学 位 論 文

Analysis of Chinese Healthcare Resources Allocation's Equality
（中国の医療資源配分の平等性に関する研究）

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２０２３年度

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Abstract

The equality of healthcare resource allocation is considered an essential issue worldwide, especially for developing countries such as China. China, with a large population, has a broad landscape. It has always been facing whether there are enough medical services to meet the needs of people and whether people can access healthcare services equally. Many studies have tried to reach the medical equality level in China by different methods and directions. This study tried to reveal that gradually by horizontal and vertical comparison. For the horizontal side, the medical equality level of 31 Chinese provinces was assessed and compared to find the inequality areas; that of Chinese rural and urban regions was evaluated and compared to find the gap between the two regions. The Chinese government has been promoting the level of medical accessibility. It tried to narrow the gap between the developing and developed areas. This study aims to show the changes in medical services over ten years, which is the vertical direction. It was presented whether the medical reforms make the healthcare services developed. This study was conducted step by step. First, the allocation of healthcare resources was evaluated by the Health Resources Density Index method to learn whether it reached the medical allocation requirements of the government (Chapter 2). Next, the Theil Index assessed the equality of healthcare resource distribution. China was divided into different segments to compare the level of that (Chapter 3). Then, the healthcare institution's efficiency was considered an indicator of equality

of medical service to be evaluated by A data envelopment analysis and Malmquist Productivity Index (Chapters 4 and 5). There were three methods used in this study to evaluate the equality situation. The Health Resources Density Index was used to learn the general situation of the medical resource allocation. The Theil Index has a positive feature that presents the distinction among groups and shows the contribution of equality from within and between groups. A data envelopment analysis and the Malmquist Productivity Index were used to assess the efficiency of institutions and the changes. Inefficient institutions' abundant input resources were shown as evidence for policymakers. There are some merits in this study. First, it modified the formula of the Theil Index. The traditional formula just considered the population as a parameter, but for countries with broad landscapes, the area of land plays a key role in assessing equality level. That's why this study put the land area into the Theil Index as a parameter, making people learn the real situation. Second, this study considered the efficiency of institutions as an indicator of equality level. To be efficient, institutions can make the medical system equal. The redundant medical resources could be invested in the areas with a shortage of healthcare resources.

Chapter 1 Introduction

1.1. Background:

The equality of healthcare allocation is considered a key issue worldwide. Health equity is the absence of differences in the healthcare system among populations regardless of economic, geographical, social, power and prestige status[1-3]. The guiding principle in this concept is to achieve health equality by ensuring accessibility to healthcare and addressing any socially unacceptable disparities in healthcare that can be remedied through policy decisions[4-6]. The World Health Organization promotes three fundamental ethical principles for health resource allocation: equity, efficiency, and utility[7]. In 2006, the World Health Organization (WHO) identified a global shortage of 2.4 million doctors, nurses and midwives[8]. For developed countries, it is early to focus on this issue to involve many resources for people, so they have a high level of equality of healthcare allocation. However, Japan has been reducing the number of medical students due to an anticipated decline in the need for doctors. Despite being a developed country, Japan has one of the lowest per capita physician numbers. There is a significant demand for doctors in Japan, which raises concerns about the fairness of healthcare resources distribution in the country[9].

For developing countries or low- and middle-income countries, inequality is presented as a problem. Governments try to promote the level of health care services to meet the needs of people. Therefore, many studies were conducted to reveal the situation of national medication capacity that was taken into consideration by policymakers. According to research by the World Health Organization, 80% of low- and middle-income countries face a shortage of healthcare resources, such as doctors and midwives[8]. Fiji demonstrates relatively better fairness in healthcare resource allocation compared to other low- and middle-income countries, although it still faces challenges related to a shortage of healthcare personnel[10]. In the case of Ethiopia, a country where approximately 80% of the population resides in rural areas, research indicates a significant inequality in healthcare resource distribution[11]. Most Asian countries are developing areas facing a shortage of healthcare resources. For example, during the prevention of epidemics in Southeast Asia, it has been observed that the fairness of healthcare resource allocation faces challenges[12].

China is also a developing country in Asia with huge geographic areas and a large population, which encounters the inequality of medication resource problem as well. Based on the geographic situation, China is often divided into three regions: the eastern, middle, and western regions. Three regions with disparity of economic development showed different levels of inequality in healthcare allocation by some studies. For example, from 2013 to 2018, there has been a consistent decrease in the equality of public health resources, primarily driven by disparities within the western region[13]. Besides, some studies focused on the provincial equality situation of that. Jiangsu is considered a developed region.

Between 2015 and 2019, the equity in the distribution of basic medical resources was better than that of financial resources[14]. Some studies focused on some single indicators or some fields, such as the number of the staffs, epidemiological field. Research on the equitable distribution of institutions like the Centers for Disease Control and Prevention (CDC) has shown disparities in fairness between low-low cluster areas in the western region and other areas[15]. A few researchers considered dividing China into urban and suburban areas and found that inequality existed between the two areas[16].

It is noticeable that a few studies mention efficiencies could be considered as a part of equality of healthcare accessibility. During the same period, efficient healthcare institutions can provide medical services to more people than inefficient ones, which could push the development of equality in healthcare allocation. The outcomes of the analysis revealed that the health systems in the majority of Asian countries are inefficient. These findings suggest that many countries have the potential to enhance the efficiency of their health systems with their existing resources[17]. A study conducted in Saudi Arabia revealed that 75.8% (69 out of 91) of public hospitals were deemed technically inefficient[18]. In Japan, a study measured 86 Hokkaido hospitals' efficiency and found that level was moderately above average [19]. Chinese researchers also conducted studies on the efficiencies of healthcare institutions. Based on province-level panel data from 2002 to 2008, empirical estimates suggest that hospital efficiency is moderate. It shows a gradual increase from 0.6881 to 0.8159 over this period. There is an efficiency gap observed between coastal and non-coastal regions. Still, the reduction in this gap is primarily attributed to the rapid improvement in efficiency in the western regions. However, the central regions consistently maintain a significantly lower efficiency score than the eastern and western regions[20].

1.2. The aim and design of this study

Because of the importance of equality in medication allocation worldwide, especially in China, regarded as a large economic system in Asia, this study involved three stages for trying to reveal the equality level of healthcare services in China systematically and comprehensively. The public data pool from the Chinese Statistic Yearbook was used to measure the equality situation. The study-specific process was presented in the following. First, the allocation of healthcare resources would be calculated (Chapter 2). Second, the equality of the healthcare allocation will be presented (Chapter 3). Finally, the efficiency of the healthcare institutions will be shown (Chapters 4 and 5).

1.3. Methods

1.3.1. Health Resource Distribution Index Methods

In the first stage, this study used The Health Resource Distribution Index (HRDI) to measure the allocation of healthcare resources. Furthermore, the results would be compared with the allocation requirement of the Chinese government to evaluate the effect of medical reforms. It is employed to assess the impact of both population and geographical factors on the concentration of health resources, thus mitigating biases that may arise from focusing solely on one aspect of population or geography[14]. HRDI is a widely used methodology in China. Since the 1990s, numerous studies have been conducted in various regions of China to evaluate the distribution of healthcare resources and highlight issues related to equity [21, 22]. This study introduces land area as a significant factor in assessing equity, especially in counties within China with extensive land areas that can affect the fairness of healthcare services.

1.3.2. Theil Index Method

In the second stage, this study will assess the equality of the healthcare allocation by the Theil Index. The World Health Organization (WHO) has identified this approach for measuring inequality in the distribution of health workers and explaining the sources of this inequality[23]. The Theil indices are regarded as straightforward measures since they do not rely on additional parameters and only require data on the numbers of doctors and the population. These indices have been extensively employed to compare the geographic distribution of doctors across regions or over time[24, 25]. The Theil index can break down equity assessments into within-group and between-group components, making it useful for identifying the source of inequity within or between different groups [25, 26].

1.3.3. Data Envelopment Analysis and Malmquist Index Methods

In the third stage, Data Envelopment Analysis (DEA) and Malmquist indices would be used to evaluate the efficiency of the healthcare institutions, which is regarded as an indicator of equality of healthcare services. It is a commonly employed method for assessing the efficiency of hospitals in various aspects, including patient visits, surgeries, and discharges. DEA operates on the fundamental principle of establishing an efficient Decision-Making Units (DMUs) frontier that encompasses all inefficient DMUs. Each DMU's efficiency is determined by measuring its distance from this frontier. Most DEA models focus on calculating a technical efficiency score, which means that the correct allocation of resources needs to be factored into the measurement. To achieve technical efficiency, a DMU only needs to maximize its theoretical production potential [27]. One significant advantage of DEA is that it does not require the specification of a production function. Instead, the processes within the DMU are considered a "black box", where all relevant inputs are transformed into characteristic outputs of the production process. Therefore, it is essential to know all pertinent inputs and outputs. This flexibility allows DEA to simultaneously consider multiple inputs and outputs, which is one of the reasons for its popularity in healthcare efficiency analysis[28]. The Malmquist index was initially introduced by Malmquist for consumption analysis, where it relied on indifference curves and input distance functions to compare different consumption bundles [29]. Subsequently, Caves et al. extended this concept to production analysis. They calculated the ratio between the distance function and the productivity index and coined it the Malmquist index [30, 31]. Calculating the Malmquist index, which measures changes in productivity over time, along with its decomposition, provides insights into the changes in its efficiency[32].

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Chapter 2 Measuring the inequalities in the distribution of public healthcare resources by the HRDI (Health Resources Density Index): data analysis from 2010 to 2019

2.1. Introduction

The equality of healthcare resource distribution is an important issue worldwide[1, 2]. The equality of the healthcare service is considered that there are not any differences in accessing health services among regions, even though there exist gaps in social, economic, geographical, power and prestige levels[3,4,5,6]. In particular, abundant studies have been conducted in developing countries[1-3, 7-9]. In Brazil, a study was conducted to monitor inequalities in the health workforce for over 15 years and showed that the equalities had increased over time. Furthermore, the distribution of doctors and nurses was more unequally distributed across the country[2]. Proverbially, China is still a developing country, although there has been an incredible improvement over the decade. Many social services, especially health services, have been enhancing. The government is trying to improve the levels to meet the requirements of the people, including the healthcare service levels[10]. Although China has prominent people and land, economic development has gaps in different areas. Based on published studies, China had an imbalance distribution of health services among other areas and had gaps between urban and suburban areas[11]. A Chinese study showed that inequalities existed between urban and suburban areas due to an imbalance of economic levels and differences in land size and population[12,13]. Many studies have focused on equality research and used the Gini or Theil Indexes, popular methods in this field[14,15]. Nevertheless, the health resource density index (HRDI) method is also commonly used to assess the equality of health service resources in China[7,16]. This method was successfully used in national-level research, which showed that there were huge gaps in the health workforce distribution between the eastern and middle-west areas[7,16,17]. In addition, it has been used for provincial health resource assessment in many studies from China[7,16,18]. A study was conducted to evaluate the equality of healthcare resource allocation and compared the distribution of health institutions in 13 cities in the Jiangsu province, China by this method[16]. In 2019, the Notice of the General Office of the State Council on Issuing the Outline for the Planning of the National Medical and Health Service System (2015-2020) was promulgated to improve the service availability, capacity, and efficiency. The governments of all provinces, autonomous regions and municipalities must implement it conscientiously[19]. That's why it is necessary to study the recent situation of healthcare resource distribution at the national level to examine the effect of this policy. This would be effective evidence to enable policymakers to make decisions or modify existing policies to balance developed and developing areas. The Theil and Gini indices consider the number of the population as an important factor[19,1], which are popular methods to assess the equality situation. It bases on the ratio of the resources to the population, the value could demonstrate the healthcare situation to support the researchers in identifying equality[20]. However, it cannot consider the area of the region's land as a factor that influences the distribution and equality of the healthcare resource. So, this study selects the HRDI method to evaluate that. It uses the density of healthcare resources to present the situation of their distribution[21]. This method considers the factors of the population and the land area. It is not an inevitable consideration that land is an important factor in the evaluation of equality in many large areas.

Published literature used this method focused on the provincial level to conduct studies but not on the national situation. So, this study aimed to evaluate the national healthcare resource distribution, which showed the health service equality level. This study extracted data from the five key health service factors over the decade from the national statistics departments. We assessed the distribution of healthcare resources via HRDI formula and attempted to show the level of equality in health services in China. The Notice of the General Office of the State Council on Issuing the Outline for the Planning of the National Medical and Health Service System (2015-2020) was announced in 2015 and offered the requirement of the ratio of vital health resources to the population[22]. We compared the data from 2019 to the aim value from the government to determine whether each province met the requirements after development over five years (2015 to 2020).

2.2. Materials and Methods

2.2.1. Data sources and Setting

Data were extracted from the Chinese Statistic Yearbook (2010-2019), which covered 31 provinces, autonomous regions, and municipalities separated into four groups: northeastern, eastern, central, and western regions. The northeastern region included Heilongjiang, Jilin, and Liaoning (three provinces). The eastern region included Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan (10 provinces and municipalities). The central region included Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan (six provinces). The western region included Inner Mongolia, Chongqing, Guangxi, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang (12 provinces, autonomous regions, and municipalities). The data included the amount of investment, the number of health institutions and beds, and the ratio of doctors and nurses per 1000 people, which were used to calculate the value of the HRDI to evaluate the distribution and equality of healthcare resources. Of the five, three factors were compared with the national medical and health service system requirements, which were the ratio of doctors, nurses, and beds to per 1000 people.

2.2.2. Statistical Analysis

The HRDI was proposed by Zheng Xiaohua to assess the healthcare resources' distribution in 1993[23]. Several studies was conducted to validate the effectiveness of the method[18,24]. The HRDI represented the influence of the population and geographical factors on the density and equality of healthcare resources, which could avoid the limitation of considering only a factor of the population[25,26]. The HRDI formula was[24,25] :

$$HRDI = \sqrt{\frac{HR_i}{P_i} * \frac{HR_i}{A_i}}$$

HRi: health resource quantity of the *ith* region

Ai: geography of the *ith* region

Pi: population of the *ith* region

HRDI: the value of the health resources density index

HRDI is a commonly used method in China to study the distribution of resauses[7,16,18,24]. From the 90s, many studies have focused on regions in China to assess the situation of healthcare resources and demonstrate their equality[27,28]. This study introduced land area as an important factor for the evaluation of equality, especially in counties like China with a relatively large land that influenced the fairness of health services. In addition, there were requirements of the ratio of doctors, nurses, and beds to per 1000 people, as announced by the government's document. This study compared the data of each province by 2020 to the aim value, which showed the effect of medical service development from 2015 to 2019.

2.3. Results

2.3.1. The results of the HRDI

The HRDI values of the healthcare resources in different areas are shown from Figure 1 to Figure 5. For investment in Figure 1, the trends of the four areas were upward over the ten years. Rapid, sustained growth occurred in the northeast and east areas (approximately 0.002–0.0045), and modest growth occurred in the central and western areas (approximately 0.001–0.003). However, in 2019, the northeast region experienced an incredible downward trend from 0.0046 to 0.0018, more than a half of the value of 2018. Before 2019, the value of the middle and west density of the investment was less compared to that of the eastern areas, however, in 2019, the situation completely reversed. There were small fluctuations in the HRDI of the institutions between 2010 and 2018 in the northeast and east areas, as shown in Figure 2, and the value decreased to the lowest in 2014. The HRDI of the two areas was almost twice as large as the values in the western and middle areas. The trend of the HRDI in the central and western areas slightly decreased over ten years. It was not disregarded that the value of the institutions in the northeastern region and the eastern region had a marked drop from 0.37 in 2018 to 0.15 in 2019 and from 0.34 in 2018 to 0.17 in 2019, respectively. Meanwhile, in Figure 3, the situation of the HRDI regarding beds was similar to that of the institutions, except for a gradual increase from 2010 to 2018 in four areas. According to the doctors and nurses in Figures 4 and Figure 5, respectively, their trends were similar, while the density of the doctors was almost slightly greater than that of the nurses. In the first nine years, it was seen that the HRDI of the northeast areas and east areas was much greater than the western and central areas, especially in 2018 when the differences were maximum. In 2019, there were changes in the four areas. Eastern areas experienced a decrease in doctors and nurses from 4.4×10^{-5} to 3.8×10^{-5} and from 4.5×10^{-5} to 4.1×10^{-5}, respectively. It was worth noting that numbers had fallen precipitously in the northeast area for both factors in 2019. However, there were dramatic increases in doctors and nurses in the two areas of western and middle areas. These values approached the HRDI value in the eastern area in 2019 (approximately 3.5×10^{-5} of doctors, 4.1×10^{-5} of nurses, respectively).

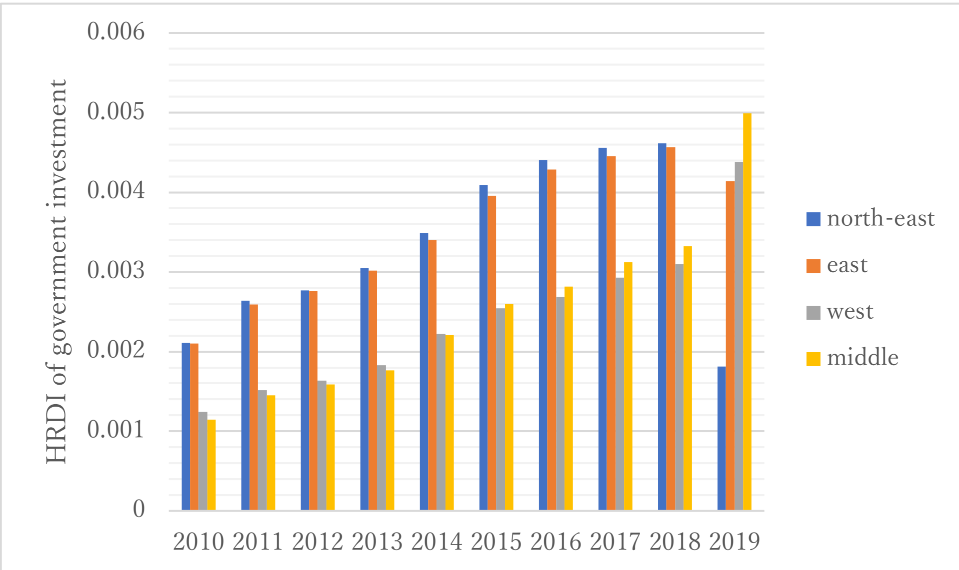

Fig 1: The HRDI of the health resources in investment when dividing China into four areas.

