Health Commission decrees that all THCs and VCs possess certain basic levels of medical equipment and facilities, many in impoverished areas lack them. Another study demonstrated that among

Fig. 5 The number of township health centers (THCs) and village clinics (VCs) in China, *China Health Statistical Yearbook 2022*

all the healthcare institutions, the proportion of pediatric resources held by PHC institutions providing pediatric services and their capability for offering such services exhibited year-over-year downward trends overall [71]. Given these challenges, the government should work more on financing PHC institutions.

Figure 6 presents patient visits to THCs and VCs from 2004 to 2021. By the end of 2021, the total inpatient and outpatient visits to THCs reached 1.161 billion, registering a surge of 66 million compared with the previous year. Nevertheless, the number of inpatient visits to THCs was 32.41 million, which was 1.61 million less than the previous year. Meanwhile, the number of total inpatient and outpatient visits to VCs has declined constantly since 2013. Per the *China Health Statistical Yearbook 2022*, the occupancy rate of beds in THCs was 48.2%, which was 2% lower than the previous year. Furthermore, the number of consultations and treatments in VCs was 1.34 billion, which was 90 million fewer than the previous year [9].

In China, THCs and VCs cover widespread rural areas and constitute an integral part of elementary medical and healthcare services. THCs mainly focus on diagnosing and treating common diseases and often-encountered diseases, whereas VCs provide primary diagnosis. In recent years, many patients choose tertiary hospitals when seeking treatment, even for post-operative rehabilitation or chronic diseases. One of the primary reasons for this is that the facilities and healthcare workers in THCs and VCs cannot fulfill their medical demands. Overall, the rural healthcare services system is a vital factor influencing the stability of rural society and is essential for healthcare development.

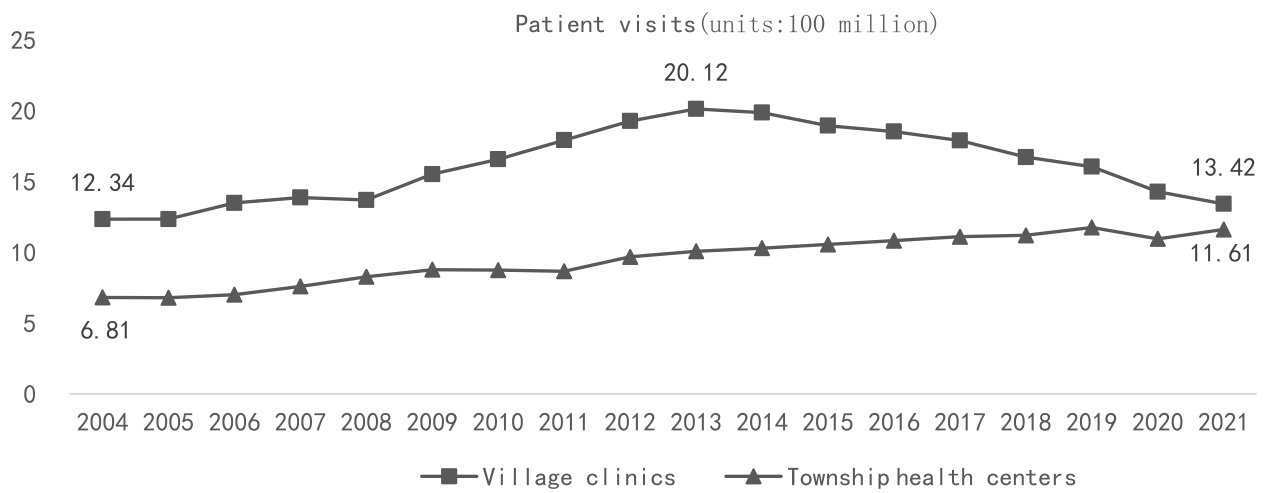

Fig. 6 Patient visits to township health centers (THCs) and village clinics (VCs) during 2004–2021 per the *China Health Statistical Yearbook 2022*