2.3.2. A comparison with requirements of the government

The situation of the 31 provinces' health services developments and each province's ratio of doctors, nurses, and beds to 1000 people in 2019 is presented in Table 1 with the aim ratio of those from the government document. The values in the orange table cells reached the requirements, while the values in the grey table cells did not. A total of 17 provinces (Liaoning, Jilin, Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Neimenggu, Shanxi, Qinghai, Ningxia, Xinjiang, Shanxi, Hubei, and Hunan) met the requirement of at least 2.5 doctors per 100 people. In addition, nine provinces met the requirement of at least 3.14 nurses per 1000 people (Beijing, Shanghai, Jiangsu, Zhejiang, Hainan, Shanxi, Ningxia, and Hubei). Furthermore, 17 provinces (Liaoning, Jilin, Heilongjiang, Jiangsu, Shandong, Neimenggu, Chongqing, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Qinghai, Xinjiang, Henan, Hubei, and Hunan) met the requirement of six beds per 1000 people. Remarkably, only four provinces met all three indicator requirements (Jiangsu, Shandong, Shanxi, and Hubei).

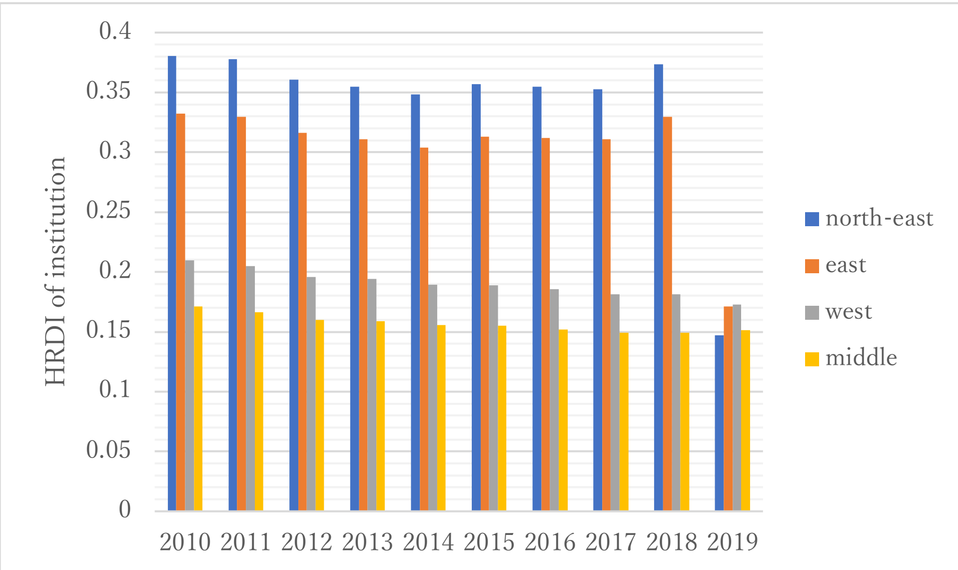

Fig 2: The HRDI of the health resources in institutions when dividing China into four areas.

2.4. Discussion

From Figure 1, it is shown that the sum of the investment gradually increased, which means that the government took efforts into healthcare services and tried to narrow the gaps between the developed and developing areas. The eastern area was a developed region in China, hence the local government invested additional money and attention in the development of health services. However, the national government found economic development differences between the eastern and middle-western areas. Based on the national medical reform of 2009, investment increased in developing areas. A study also mentioned that a great deal of financial investment in the backward region promoted the level of local medical services sustainably to meet the people's needs[19]. However, financial investment should match developing economic speed. With sufficient medical institutions and adequate workforce and equipment, too much financial investment was unnecessary and could produce fiscal profligacy problems. As a result, from 2015, the investment in medical services gradually approached stability among the four areas.

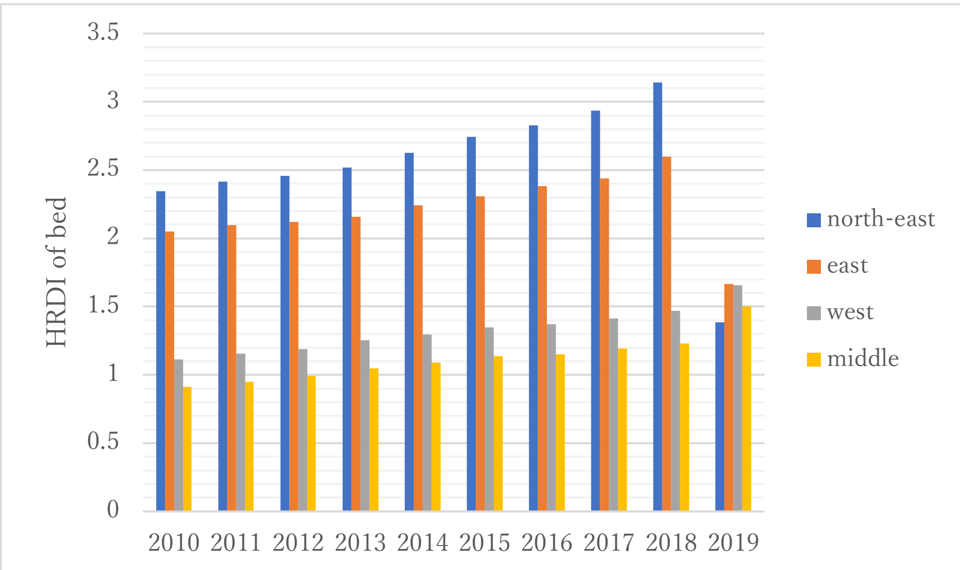

Fig 3: The HRDI of the health resources in beds when dividing China into four areas.

For the HRDI of the institutions, beds, doctors, and nurses, from 2010 to 2018, although some smaller fluctuations were seen, the situation did not show an obvious increase. In addition, the northeast and east areas had significant advantages over the western and central regions. There were many reasons for this. First, healthcare development did not catch up with the increasing speed of the population and could not meet the needs of the people. Second, medical education takes approximately eight to ten years, a long time to influence the number of medical workforces. Finally, it must be mentioned that the developed regions were more attractive to doctors and nurses than developing areas. A study stated that China's developed areas offered a higher salary for healthcare workers and a more comfortable living environment, such as children's education and public traffic systems[12]. However, it was worthy of notice that the ratio of doctors and nurses increased significantly in the west and central areas in 2019 since the government launched several policies to encourage talented workforce and professionals to work there, such as offering financial subsidies and housing.

Based on the results of this study, additional attention should be paid to 2019 as the year experienced a new change in comparison to the previous years. Above all, the northeast area faced a dramatic drop in the four indicators, and the fall reached almost 50%. Owing to decreased GDP in this area, local people were prone to find work positions in other better-developing regions that caused a significant loss of population[29]. Furthermore, the northeast area, as a heavy industry base, met the shifting industry structure since the Chinese government recently considered environmental protection. The ratio of institutions and beds with a gradual decline cannot be disregarded in the Eastern region, caused by the government's enhancement of management of medical institutions. Furthermore, it was also due to closing a part of the institutions that did not meet the new regulations of the government and combining small-sized institutions to improve healthcare service efficiency.

The inequality of healthcare service has been gradually decreasing, which was found in this study. Another research with the similar results was introduced the situation from 2013 to 2017[8]. The east area as a developed region has the best level of the allocation of the medical resources, which was also found by a study[8]. It is worthy noticed that the allocations of east, west, and center region are beginning to converge, which means the healthcare service has been becoming closely equal. That probably resulted from "Comprehensive reform of public hospitals"[30]. It was announced by National Health Commission (NHC) of the People's Republic of China in 2018. That includes that NHC should make the number and scale of the public hospitals reasonable and enhance the responsibility for management of that[30]. In China, public hospitals play a key role in Chinese healthcare service and make up majority of hospitals. That means the public hospital's distribution almost decide the equality level of medical service. That's why there is an evident change in 2019.

Regarding the requirements of the government, only four provinces met the requirements of all three indicators in 2019. However, large regions of the developing areas, such as the western and central regions, did not reach these aims. This meant that the government should pay further attention to the developing areas, even though the entire density of healthcare resources had significant growth in the western and central areas. The within-groups had relatively large differences that required to be narrowed.

This study decided to use the HRDI method, rather than other more popular methods, such as the Gini and Theil Indexes. Since the distance travelled between the healthcare institution and residents was a key factor, for example, the land of the western area in China had large land, however, a less population, the convenience of commuting to healthcare institutions should be taken into consideration. The number of institutions, doctors, and nurses in a region demonstrated this situation. As a country with a large landmass, the influence of the land should not be ignored as important as the population[17].

Equality assessment is an effective method to study healthcare service capacity, especially in countries that are developing procedures to reduce inequality among different regions. For China, since 2009, the government found that an imbalance of developments and medical services could not meet the local people's needs to launch a series of reform policies[17]. Based on this study's results, healthcare service promotions were found, and the effects of government reforms were presented. However, policymakers should be reminded that several provinces did not meet the government's requirements. In the future, the government should take a relatively backward step to consider and look out for those areas' lack of medical resources. Additionally, as they progress, the middle-western regions should maintain healthcare serviceability by developing an economic situation to offer stable and comfortable living for the healthcare workforce.

2.5. Limitation

The most recent published studies used HRDI to assess the distribution of healthcare resources, almost at the provincial level, however, not the entire national level. Hence, there were limited related papers to compare and analyze our results against. The HRDI was different from the Theil Index, and had an expected value to assess the equality level, however, it only compared the given areas to evaluate the distribution situation.

2.6. Conclusions

This study focused on the national equality of healthcare service allocation and selected the HRDI method that corresponds with the Chinese population and geography situation. Less national research was conducted, but necessary. This study tried to offer more powerful evidence about that. Additionally, the central government made a requirement of medical resource distribution. This study verified each province's result, offering direct evidence of development. The equality of the distribution of healthcare services in China was unfair between the eastern and middle-western areas. The government launched the developing requirements and paid additional attention to narrowing the imbalance among different economic level regions to meet the needs of the local people. Although many provinces did not meet the requirements for the medical resources in 2019, the distribution of healthcare services approached relatively equitably countrywide. In the future, the difference in medical resource distribution between urban and rural areas should be paid more attention. The existing inequality should be discovered; reasonable reasons should be investigated.

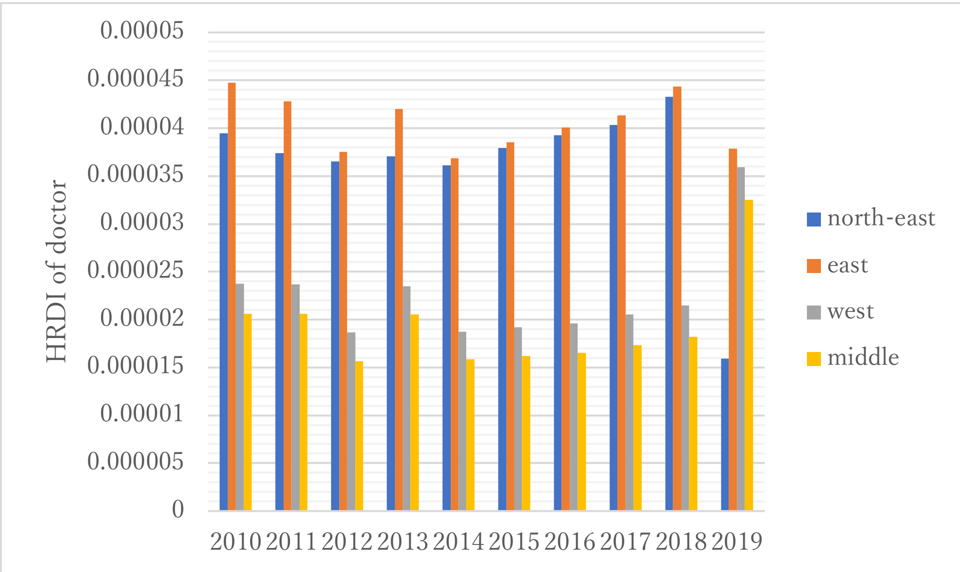

Fig 4: The HRDI of the health resources in doctors when dividing China into four areas.

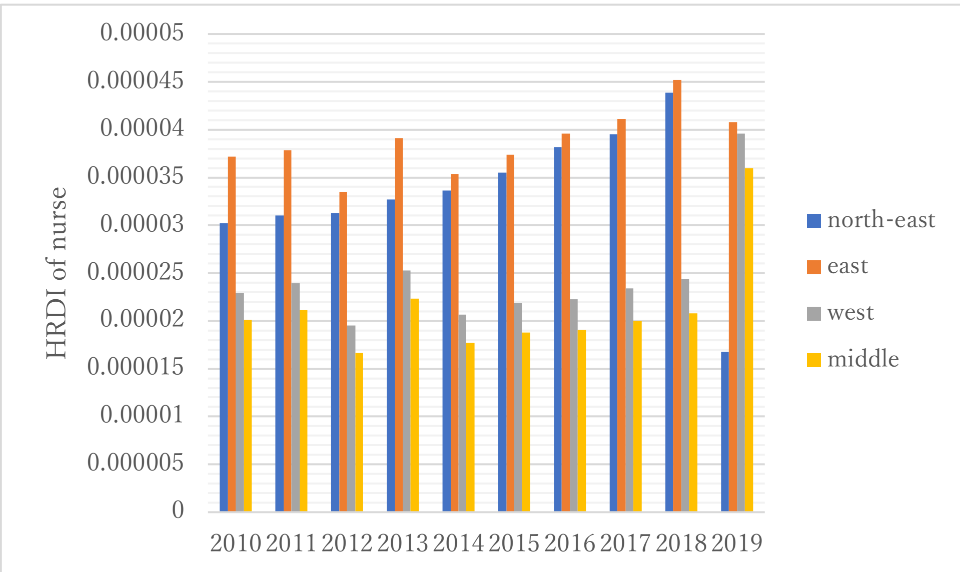

Fig 5: The HRDI of the health resources in nurses when dividing China into four areas.

Table 1. The requirements of a policy from the government, compared to each province's indicators.

Area	Province	Doctor (per thousand person)	Nurse (per thousand person)	Bed (per thousand person)
North-east	Liaoning	2.76	3.09	7.21
North-east	Jilin	2.85	2.82	6.18
North-east	Heilongjiang	2.37	2.47	6.63
East	Beijing	4.63	4.98	5.74
East	Tianjin	2.76	2.52	4.37
East	Hebei	2.8	2.29	5.58
East	Shanghai	2.95	3.63	5.74
East	Jiangsu	2.9	3.23	6.11
East	Zhejiang	3.33	3.51	5.79
East	Fujian	2.31	2.77	4.88
East	Shandong	2.89	3.21	6.06
East	Guangdong	2.44	2.95	4.56
East	Hainan	2.39	3.21	4.8
West	Nei Mongolia	2.9	3.02	6.27
West	Guangxi	2.15	2.85	5.2
West	Chongqing	2.46	3.07	7.1
West	Sichuan	2.46	2.96	7.18
West	Guizhou	2.26	3.03	6.82
West	Yunnan	2.06	2.83	6.03
West	Xizang	2.42	1.62	4.88
West	Shaanxi	2.56	3.57	6.57
West	Gansu	2.26	2.44	6.17
West	Qinghai	2.68	2.91	6.49
West	Ningxia	2.82	3.38	5.96
West	Xinjiang	2.55	2.91	7.19
Center	Shanxi	2.68	2.79	5.6
Center	Anhui	2.01	2.37	5.19
Center	Jiangxi	1.88	2.39	5.37
Center	Henan	2.45	2.74	6.34
Center	Hubei	2.57	3.23	6.65
Center	Hunan	2.62	2.67	6.99
Requirements of the government in 2020		Doctor ≥2.5	Nurse ≥3.14	Bed ≥6

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Chapter 3 Assessing the inequalities in healthcare resources in China post medical reforms: A study from 2010 to 2019

3.1. Background

Complete access to appropriate treatment and consultations for health problems means equality in the distribution of health resources, which is considered a symbol of the medical level of a country[1.2]. The unfair allocation of health resources has garnered increasing attention, especially from developing countries. Studies from many countries (India, Vietnam, and Thailand) have shown inequality in accessing health resources and unfair distribution among people from different regions[1,3,4,5]. As a developing country, China faces similar problems. It has a large population and extensive land[6,7]. Developmental differences exist among distinct and urban and suburban areas[8,9]. Therefore, with the imbalance of economic growth, a gap in the medical level between developed and poor regions has gradually been discovered[10,11,12]. For instance, it revealed unfairness in the allocation of doctors in the Eastern, Central, and Western areas of China[7]. To cope with this situation, the Chinese government announced its Opinions on Deepening the Medical and Health System Reform in 2009[13]. However, studies on the unfairness of healthcare resources have discovered that geographical differences also exist [14,15,16]. Simultaneously, the gaps between regions, and urban and suburban areas have attracted the attention of the government and public. Consequently, the Notice of the General Office of the State Council on Issuing the Outline for the

Planning of the National Medical and Health Service System (2015–2020) was launched to respond to problems and enhance medical services to meet the growing needs of people[17].

To date, few studies have focused on these aspects. Therefore, this study aimed to reveal the effectiveness of the 2015 reform at the current medical level. The 2009 medical reform attempted to increase the number of institutions, doctors, and nurses to meet the needs of people living in poor areas. However, one reform cannot exhaustively solve problems, as several types of research have studied the effectiveness of the 2009 reform, and the problems still exist. The reform should attract more attention and provide suggestions for improving the situation, such as regional inequality and the gap between urban and suburban areas. Therefore, the government considered this and offered a new reform in 2015. It is necessary to explore whether the reform promotes the local medical level and provide study results that are considered the foundation to propose reasonable suggestions.

Furthermore, China has the most extensive land in Asia, so it is not entirely appropriate to consider population as the only factor in accessing inequality. For example, let us imagine that a region has a lot of land but a small population. Although it has adequate healthcare institutions and forces to appropriately match the number of residents, is it precisely equal for the local people? It may take them a lot of time to reach a hospital to access healthcare. Regrettably, there are small time gaps in protecting patients from emergencies and serious illnesses. Consequently, some individuals may not have appropriate access to healthcare resources. Therefore, this study aims to modify the recent formula and introduce a new land factor to evaluate the equality level of healthcare resource distribution, especially in large land regions.

Several methods have been developed to assess the equality of healthcare resources. The Gini and Theil indices are the most common methods. Based on a previous study[18,11,19], the inequality of Chinese healthcare resource distribution was improved using the Gini index, as the value of the Gini indices was increasingly close to the baseline, which means an equal situation in terms of institutions, doctors, and nurses. The Theil index evaluates the general situation of national equality and can be decomposed to calculate the contribution rate from within regions and regions in between, which has the benefit of finding severe inequality problems [11,7,14]. Therefore, this study chose the Theil index to assess inequality problems, identify causes, and propose meaningful suggestions for policymakers. Based on the Theil index formula, this study modified the formula and introduced a land factor to precisely assess equality in China.

3.2. Data Source and Setting

3.2.1. Data Source

This study attempts to reveal the distribution of healthcare resources in China to explore equity in accessing medical treatment and offer suggestions for policymaking. The results of this study may attract more attention from the government, researchers, and the public regarding healthcare resource disparity. Information on healthcare resources was extracted from the China Health Statistical Yearbook (2010–2019), which covers 31 provinces, autonomous regions, and municipalities, including the amount of investment, number of institutions, doctors, nurses, and beds in health institutions. In addition, areas in China were divided into four segments: Southeastern, Eastern, Western, and Central, considered Category 1. Moreover, regions of China were divided into urban and suburban areas, considered Category 2. The equality of healthcare resources was evaluated based on these two segments.

3.2.2. Setting

Based on the economic situation, geographical location, and descriptions in the China Health Statistical Yearbook, the 31 provinces, autonomous regions, and municipalities of mainland China were separated into four groups: North-Eastern, Eastern, Central, and Western regions. The North-Eastern region includes Heilongjiang, Jilin, and Liaoning (3 provinces). The Eastern region included Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan (10 provinces and municipalities). The Central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan (6 provinces). The Western region included Inner Mongolia, Chongqing, Guangxi, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang (12 provinces, autonomous regions, and municipalities). The institutions included urban hospitals (hospitals and community health service centers) and suburban hospitals (township hospitals, village clinics, and outpatient clinics). Certified doctors and nurses were also included. Medical investments came from government financing.

3.3. Method

Many studies have used the Gini and Theil indices to assess the equality of social issues [20,21]. The Theil index was used more commonly because it presents the distinction among groups and shows the contribution of equality from within and between groups. Based on the quality of the two indices mentioned above, the Theil index was chosen in this study because the origin of equality was considered[8].

The Theil index can be used to assess the general equality in China or its divided segments and has effects similar to the Gini index. Therefore, this study did not choose the Gini index to evaluate unfair inequality in healthcare resources; only the Theil index was used to assess that. Although the Theil index assesses the equality of health resources, it can be used to evaluate contributions within regions or between groups[10]. The Theil index method considers the population factor but not the land factor. In this study, population and land were viewed as factors. Therefore, the formula of the Theil index was modified by adding the land factor to assess the inequality of healthcare resources.

The five indicators chosen were the amount of investment, and the number of institutions, doctors, nurses, and beds in health institutions s. The Theil index assesses the equity level of the distribution of healthcare resources. T is a relative indicator; no universal assessment standard for inequality levels is available [18]. The T-value ranges between 0 and 1, with a smaller T-value indicating a more equitable condition. Specifically, the closer the value is to the x-axis, the more equal the situation [20,21]. T was calculated as follows:

$$T = \sum_{i=1}^{n} P_i \, log \frac{P_i}{Y_i} \ldots\ldots (1)$$

Pi: Proportion of every province's population accounting for China's overall population.

Yi: Proportion of health resources owned by every province accounting for the total number of health resources nationwide.

The Theil index can be decomposed into two components: to describe inequality "within" and "between" subgroups. The formulae are as follows[20,21]:

$$T_w = \sum_{g=1}^{k} P_g T_g \ldots\ldots (2)$$

$$T_b = \sum_{g=1}^{k} P_g \log \frac{P_g}{Y_g} \ldots\ldots (3)$$

$$T = T_w + T_b \ldots\ldots (4)$$

T_w represents the fairness of health resource allocation in a targeted region, T_b represents the degree of equity between the different regions, and P_g and Y_g have the same meaning as Pi and Yi.

$$T' = \sum_{i=1}^{n} A_i \log \frac{A_i}{Y_i} \ldots\ldots (5)$$

In the above formula, Y_i represents the health resource, Pi represents the population of each unit, and A_i represents the square of Unit I. This study intends to introduce the land factor into the Theil index and precisely assess the inequality situation. The original Theil index formula considers the distribution of healthcare resources in a population. First, we changed the factor of population Pi to Ai, which provides a new Theil index formula (5) with a land factor (Ai) to evaluate the distribution of healthcare resources on the land.

$$T'' = T - T' = \sum_{i=1}^{n} P_i \log \frac{P_i}{Y_i} - \sum_{i=1}^{n} A_i \log \frac{A_i}{Y_i} \ldots\ldots (6)$$

Further, subtracting formula (5) from formula (1) gives the T'' of formula (6). If the results are greater than zero, the contribution of the population to inequality is greater. By contrast, if the results are less than zero, the contribution of land to inequality is greater.

$$T''' = T + T' = \frac{1}{2}(\sum_{i=1}^{n} P_i \log \frac{P_i}{Y_i} + \sum_{i=1}^{n} a_i \log \frac{a_i}{Y_i}) \ldots\ldots (7)$$

Second, addition of formulas (1) and (5) gives T'''. Correcting the formula yields values between 0 and 1. The results showed inequality in China concerning both population and land. For the two formulae, the explanations of the results are similar to those of the original Theil index. Regardless of whether the results are greater than 0 or less than 0, the closer the line is to the x-axis, the more the equality of the healthcare resources is presented.

3.4. Result

Table 1 and Fig. 1 present the Theil index of national health resource allocation using the five indicators. For the sum of government investment and the number of healthcare institutions and beds, the value of the Theil index was close to the x-axis under 0.03 from 2010 to 2019 (Fig. 1), which means that the equity of finance and health infrastructure was fulfilled. The line of the bed indicator was the lowest among the indicators. These three indicators remain stable throughout the study period. Between 2010 and 2015, downward trends with fluctuations were observed in the doctor and nurse indicators ranging from 0.145 to 0.097. There was a sharp decrease of approximately 0.103 until 2012, which then increased by approximately 0.126. From 2014, the lines of doctors and nurses remained stable at approximately 0.097, which was about two times greater than the other three indicators.

The equality of the healthcare resources distribution was represented in five areas of Category 1 (Table 2 and Fig 2); The South-East region was the most fair among all parts. The Eastern areas had the highest values among all areas for the five factors. Doctors and nurses had greater values than the other factors with values below 0.1, indicating near equality. For the Southeastern and Central areas, even for doctors and nurses, the values were closer to the x-axis, at less than 0.05. Although there were some fluctuations in the bed factor field, all values were less than 0.0045, which was close to the x-axis. For investments and institutions, the values were less than 0.025 and 0.04, respectively. For doctors and nurses, the Theil index value was greater than that of other factors, especially in the Eastern and Central regions, where values were close and between 0.1 and 0.3. Noteworthy, the most significant proportion of differences was in the contribution from within groups but not between groups (Table 2 and Fig. 2).

Regarding the contribution rate results in Table 3 and Fig. 3, when China was divided into urban and suburban areas (Category 2), the differences mostly came from between groups institutional factors from 2010 to 2018. The contribution of these groups was 93% in 2019. Regarding the doctor and nurse factors, there was a transfer from the contribution between-group to the contribution within-group. Doctor and nurse factors showed similar trends over the same time period. The proportion of contributions within the group increased during the study period (doctor factor, 93%; nurse factor, 83%). The differences in the bed factor gradually transformed from within to between groups. The bed factor in 2010 accounted for 92% of the within-group contribution; however, in 2019, it accounted for 59% of the between-group contribution.

These results are similar to those obtained using the new Theil index formulas. Results of formula (5) (Table 4 and Fig 4) indicate that, the three factors presented a stable trend with a slight increase. From 2010 to 2019, investment results were the lowest, between 0.21 and 0.26. The other two factors were slightly higher, between 0.25 and 0.28. However, doctors' and nurses' results showed similar trends. The two lines exhibit a noticeable upward increase, generally with a few fluctuations. From 2010 to 2013, the values of doctors were greater than those of nurses, and both peaked at 0.27, and 0.25, respectively, in 2012. Further, in 2015, they experienced a second peak, and their values were the same at 0.38. Subsequently, they faced a peak-to-trough in 2016 at 0.28, and from this year onwards, the value of nurses exceeded that of doctors. For the last three years, the increase upwards was kept stable until reaching 0.38 (nurse) and 0.37 (doctor) in 2019.

The results were obtained using Formula (6) (Table 5 and Fig 5)], and all lines were negative below the x-axis and remained stable. Based on the positions of lines from the farthest of the x-axis to the closest to that, were the line of bed, institution, investment, doctor, and nurse (between -0.34 and -0.15). In 2017 and 2018, the lines between doctors and nurses almost overlapped. Regarding the results of Formula (7) (Table 6 and Fig 6), three factors (investment, bed, and institution) remained stable over the study years. The line of investment was closest to the x-axis, and that of the bed was between the lines of the other two factors. The values ranged from 0.11 and 0.15. The doctors and nurses exhibited similar trends. From 2010 to 2014, they remained stable, and the nurses' line, with a value of approximately 0.18, was slightly closer to the x-axis than the doctor's line, with a value of approximately 0.19. These two factors fluctuated with an increasing trend from 2014 to 2017. They increased slightly in the three years until 2019, reaching 0.24. From 2014 to 2019, the two lines for doctors and nurses almost overlapped.

3.5. Discussion

First, the equality in the distribution of healthcare resources across the nation is satisfied. This result is similar to that of a published study[7]. Despite the level of the nurse and the doctor being higher than that of the institution, investment, and bed, the values were between 0.15 and 0.09, representing relative equality. For the line of the Theil index of the institution, the investment, and the bed all were below 0.03. The trend of the three indicators remained almost stable, especially the line of bed and investment was kept below 0.02, and the bed was closest to the x-axis, indicating best equality. There were fluctuations in the lines representing the doctor and the nurse, despite the overall downward trend. These fluctuations indicate an improvement in equality between the two indicators. These fluctuations occurred because the statistical methods of the Chinese Statistical Office changed in 2012. Doctors without certification had been working in the countryside to shoulder the responsibility of offering healthcare services, partly because it is difficult to convince talented doctors and nurses to stay in a relatively poor situation in the countryside environment. Another reason was because, in the past, a solution to the lack of doctors and nurse resources was to allow some doctors and nurses who have the experience but lack certification to be engaged in the healthcare service. However, with the development of society, the government wanted to improve the specifications and management of healthcare services, encouraging doctors and nurses to go to tier three cities and the countryside to help doctors without certification to pass doctor certification examinations, to meet the need for gradually developing standards of healthcare. After 2012, the national statistical data did not include countryside doctors who did not meet this requirement. Meanwhile, many countryside clinics were located in healthcare institutions because some did not meet the new requirements of the government’s healthcare services. Finally, healthcare equality in China was good, and the situation improved during the reform period.

When considering the different regions, Category 1 includes four different economic segments. The East is a developed area in China. Nonetheless, the Eastern area had the worst situation of equality in healthcare resources, even though all the values of the Eastern area were below 0.23, which was not unfair. In the Eastern region, five indicators showed a gradual decrease, indicating an improvement in the level of equality, except for the investment indicator. From 2005 to 2019, based on the increasing inequality of beds, the results urged the local government to pay more attention to the distribution of healthcare resources. The Central and Southeastern areas had better equality in healthcare resource distribution because all values of the Theil index were below 0.1. All the unfairness of healthcare resources in contribution came from within groups, which means that the government should consider the differences within groups. Another published study provided a similar conclusion as was drawn in this study[11]. Conversely, even though the level of inequality in healthcare resources was not profound, the values of doctors and nurses by the Theil indices in the Eastern and Western areas were greater than 0.07, which was worse than the other indicators and other areas. These indicators showed a downward trend, indicating the reform had positive effects during the study years.

In Category 2, the distribution institution had the largest Theil index value. Simultaneously, the contributions were almost entirely from the between groups. Cities have more health institutions than suburban areas. The situation improved during the development of the reform. For the indicators of doctors and nurses, the ratio of contributions from within groups increased. In contrast, contributions from within groups in the institution and bed showed an upward trend, and the number of healthcare institutions increased marginally. This was observed in another study as well[14]. In China, suburban areas have larger land areas and a low population density. Government reform attempts to improve the level of healthcare resources in suburban areas, such as increasing healthcare institutions and the number of doctors and nurses, and decreasing the differences between urban and suburban areas. After several years of effort, this unfair situation has improved. However, it has been reported that there are differences between urban and suburban areas. Even within suburban areas, gaps in healthcare resources remain.

When studies have discussed the equality of healthcare resources, the distribution of resources has been viewed as the most critical factor for assessing access to healthcare. However, when a nation has a large land and population ratio, that is, the distance from healthcare institutions to the residents should be considered as a factor in assessing healthcare abilities. Thus far, most studies have primarily focused on the number of healthcare institutions. Further, the workforce per unit of the population has been used as an index to assess equality, which is suitable for smaller countries with limited land area. However, this approach may not apply to larger countries such as China. Therefore, this study considers land as a new factor and modified the Theil index formula to calculate the equality level of the distribution of healthcare resources. Distance between residents and healthcare institutions is vital for equality. Although the same population in different land segments has the same sum of healthcare resources, the inequality in accessing treatment is probably different.

This study considers land as an essential factor in calculating inequality in China. Prior studies only showed the distribution of healthcare resources[12,22] but did not compare unfairness among distinct areas. Formula (5) shows that the reforms greatly influenced the distribution equality of doctors and nurses. Despite some fluctuations, the trend remained upward. The range of values for all factors was generally greater than those calculated for the population. Therefore, all results from Formula 6 were less than 0. Land has contributed the most to China's inequality. Based on Fig 6, it is evident that the general satiation of inequality of healthcare resource distribution and the inequality in doctor and nurse distribution is becoming severe. This is different from the results that only consider the population factor.

Admittedly, we obtained a dissatisfied equality result by adding the land factor to the Theil index. However, the government should not establish additional health institutions in remote areas with extensive land and no counterpart population. This results in the wastage of resources. This study creatively presents the long distance for accessing health treatment as an important factor of inequality. Specifically, it takes a long time and more money to visit a hospital to seek healthcare services, which is unfair. Governments should not ignore this issue. Policymakers should pay more attention to narrowing the gap in the distribution of healthcare resources through broad and deep thinking. They must offer more measures to allow people access to fair healthcare services, such as long-distance healthcare services.

3.6. Limitation

This study modifies the Theil index formula and considers the effect of land on the equality of healthcare resource distribution. When a country has a large amount of land, such as China, the land is not ignored as a factor. This study considers additional impact factors in the assessment of equality. In the future, people taking more time and money to travel long distances will have a more significant impact on the distribution of inequality of healthcare resources, which should be studied further.

3.7. Conclusion

This study used the traditional Theil index to evaluate the inequality in healthcare resources. This shows that the inequality situation in China was excellent after the two deep reforms. Apart from the institutional inequality from the between group, other factor inequalities stemmed from within the group, even though there were some fluences over time. However, when considering land and population impacts, the inequality was not better than when only considering population. This means that the government should consider long distances for people in the unfair situation of access to healthcare services.