Policy recommendations

Education and training for village doctors and other healthcare workers in rural areas should be arranged. It is essential to uplift their knowledge and skills meaningfully, aiming to create a new standard in healthcare worker proficiency, especially in serving rural residents. First, village doctors should be reinforced and stimulated to undergo all-inclusive education, including on-the-job training, to satisfy the requirements and become qualified doctors. In addition, they should proactively engage in continuing education and training activities to augment their professional skills. Second, the training of general practitioners in rural areas should be accelerated. The government could also consider signing a general practitioner orientation training agreement with students from underprivileged families; this initiative aims to tackle the challenge of talent scarcity in rural areas efficiently, as well as assist underprivileged students in completing their studies. Third, efforts should be made to enable support from tertiary hospitals to THCs and VCs, from urban areas to rural regions, and from developed provinces to underdeveloped provinces. China has four levels of doctors, namely, chief physicians, associate chief physicians, attending physicians, and residents. Authorities should strictly impose guidelines necessitating urban doctors to serve at PHC facilities in rural areas before advancing to the rank of associate chief physicians; this measure aims to augment the overall quality and efficiency of healthcare workers in rural areas.

The functions and business scope of THCs and VCs require further elucidation. It is compulsory to fortify the formation of an orderly hierarchical treatment system to minimize on-site waiting times for patients. In addition, THCs should prioritize covering public health, preventive care, elementary medical services, rehabilitation, and diagnosis and treatment of chronic diseases for patients. Besides, they should smoothen the transfer of critically ill patients to larger hospitals for intensive medical care. Meanwhile, VCs should focus on immunizations, epidemic prevention, chronic disease management, basic hygiene education, and guaranteeing access to vital healthcare services for rural populations.

Augmenting the allocation of healthcare expenditure on rural medical resources and services is essential. Presently, a conflict exists between surged healthcare investment and inefficient output. The government should prioritize healthcare expenditures by fast-tracking the construction of medical institutions like THCs and VCs; this encompasses infrastructure development, procurement of equipment and medical supplies, and investment in the training of rural healthcare workers, predominantly village doctors. Moreover, efforts should be directed toward constantly enhancing management skills, medical technology, and service quality within the healthcare system; this approach will advance the diagnosis and treatment processes, eventually leading to better healthcare services for rural populations.

Limitations

First, healthcare workers are the only independent variable. Nevertheless, hospitals in economically developed provinces prioritize scientific research to upgrade techniques and medical technology, which could not be sufficiently measured in terms of efficiency in this study. Besides, this limitation deters a comprehensive understanding of the impact of healthcare workers on the efficiency of healthcare expenditures. Second, healthcare investments over several years ascertain the number of beds and healthcare facilities in any province. The healthcare expenditure in one given year does not precisely depict the number of beds in any given year. We only used healthcare expenditures in one given year, which is another significant limitation.

Conclusions

First, the overall efficiency of healthcare expenditures in rural areas typically trails that of the entire province, with second-stage efficiency mostly beating first-stage efficiency. This signifies that rural areas, which face scarcities of medical resources, do not receive satisfactory support from extensive government and social healthcare expenditures. Second, for the rural healthcare system, the priority should be on increasing healthcare expenditures for medical services in high-efficiency provinces. Meanwhile, healthcare expenditures should be increased on medical resources in provinces with relatively low efficiency. Regarding provincial efficiency, investing in social healthcare expenditures in the first stage can successfully augment the overall provincial efficiency; specifically, these funds should be directed toward enhancing medical resources. Finally, village doctors complement doctors in offering medical services, markedly enhancing provincial and rural efficiency across all stages. Besides, they play a pivotal role in increasing the efficiency of healthcare expenditures compared with other healthcare workers. Conversely, higher proportions of pharmacists, nonmedical technologists, and health administrators undermine the overall efficiency and health outcomes. Furthermore, administrative overstaffing in THCs and VCs indicates a necessity for a moderate reduction in excessive management positions.

Abbreviations

DEA	Data Envelopment Analysis
PHC	Primary Healthcare
THCs	Township Health Centers
VCs	Village Clinics

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Authors' contributions
JJC analyzed the data and wrote the manuscript. XMK was the project supervisor and sequentially aligned the parts of the research paper. PZ and WRS was involved in the data collection and participated in manuscript writing and revision. All authors have read and agreed to the published version of the manuscript.

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Data availability
The data were acquired from the *China Statistical Yearbook, China Health Statistical Yearbook* and *China Rural Statistical Yearbook* in 2021 and 2022, which was published in the Chinese language by the Chinese central government. Please contact the author for data requests.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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