Table 1 Theil index of health resources allocation from 2010 to 2019

Year	Healthcare Investment	Healthcare Institutions	Healthcare Beds	Healthcare Doctors	Healthcare Nurses
2010	0.0141	0.0265	0.0044	0.1377	0.1453
2011	0.0098	0.0270	0.0038	0.1354	0.1413
2012	0.0088	0.0267	0.0035	0.1027	0.1037
2013	0.0076	0.0268	0.0032	0.1257	0.1263
2014	0.0070	0.0266	0.0033	0.0985	0.0965
2015	0.0073	0.0263	0.0033	0.0990	0.0954
2016	0.0083	0.0261	0.0035	0.0990	0.0957
2017	0.0087	0.0260	0.0037	0.1001	0.0965
2018	0.0098	0.0252	0.0039	0.0998	0.0956
2019	0.0110	0.0234	0.0040	0.0997	0.0944

Fig. 1 Theil index of healthcare resource allocation from 2010 to 2019

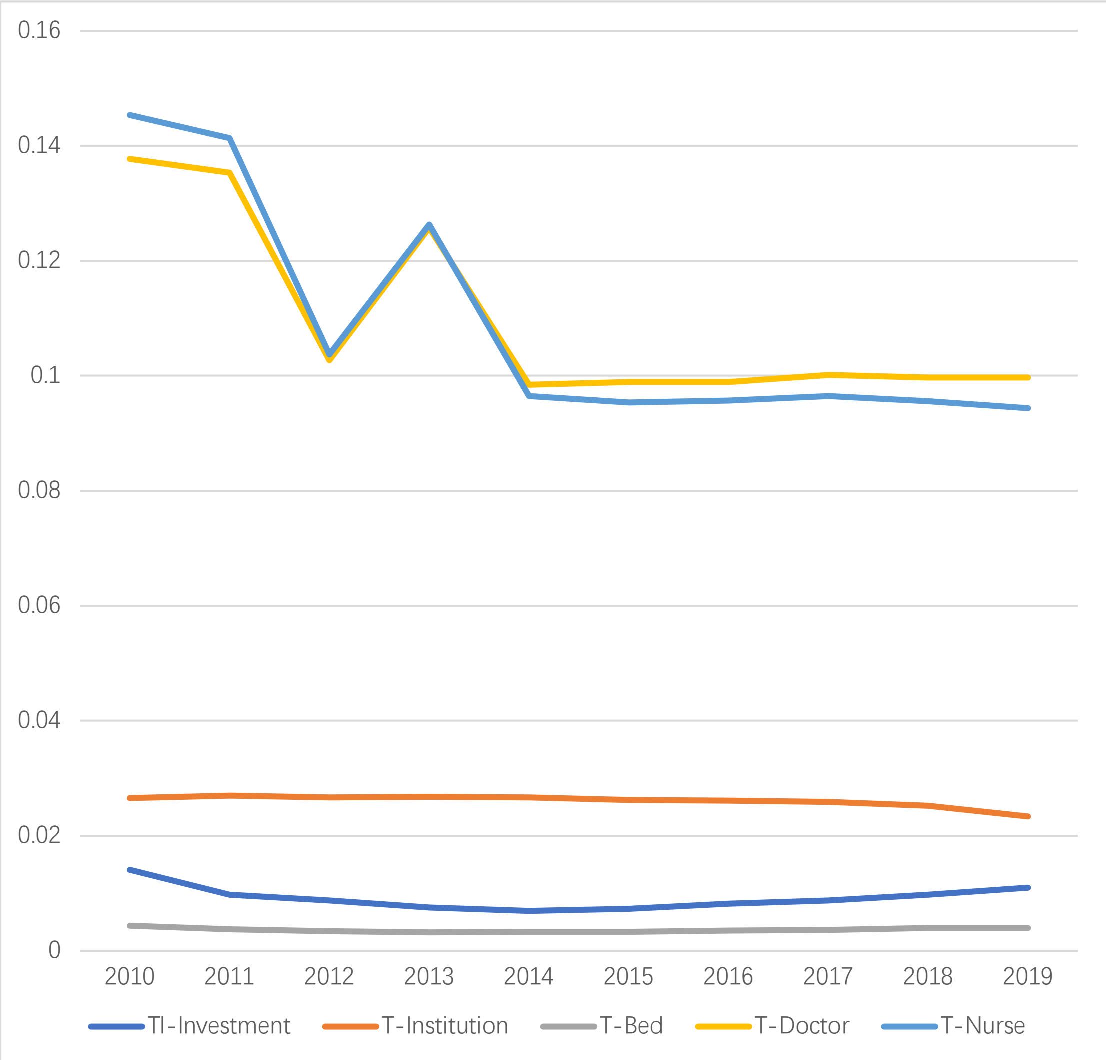

Table 2 Theil index of healthcare investment allocation and proportion of differences in the contribution by Category 1 from 2010 to 2019

	Healthcare Investment						Healthcare Institutions						Healthcare Doctors					
	ES	E	W	C	Contribution rate		ES	E	W	C	Contribution rate		ES	E	W	C	Contribution rate	
Year	Tg	Tg	Tg	Tg	within	between	Tg	Tg	Tg	Tg	within	between	Tg	Tg	Tg	Tg	within	between
2010	0.0009	0.0249	0.0080	0.0009	84.78%	15.22%	0.0042	0.0371	0.0121	0.0210	87.94%	12.06%	0.0087	0.1828	0.1383	0.0471	87.25%	12.75%
2011	0.0019	0.0168	0.0046	0.0012	82.92%	17.08%	0.0049	0.0359	0.0134	0.0209	86.16%	13.84%	0.0077	0.1812	0.1317	0.0442	86.46%	13.54%
2012	0.0027	0.0148	0.0043	0.0009	82.67%	17.33%	0.0061	0.0354	0.0131	0.0200	85.67%	14.33%	0.0080	0.1256	0.1128	0.0312	85.08%	14.92%
2013	0.0029	0.0126	0.0039	0.0007	83.20%	16.81%	0.0057	0.0363	0.0130	0.0187	85.28%	14.72%	0.0074	0.1631	0.1293	0.0373	85.77%	14.23%
2014	0.0016	0.0112	0.0037	0.0007	80.70%	19.31%	0.0058	0.0357	0.0136	0.0185	85.32%	14.68%	0.0085	0.1171	0.1151	0.0260	84.88%	15.12%
2015	0.0037	0.0107	0.0043	0.0011	79.70%	20.40%	0.0064	0.0349	0.0131	0.0190	85.58%	14.42%	0.0086	0.1190	0.1173	0.0244	85.42%	14.58%
2016	0.0048	0.0122	0.0035	0.0019	78.87%	21.13%	0.0078	0.0340	0.0132	0.0198	86.18%	13.82%	0.0100	0.1189	0.1159	0.0231	84.86%	15.14%
2017	0.0033	0.0122	0.0053	0.0016	78.14%	21.86%	0.0077	0.0347	0.0133	0.0193	87.44%	12.56%	0.0087	0.1193	0.1190	0.0214	84.45%	15.55%
2018	0.0029	0.0135	0.0060	0.0020	77.71%	22.29%	0.0088	0.0356	0.0129	0.0180	89.78%	10.22%	0.0116	0.1178	0.1186	0.0209	84.24%	15.76%
2019	0.0021	0.0157	0.0066	0.0024	78.67%	21.33%	0.0072	0.0328	0.0125	0.0168	90.09%	09.91%	0.0112	0.1182	0.1160	0.0203	83.66%	16.34%

	Healthcare Nurses						Healthcare Beds					
	ES	E	W	C	Contribution rate		ES	E	W	C	Contribution rate	
Year	Tg	Tg	Tg	Tg	within	between	Tg	Tg	Tg	Tg	within	between
2010	0.0044	0.2119	0.1284	0.0416	87.16%	12.84%	0.0006	0.0044	0.0038	0.0027	79.40%	20.60%
2011	0.0042	0.2068	0.1258	0.0366	86.98%	13.02%	0.0008	0.0036	0.0038	0.0021	79.87%	20.13%
2012	0.0043	0.1493	0.1004	0.0257	88.08%	11.92%	0.0008	0.0039	0.0034	0.0013	80.95%	19.05%
2013	0.0039	0.1852	0.1091	0.0314	86.31%	13.70%	0.0007	0.0033	0.0026	0.0018	77.27%	22.73%
2014	0.0051	0.1332	0.0944	0.0225	85.95%	14.05%	0.0007	0.0027	0.0023	0.0024	72.64%	27.36%
2015	0.0054	0.1338	0.0902	0.0230	86.20%	13.80%	0.0008	0.0023	0.0024	0.0031	72.88%	27.12%
2016	0.0061	0.1301	0.0914	0.0234	85.06%	14.94%	0.0010	0.0024	0.0025	0.0033	72.32%	27.68%
2017	0.0049	0.1282	0.0924	0.0217	83.48%	16.52%	0.0012	0.0028	0.0026	0.0027	69.56%	30.44%
2018	0.0080	0.1234	0.0932	0.0206	82.56%	17.44%	0.0008	0.0030	0.0025	0.0026	66.03%	33.97%
2019	0.0080	0.1242	0.0888	0.0193	82.42%	17.58%	0.0006	0.0030	0.0023	0.0024	62.20%	37.80%

SE: Southeastern region; E: Eastern region; W: Western region; C: Central region.

Fig. 2 Theil index of healthcare resource allocation by areas and years

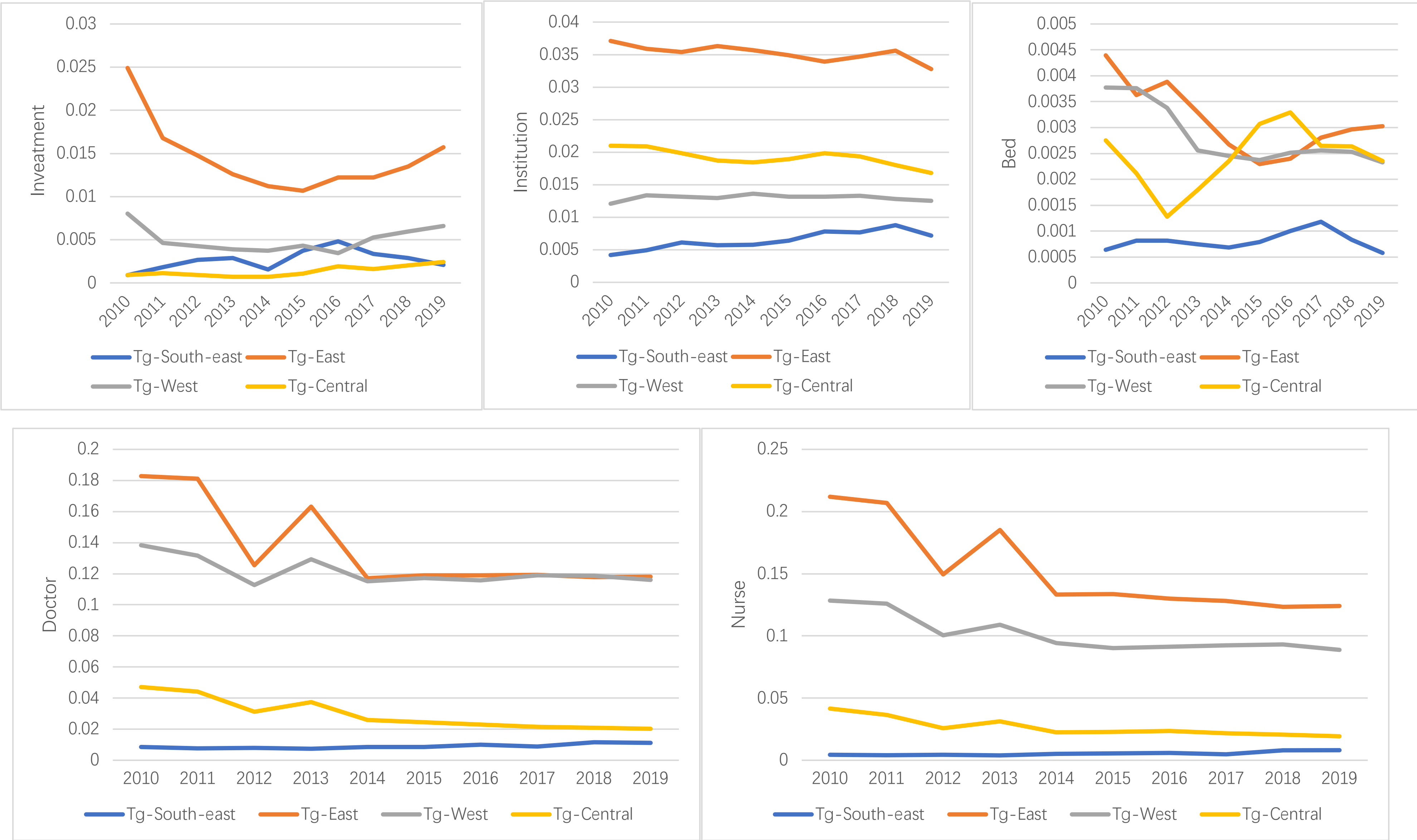

Table 3 Theil index of healthcare investment allocation and proportion of differences in the contribution by Category 2 from 2010 to 2019

	Institution			Contribution		Doctor			Contribution		Nurse			Contribution		Bed			Contribution	
Year	Tg-U	Tg-S	T-T	within	between	Tg-U	Tg-S	T-T	within	between	Tg-U	Tg-S	T-T	within	between	Tg-U	Tg-S	T-T	within	between
2010	0.0392	0.0247	0.3173	10%	90%	0.1351	0.1894	0.1914	85%	15%	0.1248	0.1651	0.2216	65%	35%	0.0096	0.0096	0.01037	92%	8%
2011	0.0353	0.0246	0.3341	9%	91%	0.1281	0.1888	0.1802	87%	13%	0.1173	0.1676	0.2019	70%	30%	0.0082	0.0087	0.00967	87%	13%
2012	0.0364	0.0248	0.3418	9%	91%	0.1242	0.1761	0.1693	88%	12%	0.1124	0.1501	0.1871	70%	30%	0.0074	0.0096	0.01096	77%	23%
2013	0.0332	0.0250	0.3447	9%	91%	0.1255	0.1696	0.1652	88%	12%	0.1109	0.1460	0.1784	71%	29%	0.0068	0.0097	0.01188	69%	31%
2014	0.0324	0.0254	0.3512	8%	92%	0.1232	0.1672	0.1609	89%	11%	0.1105	0.1407	0.1715	72%	28%	0.0068	0.0099	0.01285	64%	36%
2015	0.0307	0.0262	0.3570	8%	92%	0.1230	0.1626	0.1566	90%	10%	0.1097	0.1371	0.1638	74%	26%	0.0067	0.0118	0.01425	63%	37%
2016	0.0294	0.0269	0.3656	8%	92%	0.1239	0.1448	0.1480	90%	10%	0.1130	0.1183	0.1541	75%	25%	0.0071	0.0104	0.01499	57%	43%
2017	0.0275	0.0274	0.3692	7%	93%	0.1213	0.1420	0.1422	91%	9%	0.1158	0.1107	0.1476	77%	23%	0.0075	0.0114	0.01744	52%	48%
2018	0.0247	0.0202	0.4294	5%	95%	0.1106	0.1390	0.1283	95%	5%	0.1035	0.1062	0.1270	82%	18%	0.0074	0.0121	0.01975	47%	53%
2019	0.0225	0.0274	0.3723	7%	93%	0.1065	0.0917	0.1085	93%	7%	0.1021	0.0833	0.1147	83%	17%	0.0078	0.0097	0.02091	41%	59%

U: Urban, S: Suburb, T: Total

Fig. 3 Theil index of the proportion of differences in the contribution by Category 2 and years

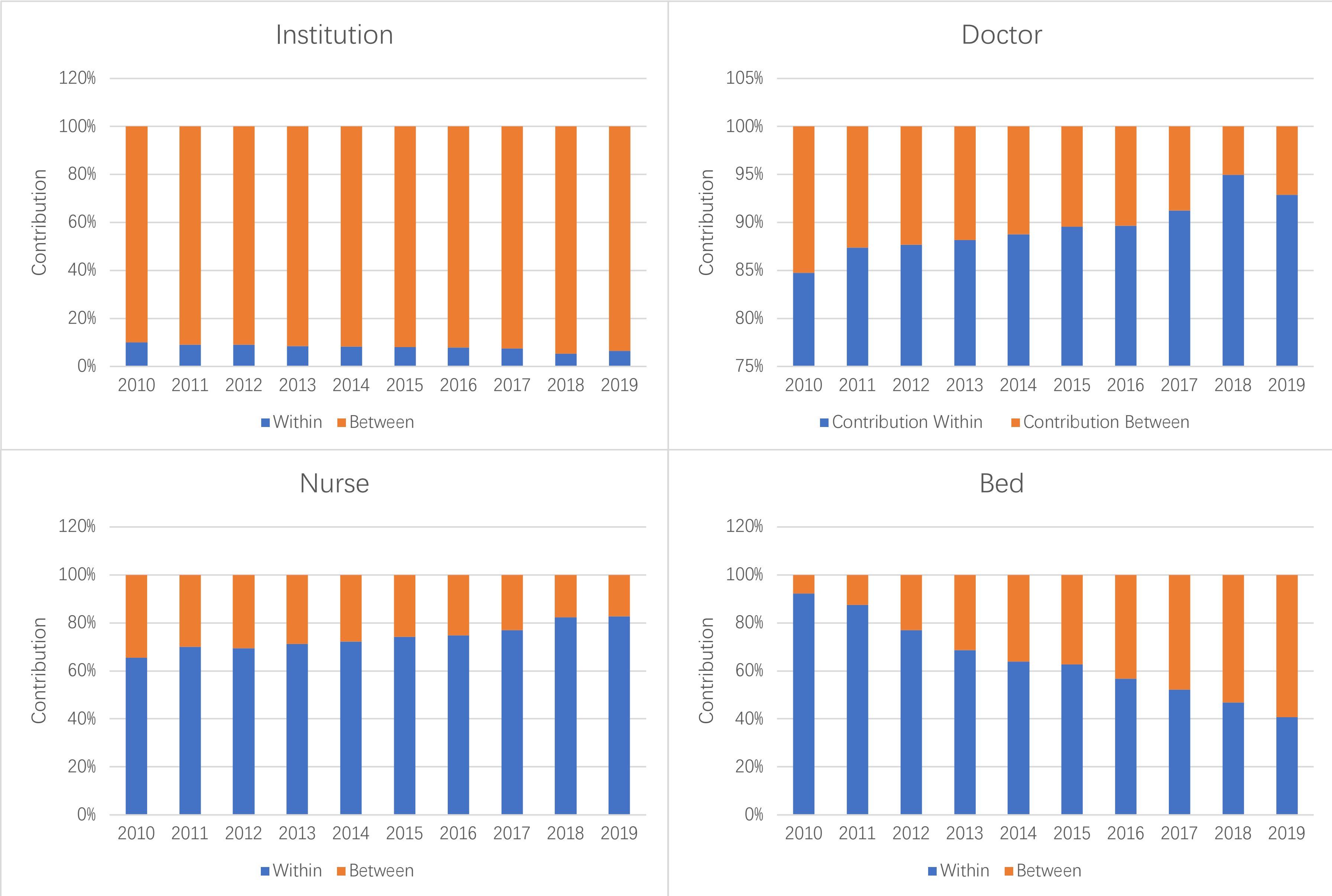

Table 4 The modified Theil index in different factors (T')

T'	Investment	Institution	Doctor	Nurse	Bed
2010	0.2143	0.2688	0.24	0.2006	0.2576
2011	0.2196	0.2671	0.2409	0.2043	0.2575
2012	0.2252	0.2679	0.273	0.2491	0.2611
2013	0.2261	0.2683	0.2507	0.2273	0.2612
2014	0.2301	0.2682	0.2768	0.2648	0.2621
2015	0.2299	0.2693	0.3377	0.3375	0.2638
2016	0.2322	0.2662	0.2839	0.2869	0.267
2017	0.2297	0.2713	0.3516	0.3673	0.2703
2018	0.2318	0.2799	0.3574	0.3735	0.2735
2019	0.251	0.2776	0.3727	0.3859	0.277

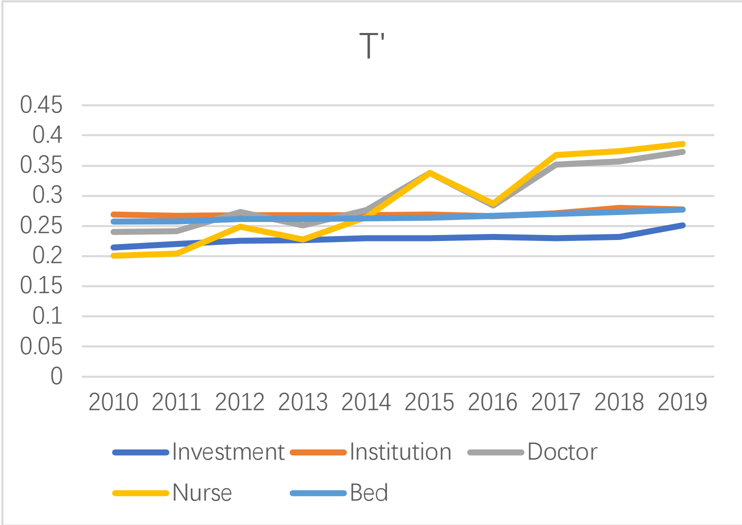

Fig. 4 The trend of the modified Theil index

Table 5 The modified Theil index in different factors(T'')

T''	Investment	Institution	Doctor	Nurse	Bed
2010	-0.2089	-0.2448	-0.1781	-0.1548	-0.2541
2011	-0.2119	-0.2422	-0.176	-0.1526	-0.2539
2012	-0.2175	-0.2424	-0.1778	-0.1614	-0.2576
2013	-0.2191	-0.2425	-0.1785	-0.1628	-0.2579
2014	-0.2231	-0.2415	-0.1784	-0.1682	-0.2589
2015	-0.222	-0.242	-0.1853	-0.1803	-0.2606
2016	-0.223	-0.239	-0.1776	-0.1753	-0.2635
2017	-0.2189	-0.2433	-0.181	-0.1811	-0.2664
2018	-0.2134	-0.252	-0.1817	-0.1784	-0.2686
2019	-0.2254	-0.2543	-0.1795	-0.1693	-0.2699

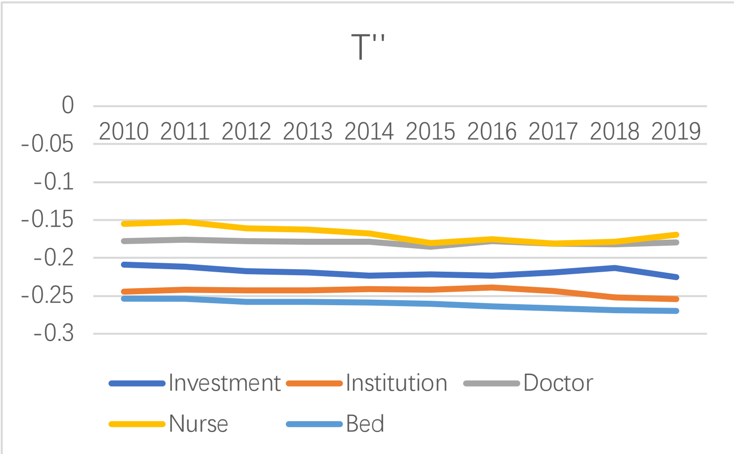

Fig. 5 The trend of the modified Theil index

Table 6 The modified Theil index' in different factors (T''')

T'''	Investment	Institution	Doctor	Nurse	Bed
2010	0.1142	0.14765	0.18885	0.17295	0.131
2011	0.1147	0.14705	0.18815	0.1728	0.13065
2012	0.117	0.1473	0.18785	0.1764	0.1323
2013	0.11685	0.14755	0.1882	0.1768	0.1322
2014	0.11855	0.1474	0.18765	0.18065	0.1327
2015	0.1186	0.1478	0.21835	0.21645	0.13355
2016	0.12025	0.14615	0.19145	0.1913	0.13525
2017	0.1192	0.14865	0.22585	0.2319	0.137
2018	0.1208	0.15255	0.2286	0.23455	0.1387
2019	0.131	0.1505	0.2362	0.24015	0.1405

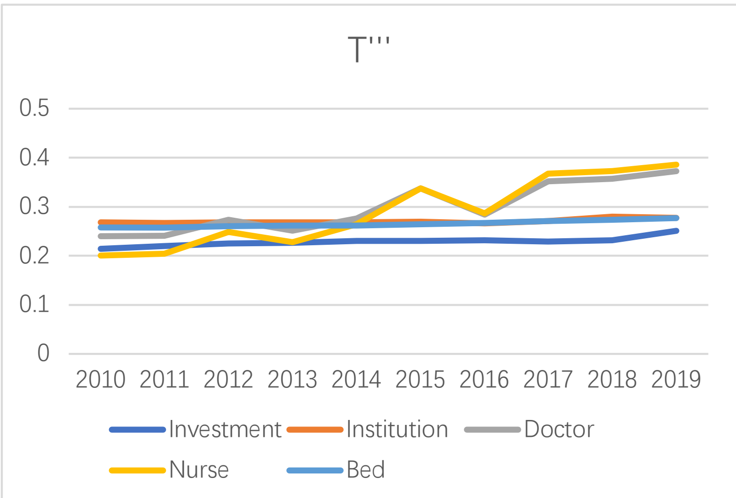

Fig. 6 The trend of the modified Theil index

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Chapter 4 Efficiency evaluation of public hospitals in China from 2010 to 2019: A data envelopment analysis

4.1. Introduction

Equality in healthcare services is a significant issue worldwide [1]. Especially in developing countries, many researchers have tried to determine the current situation and offer reasonable suggestions to improve the level of healthcare services [1-4]. The efficiency of healthcare institutions or systems has attracted increasing attention, as it could influence the serviceability of hospitals and institutions in terms of their quality and equality. One study measured the efficiency of health systems in Asia and found that most countries had a lower level of efficiency [2,5]. These counties could improve the efficiency of their health system by using the current healthcare resources [2]. Another study reported that 58.33% of African healthcare systems were just found to be efficient [4]. Therefore, developing countries should enhance their investment and management to improve the healthcare provided. However, both developing and developed countries have tried to assess the efficiency of their healthcare institutions to resolve identified problems. In a study in Japan, Japanese hospitals found that the quality of medical services must be sustained even if it is difficult to operate the hospital profitably. Here, the solution is to find the efficiency problem and gradually improve it [6,7].

Studying the efficiency of healthcare systems plays a core role in developing the level of medical services [5,8-11]. China, a developing country, has a vast population and large area, and an imbalance in economic development has long existed [8-10]. The government is making significant efforts to address this problem. For example, in 2019, the Chinese government spent only 6.6% of the GDP on healthcare, less than that of other developing countries, but increased funding for medical care by 1–1.5% of the GDP in subsequent years [12]. Recently, many studies in China have assessed the efficiency of hospitals at the provincial and national levels to identify equality problems [13-21]. A study found that the top hospitals in China were more efficient, and that coastal cities were more efficient than central ones [22]. Another study mentioned the changes after the launch of the health insurance reform of the New Cooperative Medical System, which positively impacted efficiency [17,22-24]. Most recent studies focused on one province or region [19,20], and some on one field such as operational efficiency or traditional Chinese medication efficiency [9,16,25]. However, few studies pay attention to national-level efficiency and the impact factors related to an efficiency assessment. This study aims to evaluate the efficiency of hospitals in the whole country divided into several regions for ten years to identify the differences among regions and reasons for those to make suggestions for supporting the government's sustained reforms.

A data envelopment analysis (DEA) is so named because of the way it “envelops” observations to identify a “frontier,” which is used to assess comments showing the performance of all the units to be evaluated [26-28]. Use of the DEA has involved a vast range of units including not only business companies but also government agencies such as hospitals [10,26]. Therefore, the term "decision-making unit" (DMU) was introduced to cover an agency or region. Hospital efficiency is crucial in assessing the level of healthcare services [5,11]. Using the DEA method, scale efficiency, technological efficiency, and so on were considered in the model. Moreover, the Malmquist Productivity Index (MPI) was introduced to evaluate the annual change in efficiency [1,29,30]. These two methods clarified the situation of the region's efficiency and trend of changes over the stipulated period.

4.2. Methods

The DEA, introduced by Charnes, is a non-parametric programming method (Cooper and Rhodes, 1978). Compared to the parametric technique, it has some core advantages in appropriately estimating hospital efficiency [26,27]. Using linear programming techniques, DEA is a tool for measuring the efficiency and productivity of DMUs to envelop observed input-output vectors [1,29]. Multiple inputs and outputs are considered in the same model and period without any assumption of data distribution. The efficiency of each case is assessed by a proportional change in inputs or outputs [24]. A DEA model is divided into an input-oriented model, which minimizes inputs while satisfying at least the given output levels, and an output-oriented model, which maximizes outputs without requiring more observed input values. Charnes and Cooper originally proposed the efficiency measurement of DMUs. Rhodes (1978) advocated for a constant returns to scale (CRS), wherein all DMUs operate at their optimal scale [8,26,31,32]. Banker, Charnes, and Cooper (1984) introduced the variable returns to scale (VRS) efficiency measurement model, allowing the breakdown of efficiency into technical and scale efficiencies in the DEA [26,27].

Figure 1 shows how economies of scale determined frontiers that are presented considering one input and one output for 5 DMUs, which are labeled A through E. Figure 1 also shows the CRS and VRS frontiers. If CRS is assumed, DMU C is efficient only; if VRS is accepted, DMUs A, C, and E are efficient. Scale efficiency (SE) is defined as the ratio of CRS to VRS efficiency scores. It indicates whether the DMU is in an optimal situation. The distance from a virtual point to a point on the frontier was measured as efficiency. When the DMU is efficient, its DEA scores are equal to 1 and all slacks are 0. The play shows the extent of the enhancement. The value of a slack calculated in an input-oriented or output-oriented model is better, meaning there is more room to improve an input or output factor [26,27].

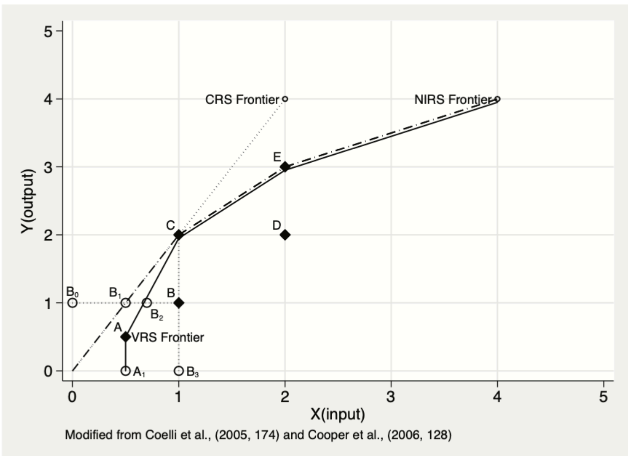

Figure 1. Concepts of efficiency and returns to scale

Input-oriented means that the value of the output remains at the same level, but enhances the input level to achieve the corresponding output value, and vice versa [1,8,26,31]. The efficiency of point B is defined as $\theta_{B,\ input,CRS} = B_0B_1/B_0B$ for the input-oriented CRS DEA model. It shows that one can achieve the same output by decreasing the input by the ratio of $1 - \theta_{B,\ input,CRS}$ [26,27]. The efficiency of the output-oriented CRS DEA model is defined as $\theta_{B,\ output,CRS} = B_3B/B_3C$, and shows that one can achieve the same input by increasing the output by the ratio of $1 - \theta_{B,\ output,CRS}$. Therefore, the input-oriented efficiency related to the VRS frontier is defined as $\theta_{B,\ input,\ VRS} = B_0B_2/B_0B$ [26,27]. Using the DEA method, studies can choose an input- or output-oriented model to evaluate efficiency. However, previous studies argued that it is difficult for hospitals to control output factors. Note though that it is relatively easy to control the input factors to change efficiency [8,26,27,29,31]. Therefore, many studies adopt an input-oriented model for their analysis. Following this explanation, an input-oriented model was selected for the purposes of this study. CRS technical inefficiency can be decomposed into scale efficiency and "pure" technical efficiency. In Figure 1, B_2B contributes to the technical efficiency of observation B in the VRS model and B_1B contributes to the technical efficiency of observation B in the CRS model. Thus, B_1B_2 contributes to scaling efficiency. Each hospital has several inputs and outputs. A hospital's efficiency is defined as the ratio of the weighted value of outputs (total virtual output) to the weighted value of inputs (total virtual input), with the weights being obtained in favor of each evaluated unit by the optimization [1].

The MPI was named after Malmquist and introduced by Caves, Christensen, and Diewert to evaluate efficiency changes among different production units [1,29]. MPI can be divided into technical efficiency changes (TEC) and technical changes (TC). TEC can also be decomposed into pure technical efficiency changes (PTEC) and scale efficiency changes (SEC) [13,28,30]. In this study, MPI was selected to calculate the dynamic efficiency of the healthcare service system. MPI is often used to measure total factor productivity changes (Tfpch). A score of Tfpch > 1 means that the total factor productivity has improved, the cost has been reduced, and productivity has increased. Tfpch can be subdivided into technical changes (Techch) and technical efficiency changes (Effch). The latter can also be decomposed into pure efficiency (Pech) and scale efficiency (Sech). Techch was employed to evaluate the impact of technological advances on product changes [31]. A Techch score > 1 indicates that technological innovation improved the cost economy and productivity. Effch was applied to assess the degree of innovation in technical progress in two periods. A score of Effch > 1 indicates that the improvement was efficient. Pech presents management efficiency, whereas Sech primarily presents scale changes among different DMUs. A score of Pech < 1 indicates that management should be enhanced. Finally, a score of Sech < 1 indicates an urgent need for scale adjustment [1,28,30].

4.3. Input and output data in the DEA model

The input and output variables were selected, which is a crucial issue in the assessment of healthcare services [1]. The data resources for this study come from the China statistic yearbooks 2011–2020

[33]. Capital was considered necessary for human resources. Thus, the sum of the financial investment and number of healthcare institutions and beds represented the capital input. The number of doctors and nurses is considered a human resources input indicator. The average number of visits and annual hospitalization rate were the same as the output. Specifically, in this study, they were the number of outpatients (per hundred million) and inpatients (per ten thousand). Thirty-one provinces, autonomous regions, and municipalities were chosen as DMUs, and divided into three regions: the eastern area: 12 provinces (Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong, Guangxi, Liaoning, Beijing, Fujian, Hainan, Tianjin); western area: 10 provinces (Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang); and middle area: 9 provinces (Anhui, Jiangxi, Henan, Hubei, Hunan, Shanxi, Inner Mongolia, Jilin, Heilongjiang). The subsequent analysis identified the efficiency of each province and compared the performance of different areas. This study collected data from 2010–2019 on 5 input indicators and 2 output indicators for 31 provinces.

4.4. Results

Table 1 provides an efficiency summary of the CRS, VRS, and scale models for the three areas over 10 years. Based on Table 1, Figures 2, 3, and 4 show the efficiency trends over 10 years using different models. For CRS, in Figure 2, all efficiency numbers are below 1. Thus, there was a significant increase in these three areas from 2010–2011. From 2011 to 2016, the three lines experienced a slight upward trend with some fluctuations. Subsequently, the whole movement demonstrated a slight downward trend. For the central area, the lowest efficiency was seen in 2010 at 0.64. In 2011, it reached 0.85, and finally, in 2019, the efficiency was 0.87. All efficiency measurements for the western area were greater than those in the central area. For the three time points (2010, 2011, and 2019), the values are 0.78, 0.93, and 0,93, respectively. The eastern area had the most significant efficiency value over the ten years for the three areas. It demonstrated slight changes from 0.87 in 2010 to 0.97 in 2019. Figure 3 shows the results of the VRS model. The trend was similar to that of the CRS model. An obvious increase was observed from 2010 to 2011. After 2011, the eastern and western areas remained stable, with efficiency values of the two areas remaining the same at approximately 0.97. However, there was a difference between the two areas and the central area in terms of the lowest efficiency. An increase was observed from 2010 (0.64) to 2011 (0.87). After 2019, the value reached 0.89. Figure 4 shows the scale efficiency. The changes here were smaller than those of the other two models over the 10 years, and the efficiencies of the three areas were similar. The values for the three areas ranged from about 0.93 to about 0.95. However, the western region had the smallest efficiency values.

Table 2 summarizes the MPI. For the Effch from the second to the seventh year, the values were greater than or equal to 1, and for the next three years, they were smaller than 1. Regarding Techch, for the first 10 years except the 3rd year, all the values were greater than 1. In the last year, the value increased to 1.456 (> 1). With respect to Pech, except for the previous year, all values were greater than 1, but the value of the previous year was 0.991. According to Sech, from the seventh year onward, the value was smaller than 1. Finally, for the total factor productivity changes (TFPC), the value of the second year was greater than 1, which was different from that of the first year. However, the value for the third year was 0.979, which was maintained until the ninth year. In the tenth year, the status changed to a value greater than 1 (1.413). During the 10-year period, two means were more significant than (Effch: 1.019, Pech: 1.021), and the other three means were 0.977 (Techch), 0.999 (Sech), and 0.996 (Tfpch), respectively. Table 3 summarizes the MPI of the means of the 31 provinces over the period of 10 years. For the means of the five models, two means (Effch and Pech) were greater than 1 (1.019 and 1.021). The means of the other three models were less than 1 (Techch: 0.977, Sech: 0.999, Tfpch: 0.996). On the Effch line, the means of the seven provinces were smaller than 1 (Beijing, Jiangsu, Shandong, Guangdong, Sichuan, Yunnan, and Xizang). The means of 19 provinces were smaller than 1 on the Techch line. For Pech, only the means of four provinces were smaller than 1 (Beijing, Jiangsu, Guangdong, and Yunnan). On the Sech line, the means of the 11 provinces were smaller than 1. For Tfpch, 12 provinces demonstrated the former situation as smaller than 1.

Figures 5–9 show the input slack value for the 31 provinces over a ten-year period. Regarding slack in input investment, Hebei, the western provinces (Chongqing, Sichuan, Guizhou, and Yunnan), and central provinces (Inner Mongolia, Anhui, Jiangxi, and Henan) had a slack value in 2010, with

Yunnan having the highest slack value at about 50. For ten years, Liaoning and Beijing had slack values between 40 and 85. Jiangxi had the highest slack value in 2019 at 113. Regarding the slack of input institutions, in 2010, 10 provinces had slack values of 0. Other areas had different slack values. That of Hebei was the highest at 46000. From 2010 to 2019, Gansu and Shanxi had slack values of approximately 8000 and 20000, respectively. In 2019, Hebei again had a high slack value of 40000. Regarding the slack of input doctors, 2010 had more provinces with slack values than other years. Liaoning and Beijing had slack values between 35000 and 70000 for 9 years. Jilin, Heilongjiang, Inner Mongolia, and Shanxi had slack values of approximately 25000 for 9 years. In 2019, Anhui had a slack value of 8000. For the slack of input nurses, Liaoning and Beijing had high slack values of around 20000 for almost 9 years. The slack value for Shanxi increased from 2500 in 2011 to 12500 in 2019, except in 2016, when it peaked at 13000. Guangdong had slack values of approximately 4000 for 6 years (2012, 2014, 2015, 2016, 2017, and 2018), but in 2019, its slack value was 0. Heilongjiang demonstrated a similar situation to that of Guangdong. Regarding the slack of the input bed, in 2010, except for nine provinces with a slack value of 0, other areas had different slack values. The highest value was approximately 100000 in Shandong. The slack values for Heilongjiang increased from 10000 in 2010 to 80000 in 2019. In 2019, Liaoning, Hebei, Jilin, Heilongjiang, Inner Mongolia, and Shanxi had slack values of 90000, 10000, 17000, 80000, 8000, and 8000, respectively. Among them, Heilongjiang and Liaoning had the highest values.

4.5. Discussion

Based on Table 1 and Figures 2–4, a significant increase in the three types of efficiency from 2010 to 2011 is evident. This is subsequent to the government launching its medical reforms to enhance the level of healthcare services. After 2011, the efficiency remained stable until 2019. This result is consistent with that reported by Chen et al. and Jingmei et al. [34, 35]. Constant efficiency indicates the comprehensive efficiency of healthcare institutions. This situation was good in the western and eastern areas. The efficiency of these two areas was approximately 0.9, which is close to 1, indicating excellent efficiency. This is because the eastern area is a developing area with plentiful resources to meet people’s requirements. However, the situation differs in the central area, which did not achieve higher efficiency. This can be attributed to the fact that the input of this area was not taken advantage of enough, and local healthcare services should be more helpful for offering healthcare services to local people. A similar result was found in a study by a study from H-H H et al. [27]. The central area also demonstrated lower technical efficiency; therefore, the new technological system did not play an essential role in the provided health services. The main area is considered a poor segment of China. As such, it is difficult for this area to attract talent who can use new technology to stay here for work. For scale efficiency, the three regions demonstrated similar levels of efficiency. Scale efficiency refers to the scale of institutions and hardware level [1,27]. Because of the government’s massive investment, the western, eastern, and middle areas have enough facilities for healthcare institutions to meet the needs of local people [17,36].

The MPI shows changes in the efficiency of the different models. Effch is the efficiency change used to measure the degree of innovation in technical progress within two periods. This can be used to evaluate the effects of the implemented reforms. From 2010 to 2016, the MPI of Effch for each area was greater than 1, meaning that innovation contributed to advancing the level of healthcare services. For technical efficiency, in the last ten years, while new healthcare technology had brought progress, it dramatically enhanced efficiency only in 2019. The results show that new technology drove improvements. This is because Internet utility and artificial intelligence are increasingly being used in the healthcare field to improve healthcare service efficiency and quality. Note that the results for pure efficiency were greater than 1, except for 2019. This means that management could meet needs through higher-level management. The mean for SE for the 10-year period was 0.999, which is close to 1. Therefore, the scale of healthcare institutions met requirements and no adjustment was needed. The government increased investment in every area after the medical reforms [37,38], as seen in the effects of this model. Finally, the total factor productivity changes give the whole efficiency level. The change in 2019 was 1,413, demonstrating high efficiency. During several years of efforts by healthcare staff and the government, institutions decreased costs and increased efficiency. Now that the level of living is increasing, people are paying more attention to health, so the increasing need for healthcare services to push healthcare zones requires more effort to improve efficiency [34,39].

Regarding the MPI of the province means, the Effch and Pech values were greater than 1. This means that the efficiency of the seven provinces enhanced their services, but the change in efficiency did not total 1. These areas are in the eastern and western regions, and all central areas demonstrated efficiency. Beijing, Jiangsu, Guangdong, and Yunnan scored below 1 for Pech changes. Beijing, Jiangsu, and Guangdong are developed provinces in China and have high-level management ability compared to other regions. As such, there is some room for them to improve their management. Yunnan is a relatively poor area, and its improvement in health services did not enhance its service efficiency. The scale efficiency means were very close to 1, so every province differed slightly in this regard. The recent scale of intuitions can meet the requirements for the development of healthcare services and the needs of people. The Techch means were greater than 1 in half the provinces of China and nine provinces in the western and central areas. The eastern area has higher economic and technology levels than the western and central regions; therefore, these areas have been able to decrease gaps and improve the efficiency of healthcare services by introducing new technology. The total factor productivity change situation was good, as most provinces' efficiency changes were greater than 1 and the mean (0.996) was close to 1. Finally, Beijing was inefficient in all five models. This means that Beijing, as the capital of China, has more financial resources that attract much human resource talent. This is also why Beijing demonstrates redundancy all the time [18,19,21,41].

Figures 5–9 show the effects of the medical reforms. From 2011 to 2019, some parts of China improved on various indicators. Noticeable is that Beijing should decrease healthcare resources like investment, doctors, nurses, and institutions. Beijing is the capital of China. It is a developed area and has significant input, even though it is sometimes redundant. Shannxi and Gansu are in the western region, and they should reduce the number of institutions and beds. The western area has a large amount of land, but the number of people is small compared to other regions. Jilin, Heilongjiang, and Liaoning should reduce the number of institutions and staff. Because the three provinces have undergone industrial restructuring, heavy industries are declining and green energy is being considered in various industry fields. People prefer to leave the three areas to pursue new job positions in other provinces. This means that the decline in the number of people caused redundancy in healthcare resources [27,30].

4.5.1. Limitations

This method is often used to evaluate the efficiency of health institutions. However, management and environmental factors cannot be excluded. Furthermore, it is difficult to decompose factors into subgroups to discover problems related to efficiency. Further research is required to develop these directions. Finally, this study does not show the situation in each province. Therefore, further research is needed to elaborate certain factors.

4.5.2. Conclusions

In conclusion, after the medical reforms, efficiency in the western and central areas improved. This means that more health resources are concentrated in the two areas to meet people's needs and decrease the inequality in the allocation of health services stemming from the imbalance in economic development. Poor regions have opportunities to use advanced technology for healthcare services. Professional staff are distributed in all three areas on average, thus demonstrating equality. Note that the management ability of healthcare institutions in China has always been excellent. Finally, other studies have also used this method to investigate efficiency and equality. However, most focus on one year or place. However, this study focused on the data of 31 provinces for a 10-year period.

Table 1. Summary of the efficiency in CRS, VRS and scale model among three areas for ten years

Ten-year out-input-oriented efficiency summary											
Year		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CRS model	East-area	0.8821	0.9405	0.9487	0.9503	0.9503	0.9593	0.9687	0.9633	0.9625	0.9335
	West-area	0.7757	0.9181	0.9274	0.9219	0.9219	0.9388	0.9489	0.9403	0.9417	0.9202
	Central-area	0.6493	0.8500	0.8566	0.8596	0.8682	0.8727	0.8893	0.8938	0.8879	0.8651
Year		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
VRS model	East-area	0.9244	0.9748	0.9784	0.9794	0.9751	0.9812	0.9881	0.9848	0.9849	0.9717
	West-area	0.8508	0.9646	0.9716	0.9697	0.9710	0.9741	0.9866	0.9821	0.9903	0.9824
	Central-area	0.6817	0.865	0.8706	0.8776	0.8854	0.8861	0.9024	0.9136	0.9098	0.8951
Year		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Scale model	East-area	0.9518	0.9644	0.9686	0.9699	0.9743	0.9773	0.9798	0.9780	0.9767	0.9605
	West-area	0.9120	0.9529	0.9553	0.9507	0.9574	0.9635	0.9618	0.9569	0.9508	0.9372
	Central-area	0.9477	0.9783	0.9800	0.9756	0.9773	0.9814	0.9828	0.9754	0.9731	0.9606

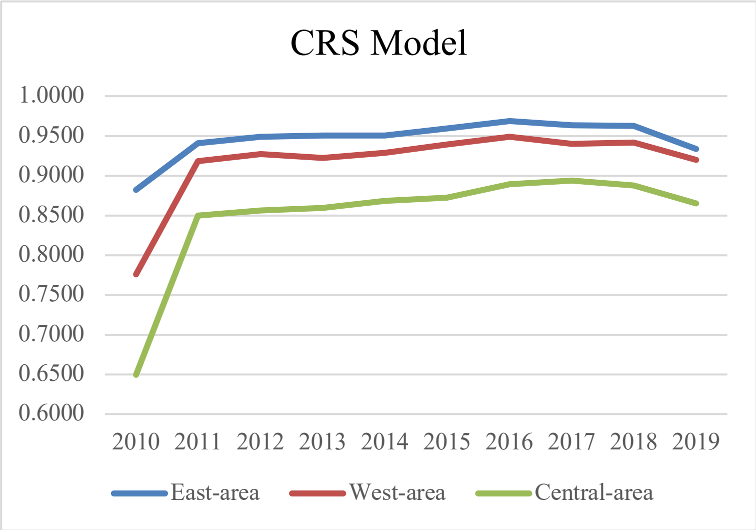

Figure 2: the efficiency in CRS model for ten years.

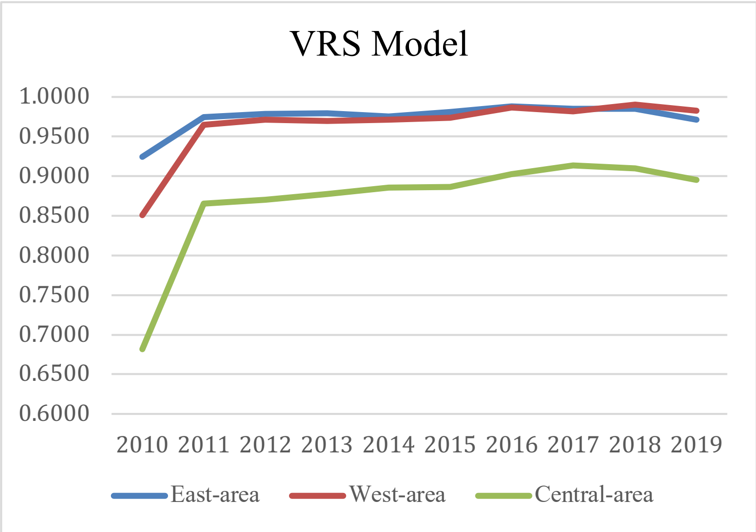

Figure 3: the efficiency in VRS model for ten years.

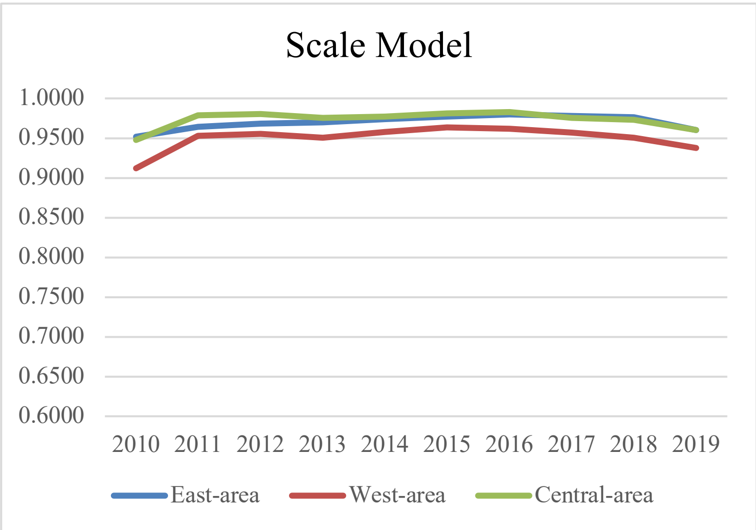

Figure 4: the efficiency in scale model for ten years.

Table2: Summary of the Malmquist Index each year.

MALMQUIST INDEX SUMMARY OF ANNUAL MEANS					
year	Efficiency change	Technical change	Pure efficiency change	Scale efficiency change	Total factor productivity changes
2	1.184	0.654	1.174	1.008	0.764
3	1.01	1.045	1.007	1.003	1.055
4	1	0.979	1.002	0.997	0.797
5	1.007	0.947	1.002	1.005	0.953
6	1.009	0.939	1.004	1.005	0.947
7	1.014	0.983	1.016	0.999	0.997
8	0.997	0.994	1	0.996	0.99
9	0.998	0.973	1.002	0.996	0.971
10	0.97	1.456	0.991	0.98	1.413
mean	1.019	0.977	1.021	0.999	0.996

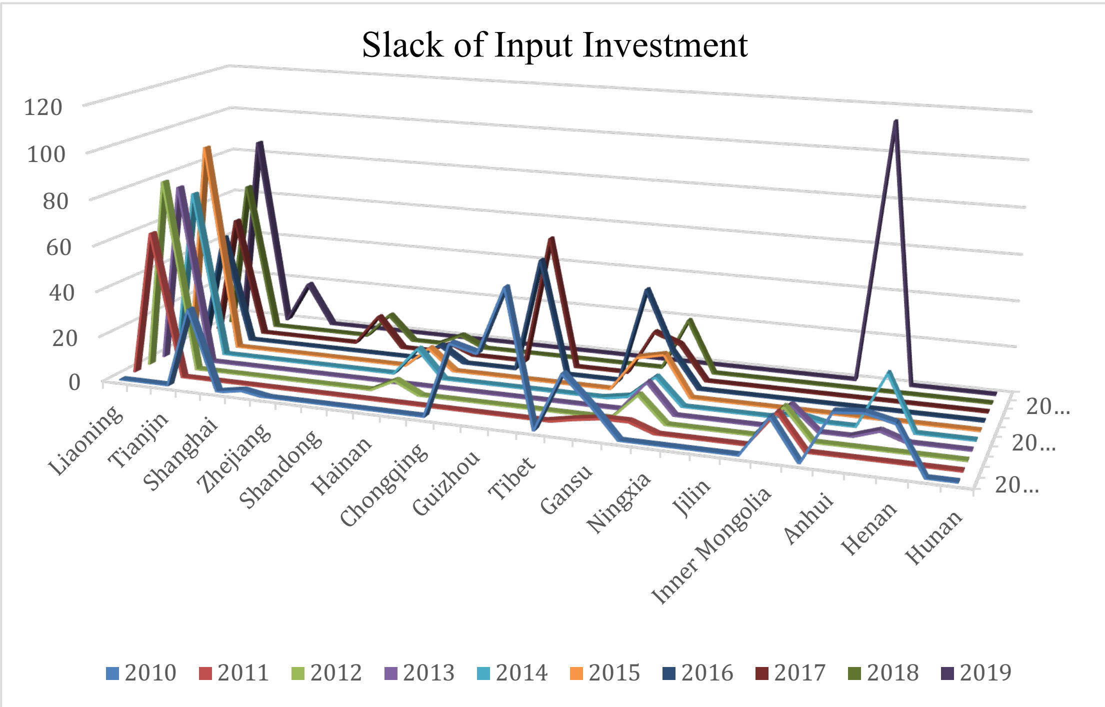

Figure 5: the slack of input investment in 31 provinces from 2010 to 2019.

Table 3: The Malmquist Index summary of the province mean

MALMQUIST INDEX SUMMARY OF FIRM MEANS					
Province	Efficiency change	Technical change	Pure efficiency change	Scale efficiency change	Total factor productivity changes
Liaoning	1.066	0.924	1.067	1	0.985
Beijing	0.996	0.843	0.997	0.999	0.84
Tianjin	1.017	0.985	1.004	1.014	1.002
Hebei	1.003	0.987	1.001	1.001	0.99
Shanghai	1	1.012	1	1	1.012
Jiangsu	0.997	1.026	0.997	1	1.023
Zhejiang	1	0.999	1	1	0.999
Fujian	1.019	0.993	1.019	1	1.012
Shandong	0.961	0.968	1.002	0.959	0.93
Guangdong	0.993	1.021	0.995	0.998	1.014
Hainan	1.031	0.945	1	1.031	0.974
Guangxi	1.015	0.996	1.02	0.996	1.011
Chongqing	1.019	1.059	1.019	1	1.079
Sichuan	0.998	0.974	1.005	0.992	0.972
Guizhou	1.003	0.937	1.003	1	0.941
Yunnan	0.991	1.033	0.989	1.002	1.024
Tibet	0.969	0.835	1	0.969	0.809
Shannxi	1.023	1.012	1.051	0.973	1.035
Gansu	1.012	1.02	1.011	1.002	1.033
Qinghai	1.04	0.934	1.046	0.995	0.972
Ningxia	1.04	1.049	1	1.04	1.091
Xinjiang	1.034	0.986	1.041	0.993	1.02
Jilin	1.052	0.934	1.055	0.997	0.982
Heilongjiang	1.085	0.962	1.09	0.996	1.044
Inner Mongolia	1.06	1.006	1.059	1.002	1.067
Shanxi	1.021	0.927	1.017	1.005	0.947
Anhui	1.035	1.016	1.035	1	1.052
Jiangxi	1.035	1.005	1.034	1	1.04
Henan	1.006	1.002	1.004	1.001	1.008
Hubei	1.037	0.973	1.035	1.002	1.009
Hunan	1.052	0.966	1.052	1	1.017

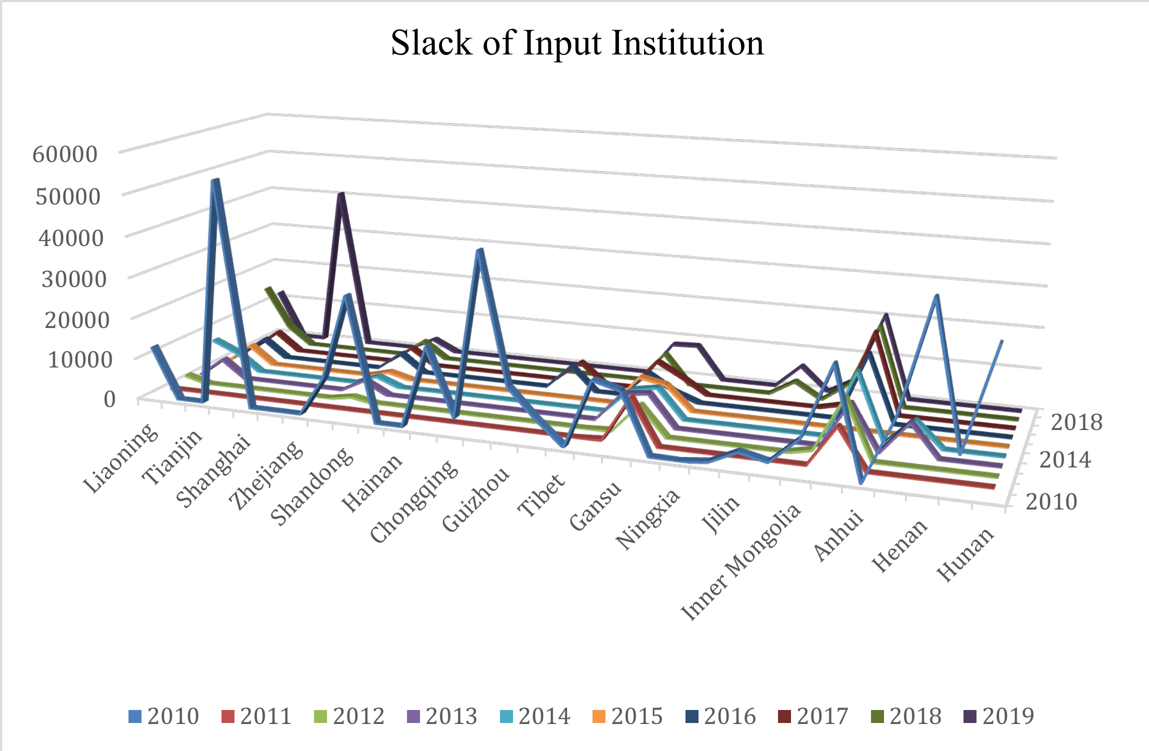

Figure 6: the slack of input institutions 31 provinces from 2010 to 2019

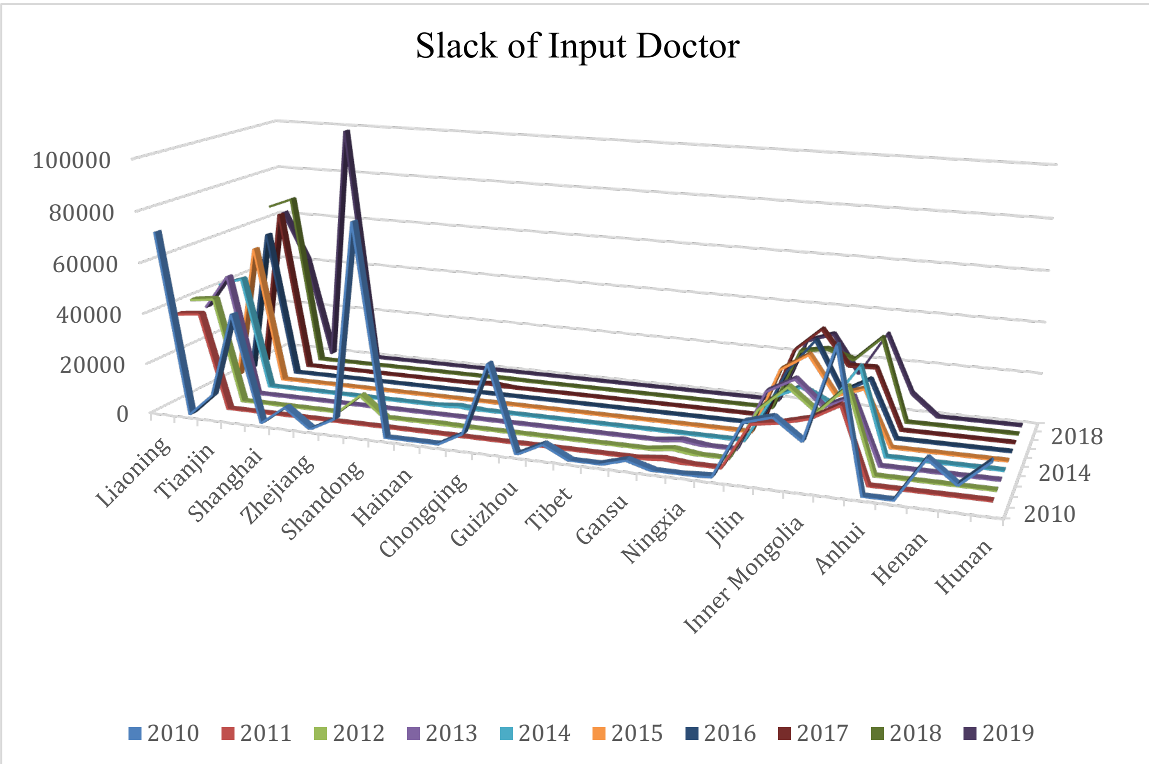

Figure 7: the slack of input doctors in 31 provinces from 2010 to 2019.

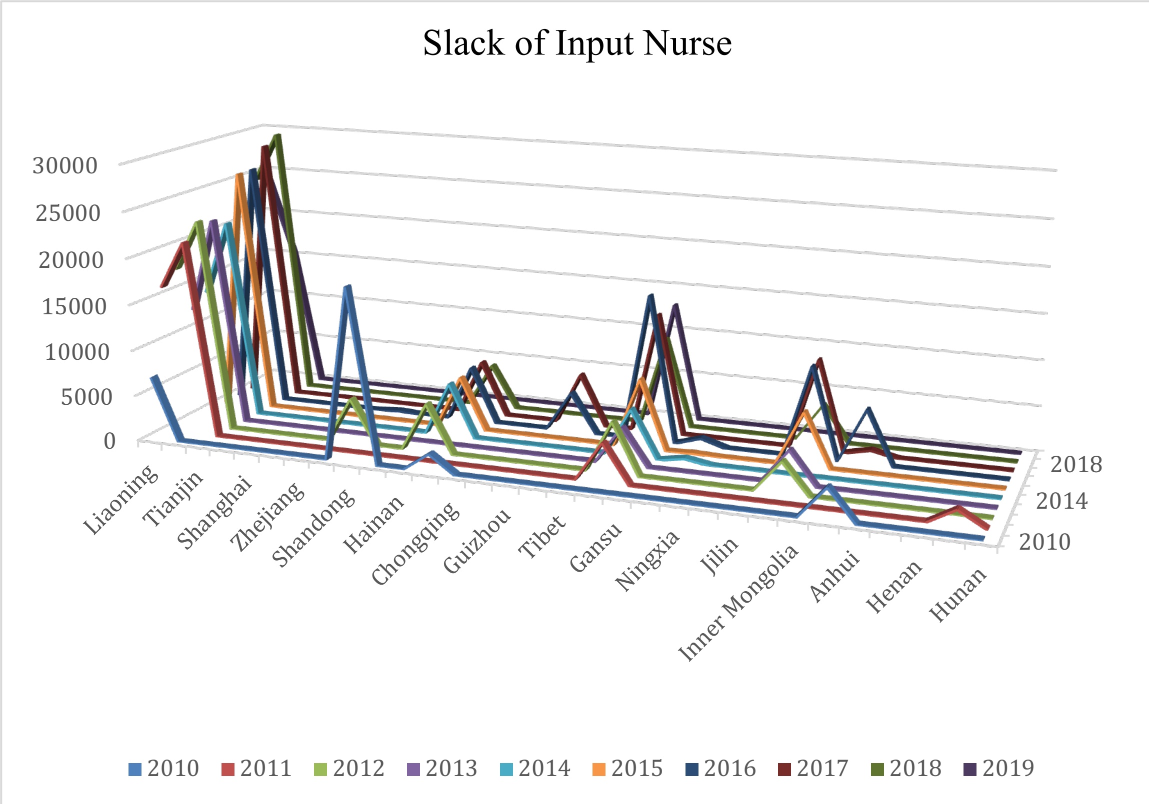

Figure 8: the slack of input nurses in 31 provinces from 2010 to 2019.

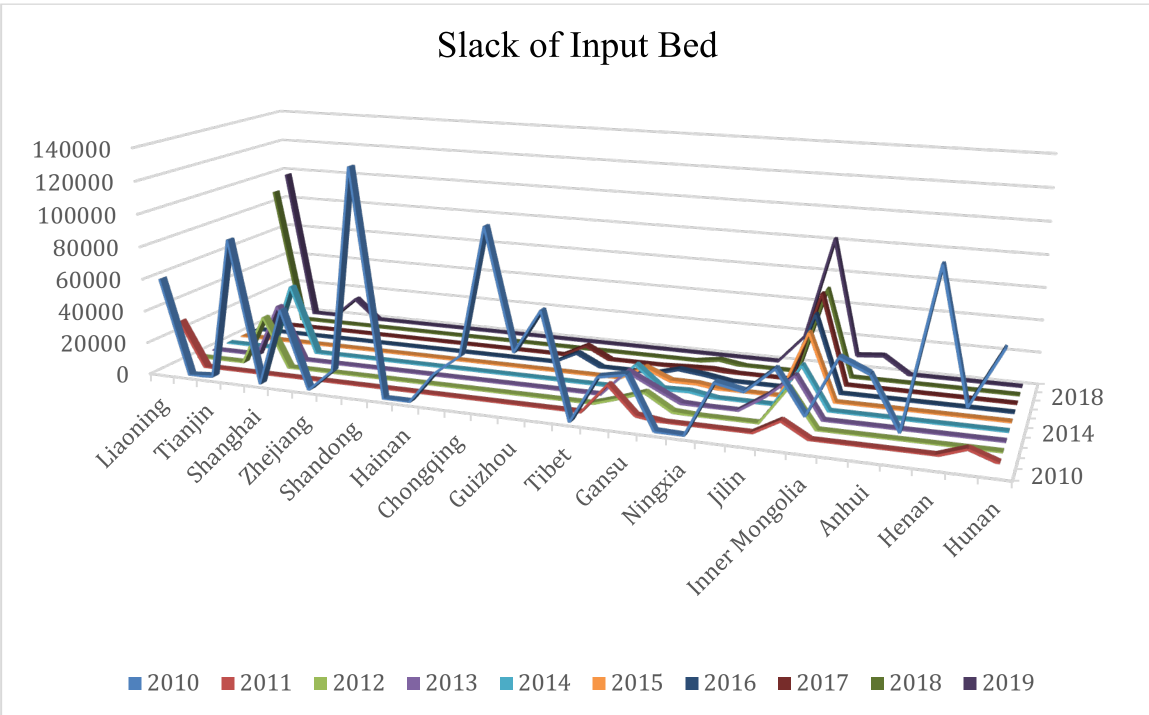

Figure 9: the slack of input beds in 31 provinces from 2010 to 2019.

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Chapter 5 Evaluation of Chinese Healthcare Service Institution' efficiency in 2019 by Data Envelopment Analysis Model

5.1. Background:

The global healthcare system is trying to decrease the gap in healthcare resource allocation, which is increasingly improving healthcare access inequality[1]. It is an important issue not only for developed countries but also for developing countries. China is one of the largest economies in the world. Even though China experienced economic growth, the Chinese government spent 6.6% of the GDP on healthcare in 2019 [2]. The percentage was lower than other developing countries with similar GDP[3]. With the living level growing gradually in China, the need for high-quality health services has increased. Based on published studies' findings, healthcare access inequality was witnessed. Many studies have tried to show the situation in China. The eastern area has developed provinces and cities (such as Beijing, Shanghai, and Hangzhou) with abundant healthcare resources, and people can access healthcare easily[3-5]. However, some growing regions (such as those in the middle and western areas) have a relatively big gap with the coastal regions. Rural and urban areas, therefore, still have large differences in the same place[6,7]. This diversity varies, attracting an increasing number of experts' eyes. Indeed, the government launched medical reforms gradually to narrow the gaps between different regions. Many studies tried to find whether the reforms were effective.

Besides, there are many methods to be used for inequality study. The Gini and Theil indexes are the most typical methods for analyzing equality research because allocating healthcare resources is essential[3,8]. However, the efficiency of healthcare institutions can also represent the inequality situation through a new study direction. Healthcare resources should be used effectively, including equality of allocation and hospital efficiency[9,10]. Furthermore, the efficiency could be the serviceability of the hospital and whether the resource exchange into the healthcare service effectively meets the needs of local people. Some papers have focused on the countrywide or provincial-level situation of hospital efficiency for several years[11-14]. A study found that coastal area' hospitals are more efficient than non-coastal areas[15]. Another study found a negative relationship between government subsidies and the efficiency of the coastal area hospitals[6]. It is worth noting that the government and a hospital's management could adjust the amount of healthcare resources to meet people's requirements based on efficiency studies' results. Little research focuses on each province's efficiency situation and analyzes how to adjust the resources to match the needs. This study will use 2019 data to present each Chinese province's hospital's efficiency and make some suggestions to improve the efficiency[5,15].

5.2. Method:

Data envelopment analysis (DEA) was introduced by Charnes, Cooper, and Rhodes in 1978 as a non-parametric programming method. It is a valuable and appropriate way to estimate hospital efficiency because it has some advantages compared with the parametric technique. [14,16] DEA is used for measuring the efficiency of DMUs using linear programming techniques to envelop observed input–output vectors as tightly as possible [17,18]. "envelops" is to identify a "frontier" that used to evaluate observations representing the performances of all of the entities that are to be assessed (such as business firms, government, schools, hospitals)[16,19]. DEA can consider multiple inputs–outputs at the same time without any assumption on data distribution. Therefore, A DEA model can be divided into an input-oriented model, which minimizes inputs while satisfying at least the given output levels, and an output-oriented model, which maximizes outputs without requiring more of any observed input values[16,19]. DEA models can also be divided into returns to scale by adding weight constraints. Decision Making Unit (DMU) is, in a flexible manner, any such entity, with each entity to be evaluated as part of a collection that utilizes similar inputs to produce identical outputs[16,19]. In 1978, Charnes, Cooper, and Rhodes proposed the efficiency measurement of the DMUs for constant returns to scale (CRS) originally, where all DMUs are operating at their optimal scale[16,19]. In 1984 Banker, Charnes, and Cooper introduced the variable returns to scale (VRS) efficiency measurement model, allowing the breakdown of efficiency into technical and scale efficiencies in DEA[16,19]. The degree of efficiency represents the performance score of each DMU, which is between 0 and 1. The DMU is called efficient when the DEA score equals 1[16,19]. Efficiency extends through "scale" and "technical" efficiency, as well as "mix" and other kinds of efficiencies. Scale efficiency (SE) is defined as a ratio of CRS to VRS efficiency scores and provides evidence of whether the DMU is operating on the optimal scale size.[20,21]

Compared with the output factors, it is easy for hospital managers to control the input factors. That's why most studies chose the input-oriented model. However, this study aims to estimate the hospital's efficiency and identify which input factors need to be adjusted to meet the needs of output and which output factors could be expanded to meet more people's needs. Consequently, this study used input-oriented and output-oriented models to evaluate.

The dual linear programming problems to the envelopment models are called multiplier models. See the following Table:

Frontier Type	Input-Oriented	Output-Oriented
	$\max \sum_{r=1}^{s} \mu_r y_{ro} + \mu$ subject to $\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + \mu \leq 0$ $\sum_{i=1}^{m} v_i x_{io} = 1$ $\mu_r, v_i \geq 0(\varepsilon)$	$\min \sum_{i=1}^{m} v_i x_{io} + v$ subject to $\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} + v \geq 0$ $\sum_{r=1}^{s} \mu_r y_{ro} = 1$ $\mu_r, v_i \geq 0(\varepsilon)$
CRS	where $\mu = 0$	where $v = 0$
VRS	where μ free	where v free
Source: Zhu, J., 2009. Multiplier and slack-based models. In Quantitative Models for Performance Evaluation and Benchmarking. Springer, Boston, MA.		

Table 1: The envelopment models are input-oriented and output-oriented models.

It presents efficiency scores that do not exaggerate the units' performance at the weak part of the frontier under variable return to scale (VRS) and constant variable return to scale assumption. The modified DEA model used is as follows. Considering nDMUs (years in our case) with each DMU $_j(j=1,\ldots,n)$ using m inputs $x_j = (x_{1j}, x_{2j}, \ldots, x_{mj}) > 0$ to produce s outputs $y_j = (y_{1j}, y_{2j}, \ldots, y_{sj}) > 0$. The best weights for the variables are u_r for outputs and v_i for inputs. y_{r0} and x_{i0} are the input and output for a particular DMU$_j$ under evaluation.

5.3. Setting: Input and output data in the EDA model

The data resources stem from the China statistic yearbooks 2020. Capital is regarded as crucial as the human resource. So, the sum of financial investment from the government and the number of healthcare institutions and beds represented the capital input. Indeed, the number of doctors and nurses is regarded as a human resources input indicator. Capital and human resources are considered as the input indicators. The average number of visits and the annual hospitalization rate were commonly the output. Specifically, in this study, they were the number of outpatients (per a hundred million) and the number of inpatients (per ten thousand). 31 provinces, autonomous regions and municipalities were chosen as DMUs, divided into three regions: The east area includes 12 provinces (Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong, Guangxi, Liaoning, Beijing, Fujian, Hainan, Tianjin), the west area includes 10 provinces (Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang), consists of the middle area: 9 provinces (Anhui, Jiangxi, Henan, Hubei, Hunan, Shanxi, Inner Mongolia, Jilin, Heilongjiang). The subsequent analysis would assess each DMU's efficiency and compare different DMUs' performance. This study collected data on five input and two output indicators in 31 provinces in 2019. The DEAP version 2.1 was used to conduct the analysis in this study.

5.4. Results：

In this study, 31 provinces data were extracted for analysis. The east area is a developed area including 12 provinces. The west and middle areas are developing areas involving 19 and 9 provinces, respectively. The number of efficient and inefficient units is presented in Table 2, and the proportion of that is shown in Figure 1. The east and central areas' efficient regions were more than inefficient. Seven of the twelve eastern provinces were efficient, occupying 58% greater than that of the middle provinces(56%). On the other hand, the western area's efficient regions had only 40% of this area's provinces, the most minor proportion of efficient parts. For the countryside, efficient and the inefficient regions occupied approximately half of all, respectively.

CRSTE represents comprehensive technical efficiency, VRSTE is pure technical efficiency, and SCALE efficiency is defined as a ratio of CRS to VRS efficiency scores and provides evidence of whether the DMU operates on the optimal scale size. In the Figure 2, The highest CRSTE, VRSTE, and SCALE efficiency existed in the western area, 0.981, 0.984, and 0.995, respectively. The CRSTE value was high in the middle area, reaching 0.993, just slightly smaller than in the east area. The values of CRSTE and VRSTE were slightly less than those of the western area (0.972 and 0.977), respectively. The lowest values in all three indicators were in the east area, especially the CRSTE and SCALE efficiency, which were almost a half lower than other areas (0.923 and 0.905), respectively. The SCALE value in the eastern region was 0.977, less than that of the different areas.

Output slack means there is space for enhancing output. In Table 3, Six units can increase one of the outputs: Heilongjiang and Shanxi in the middle area, Beijing and Hainan in the eastern region, and Shannxi and Qinghai in the western area. Beijing had the largest slack value, 11.43, in the inpatient output indicator. Another province that should improve the inpatient output was Hainnan, with a slack value of 1.67, far less than Beijing. For the outpatient aspect, Heilongjiang, Shannxi, Qinghai, and Shanxi could enhance; the largest value was 0.27 for Heilongjiang, and The lowest was 0.05 for Shanxi. Between the values of the two areas, 0.147 and 0.079 were in Shannxi and Qinghai, respectively.

To be minimum input, 10 provinces in three areas could decrease input in Table 4. Beijing and Liaoning had four input indicators exceeding the optimal inputs. For Beijing, except for the beds, the number of institutions, doctors, nurses, and investment could be reduced. Jilin and Heilongjiang had three inputs that could be declined. The remaining 6 provinces had two inputs that could be decreased for being close to optimal values. Regarding the five input indicators, the number of institutions and doctors showed redundant in 7 provinces. The extent of redundancy of nurses was less than that of doctors and beds, but excessed institutions and investment. Only 3 provinces had excessive investment. The values of the investment indicator are the least, and the mean value is only 2.99 less than that of other indicators, obviously. The mean value of doctor slack was the largest at 6791.22 among the 5 indicators. Beijing and Liaoning' were about ten times more than the mean of the doctor slack. For the bed slack, Liaoning's value was 88444.80, more than 20 times the mean value of 4679.82. Heilongjiang's value was about more than 10 times the mean of that. Beijing and Liaoning had more than 10 times values than the mean value of the nurse indicator, 2343.95. The mean value of the Institution indicator was 1697.40, and the Liaoning value reached 14503.43, more than 10 times the mean value.

5.5. Discussion:

According to the efficiency scores in different regions, results present that half of all provinces were efficient units. More inefficient regions exist in the western area, that relatively backward part of China. This finding was mentioned in a published paper[15]. Another reason is that the western area has a somewhat larger region of land but less population. (small clinics, adequate institutions) , there are many small clinics with few beds to offer simple treatment, and the government offers adequate medical institutions for local people, making treatments accessible quickly to cope with emergencies. The efficiency Scores show that middle and west area hospitals have outstanding comprehensive technical efficiency, which was close to 1. In contrast, the pure technical and scale efficiency were lower than the comprehensive technical efficiency. That means that efficiency can be improved by developing technologies and management. Besides, enlarging the scale of institutions is to approach the optimal scales. Even though more parts in the east and central areas showed efficiency than in the western regions, the western region presented more excellent efficiency in three kinds. That means the gaps between efficient and inefficient units in the western area were smaller than in the other two areas. The eastern region had the most significant gap within the region. Even though the findings of the inefficient eastern area published in another paper are the same as this study, it mentioned the efficiency in the coastal areas decreased to show the imbalance situation[7].

It is noticeable that Beijing, as a developed region, had the largest slack value in the inpatient output indicator. Therefore, Beijing's hospitals should consider improving inpatient treatment efficiency. The reason for this may be that Beijing has abundant health resources. Some of that, without an outpatient department, only services the inpatients. Even though 6 units could increase the services for inpatients and outpatients to reach the optimal output, the values of that were not significant. However, the values of input slacks should be paid more attention. China is a developing country with a problem of development imbalance. This issue was found in this study as well. The input slacks show that developed areas have more extensive medical resources than poor areas because those areas (such as tier-1 cities) attract great talent. It is remarkable that Heilongjiang, Jilin, and Liaoning had prominent redundancy of health resources as the ratio of healthcare resources to population was increasing. Those three regions considered heavy industry provinces before are facing the loss of workforce population because of reduced production and factory closures to protect the environment. However, healthcare staff with stable salaries and work positions there did not leave to other regions. That's why medical resources were redundant. Beijing, regarded as the capital of China with an outstanding economic situation, attracted a great deal of investment and talent to live there, including hospital owners and healthcare experts. That's the reason why Beijing showed redundant healthcare resources by the values of input and output slacks. Qinghai, being in the western area with a poor economic situation, after medical reforms, the government tried to improve the level of the healthcare service there to offer a great deal of investment and build adequate health institutions to meet the requirements of local people and attract increasing residents. However, in 2019, it was not enough to attract healthcare staff to match the number of beds. A published paper calculated the data in 2016 to show the input and output adjustments needed[5]. It also showed the redundant health resources in Heilongjiang, Jilin, and Liaoning in 2016. However, Beijing, Hainan, and Qinghai in 2016 did not present excess healthcare resources, compared with this study in 2019. That may be because Beijing attracted more investment, construction, and talent in three years. Furthermore, the government focused on investing and building health construction in Qinghai and Hainan. The former was a poor region that needed more support, and the latter was a new special economic zone in China.

It must be admitted that limitations existed in this study. Firstly, it is general research of efficiency in provinces, compared among three areas, so it is difficult to offer specific information about within groups. Secondly, one-year data was analyzed in the study so that the trend of the efficiency of hospitals over time cannot be witnessed. However, this study showed that the redundant healthcare resource input at each unit level, which is core, details how to improve efficiency.

5.6. Conclusion:

During China's development and medical reforms, hospitals' performance has been outstanding as more than half of provinces' hospitals reached efficiency. The efficiency gaps within the eastern area were significant and should be paid more attention. The old heavy industry provinces dealt with excess healthcare resources, which should improve to balance the healthcare resources. Beijing, as the Capital of China, has attracted many resources beyond the people's needs. The government should focus more on inefficient provinces to look for causes of poor performances and make strategies to improve the situation.

Table 2: The number of efficient and inefficient provinces in different areas.

	east area	**west area**	**middle area**	**countryside**
efficient	7	4	5	16
inefficient	5	6	4	15
total	12	10	9	31

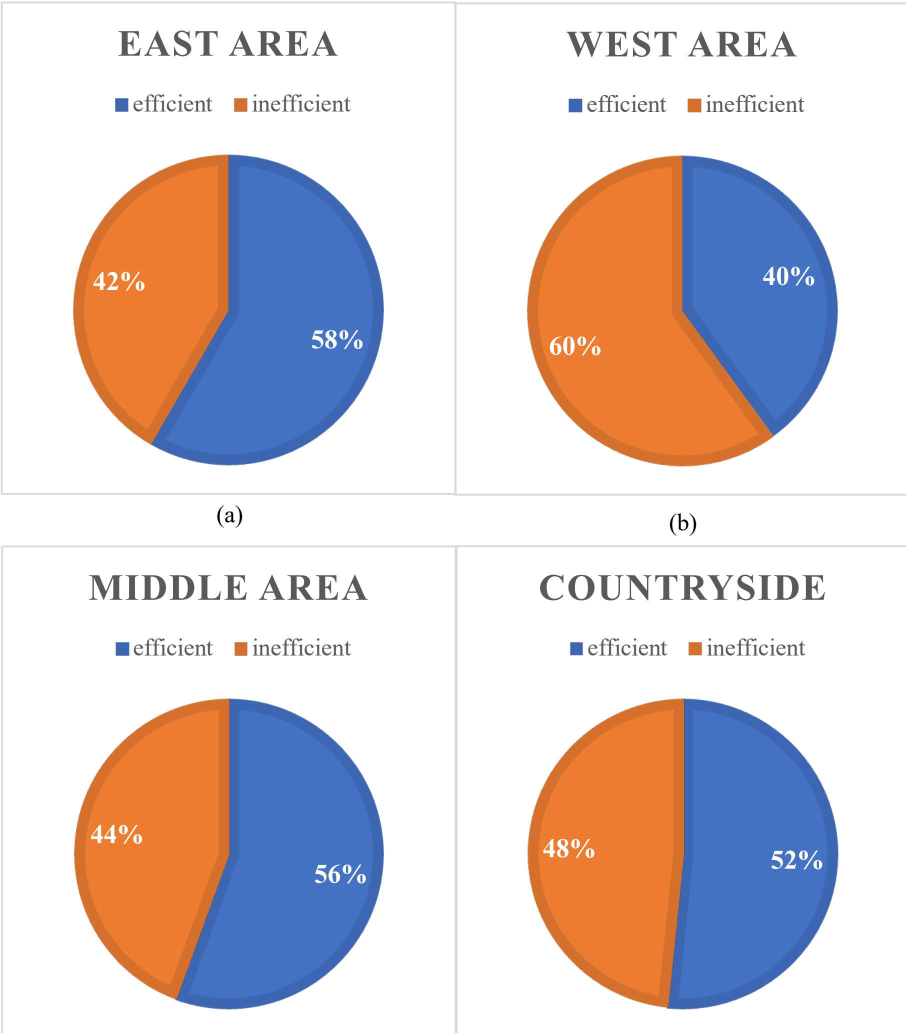

Figure 1: The proportion of the efficient and inefficient units in total area. (a) The proportion of that in the eastern area; (b) The proportion of that in the western area; (c) The proportion of that in the middle area; (d) The proportion of that in the countryside.

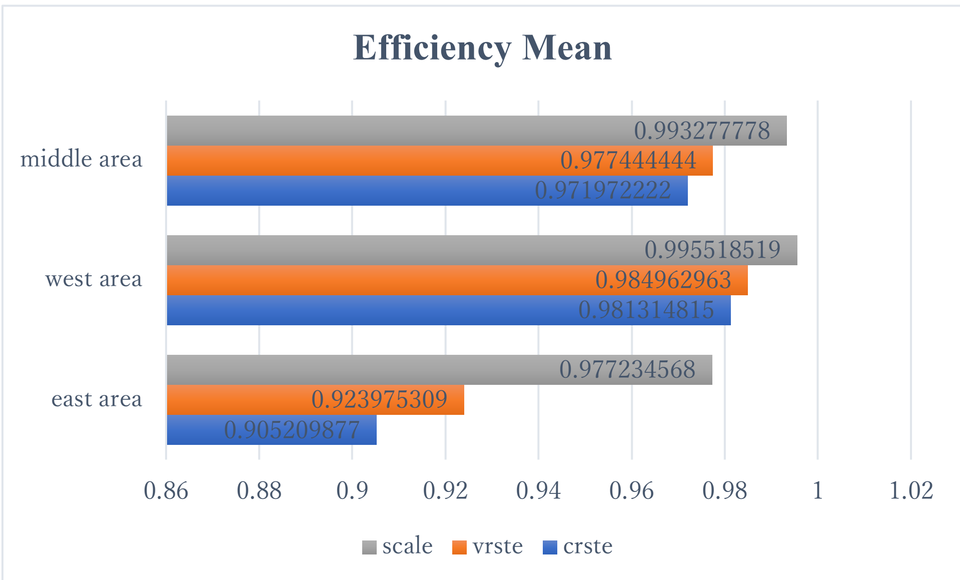

Figure 2: The efficiency mean of scale, verste, and crste models in three areas.

Table 3: The summary of output slack values.

SUMMARY OF OUTPUT SLACKS:				
Unit output:	Outpatient	Inpatient	Region	Province
3	0.27	0	Middle area	Heilongjiang
4	0	11.43	East area	Beijing
13	0	1.67	East area	Hainan
21	0.15	0	West area	Shannxi
23	0.079	0	West area	Qinghai
26	0.05	0	Middle area	Shanxi
Mean	0.018	0.42		

Score after the decimal point to retain two significant.

Table 4: The summary of output slack values.

SUMMARY OF INPUT SLACKS:							
Unit input:	Investment	Institution	Doctor	Nurse	Bed	Region	Province
1	0	14503.43	65609.60	24281.36	88444.80	East area	Liaoning
2	0	3252.93	12465.92	0	770.40	Middle area	Jilin
3	0	0	25655.91	5025.12	53030.10	Middle area	Heilongjiang
4	64.30	4434.01	68967.67	29453.12	0	East area	Beijing
10	0	3784.19	182.99	0	0	East area	Fujian
13	6.29	0	0	4536.30	0	East area	Hainan
14	0	4383.46	15521.97	0	0	Middle area	Neimenggu
21	0	7141.19	0	9366.47	0	West area	Shannxi
23	22.15	0	0	0	2829.13	West area	Qinghai
26	0	15120.25	22123.96	0	0	Middle area	Shanxi
Mean	3.0	1697.40	6791.23	2343.95	4679.82		

Score after the decimal point to retain two significant.

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Chapter 6 Summary

In this study, results showed the equality of Chinese healthcare resource allocation. It was seen that there is a gap between the urban and rural areas. China was trying to narrow the economic situation between two areas and received the effect, but for the medical service, the government need to pay more attention. The developing regions, such as the middle and western parts, were not reaching the equality level of medical services in the eastern area. Furthermore, the developed areas such as Beijing were prone to present abundant healthcare resources.

Chapter 2 focused on the national equality of healthcare service allocation and selected the HRDI method that corresponds with the Chinese population and geography situation. Less national research was conducted, but necessary. This study tried to offer more powerful evidence about that. Additionally, the central government made a requirement for medical resource distribution. This study verified each province's result, offering direct evidence of development. The equality of the distribution of healthcare services in China was unfair between the eastern and middle-western areas. The government launched the developing requirements and paid additional attention to narrowing the imbalance among different economic level regions to meet the needs of the local people. Although many provinces did not meet the requirements for medical resources in 2019, the distribution of healthcare services approached relatively equitably countrywide.

Chapter 3 used the traditional Theil index to evaluate the inequality in healthcare resources. This shows that the inequality situation in China was excellent after the two deep reforms. Apart from the institutional inequality from the between group, other factor inequalities stemmed from within the group, even though there were some fluences over time. However, when considering land and population impacts, the inequality was not better than when only considering population. This means that the government should consider long distances for people in the unfair situation of access to healthcare services.

In Chapter 4, after the medical reforms, efficiency in the western and central areas improved. This means that more health resources are concentrated in the two areas to meet people's needs and decrease the inequality in the allocation of health services stemming from the imbalance in economic development. Poor regions have opportunities to use advanced technology for healthcare services. Professional staff are distributed in all three areas on average, thus demonstrating equality. Note that the management ability of healthcare institutions in China has always been excellent. Finally, other studies have also used this method to investigate efficiency and equality. However, most focus on one year or place. However, this study focused on the data of 31 provinces for a 10-year period.

In Chapter 5, during China's development and medical reforms, hospitals' performance has been outstanding as more than half of provinces' hospitals reached efficiency. The efficiency gaps within the eastern area were significant and should be paid more attention. The old heavy industry provinces dealt with excess healthcare resources, which should improve to balance the healthcare resources. Beijing, as the Capital of China, has attracted many resources beyond the people's needs. The government should focus more on inefficient provinces to look for causes of poor performances and make strategies to improve the situation.

The Chinese medical reforms were effective but could not solve all the problems. There is still a gap between distinct areas, which need to be considered, and reforms and medical systems should be improved to meet the needs of people. This study learned the equality of healthcare resource allocation in China and offered plenty of evidence for the policymakers to improve equality in the future.

Acknowledge

I am profoundly grateful to Professor Ogasawara for the guidance and assistance provided throughout my doctoral research journey. Professor Ogasawara is a distinguished scholar in the field of Information Science, having amassed a wealth of expertise and contributed significantly to advancements in the discipline. Embarking on this journey during the COVID-19 pandemic posed significant challenges to conducting research. Nevertheless, Professor Ogasawara provided invaluable advice and assistance in selecting my research direction and methodology. Under his guidance, my research was smoothly initiated and progressively advanced. As an international student, communication required additional effort and time. However, Professor Ogasawara patiently guided each aspect of my research, aiding its smooth progression. I extend my special thanks to Professor Ogasawara for their guidance and assistance.

I would like to express my sincere gratitude to Professor Hui Shuping for serving as my co-advisor and providing guidance throughout my doctoral research. Professor Hui has offered crucial advice and affirmation toward my research, for which I am deeply thankful. I am also grateful to Professor Ikeda, and Professor Ishikawa the guidance and help provided. I appreciate the help and support from Assistant Professor Ohashi and fellow students Yang Yuchen, Zhang Hongjian, Iwai, Ukai, Kaneno, and Maeda during my research journey. I hope to participate in more research and

contribute to Professor Ogasawara's laboratory in the future. Special thanks to everyone for their help and support.

Publications

1. Zhao J, Yang Y, Ogasawara K. Measuring the inequalities in the distribution of public healthcare resources by the HRDI (Health Resources Density Index): Data Analysis from 2010 to 2019, Healthcare., 2022, 10(8): 1401, https://doi.org/10.3390/healthcare10081401.

Presentations

1. Zhao Jieyu, Katsuhiko Ogasawara, Efficiency Evaluation of Public Hospitals in China in 2019: an Application, Joint Conference on Medical Informatics, 21st Hokkaido Branch Conference, Sapporo, 23rd of September, 2023 (presentation).
2. Zhao Jieyu, Katsuhiko Ogasawara, An analysis of the equality of health resources in China, the 43rd of Joint Conference on Medical Informatics, Kobe, 25th of November, 2023 (poster).