Allocation Efficiency of Higher Education Resources in China

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Dalai Ma
Chongqing University of Technology, Chongqing, China

Xuefeng Li (✉)
Yunnan Normal University, Kunming, China
forfamilyisme@163.com

Abstract—This paper uses the super-efficiency data envelopment analysis (DEA) model to measure the higher education resource allocation efficiency (HERAE) of 30 provinces from China 2005-2018, and analyzes the regional difference and dynamic evolution law of the HERAE with Theil index and kernel density estimation, respectively. The results show that: The HERAEs of most provinces are DEA effective, but the HERAEs of a few provinces are DEA ineffective, calling for further improvement to the allocation of higher education resources in these places. There was a certain difference in the HERAE trend between eastern, central, and western regions. In the sample period, eastern region had higher HERAE than central and western regions. With the elapse of time, the internal gap of HERAE decreased to different degrees in the three regions. Eastern region had the largest gap, followed in turn by central and western regions. In addition, China's HERAEs were polarized in time. With the passage of time, the polarization of regional HERAEs slowly weakened.

Keywords—Higher education resource allocation efficiency (HERAE), super-efficiency data envelopment analysis (DEA) model, Theil index, kernel density estimation

1 Introduction

Higher education has cultivated many high-quality talents, who contribute massively to the economic growth, technological innovation, and social development in China. In recent years, China has vigorously reformed its higher education system, and stepped up the investment on higher education. Thus, the development of higher education in China has moved from scale expansion to connotation enrichment. For this reason, China's institutions of higher learning have acquired more and more comprehensive strength, and some top colleges in the country have improved their rankings in the world.

However, China is a vast country with numerous institutions of higher learning. Some colleges in remote areas lack sufficient funds and high-quality education resources. Traditionally, the education resources in China are allocated through central planning through programs like Project 985 and Project 211. This allocation model creates a serious imbalance and asymmetry of higher education inputs across different regions. In this background, improving higher education resource allocation efficiency (HERAE) is the only way to effectively utilize education resources and realize sustainable development of higher education.

The evaluation of higher education efficiency has been heatedly discussed in the academic circle. At present, there are two kinds of methods to evaluate higher education efficiency: parametric analysis and nonparametric analysis. The typical parametric analysis approach is stochastic frontier analysis (SFA). McGuire et al. [1] and Dundar and Lewis [2] assessed the production efficiency of American colleges through parametric analysis. Data envelopment analysis (DEA) is the most representative strategy of nonparametric analysis. Many scholars adopted nonparametric analysis to explore the school-running efficiency [3, 4], resource allocation efficiency [5, 6], Input-output efficiency [7, 8], investment efficiency [9], and technological innovation efficiency [10, 11] of colleges. Further, Belfield and Fielding [12], and Kempkes and Pohl [13] studied the influencing factors of higher education.

The above review indicates that resource allocation efficiency is an important research area of higher education efficiency. Nonparametric analysis by DEA is the mainstream method for education efficiency evaluation. But the related studies have two defects: (1) most of them focus on the resource configuration efficiency within colleges or departments, rather than that on regional scale; (2) the education resource allocation efficiency is mostly evaluated by traditional Charnes-Cooper-Rhodes (CCR) model or Banker-Chames-Cooper (BCC) model, which are unable to sort the decision-making units (DMUs) whose efficiencies are all one.

This paper mainly makes two contributions: First, the HERAEs of 30 provinces from China were taken as the objective, marking a breakthrough in HERAE research. Second, the super-efficiency DEA model was adopted to evaluate the HERAE, which improves the evaluation accuracy and facilitates the comparison between regional HERAEs.

2 Methodology

2.1 Super-efficiency DEA model

DEA, also called non-parametric analysis, mainly evaluates the efficiency of DMUs with multiple inputs and outputs. It is a flexible and practical method, which does not need to unify the dimnesions of indices or set index weights. As a result, DEA has been widely used in the field of efficiency evaluation, and regarded as an important analysis tool for management science. Early on, Charnes et al. [14] proposed the CCR model with constant scale, which limits the DMU efficiency to 1. Hence, the model cannot sort the DMUs whose efficiencies are all 1.

Andersen and Petersen [15] established the super-efficiency DEA model in 1993. Unlike the traditional CCR model, the super-efficiency DEA model can evaluate more than one DMUs, and sort the DMUs on the efficient frontier of DEA.

Suppose there is a production system containing n DMUs. Each DMU handles x inputs and y outputs. Let $DMU_j = (x_j, y_j)$ be the j-th DMU, and $T =$

$\{(x, y): x\ can\ produce\ y\}$ be the set of all possible production scenarios. On this basis, the super-efficiency DEA model to evaluate the efficiency of the j-th DMU can be established as:

$$s.t.\begin{cases} \sum_{i=1,\ i\neq j}^{n} \lambda_i x_i + s^- = \theta x_j \\ \sum_{i=1,\ i\neq j}^{n} \lambda_i x_i - s^+ = y_j \\ \lambda \geq 0, i = 1,2,3,\cdots,n \\ s^- \geq 0,\ s^+ \geq 0 \end{cases} \tag{1}$$

where, x and y are inputs and outputs, respectively; s^- and s^+ are the slack terms of inputs and outputs, respectively; λ is the weight of the j-th DMU; θ is the evaluation value, reflecting whether DMU_j is DEA effective. If $\theta < 1$, DMU_j is not on the efficient frontier of DEA, and not DEA effective; if $\theta \geq 1$ and $s^- = s^+ = 0$, DMU_j is on the efficient frontier of DEA, and DEA effective; if $\theta \geq 1$ and $s^- \neq 0$ or $s^+ \neq 0$, DMU_j is weakly DEA effective.

In actual production, DEA effectiveness indicates that the DMU realizes the optimal efficiency, eliminating the need for improving any of its input or output; weak DEA effectiveness means the DMU efficiency cannot be improved, but the DMU faces input redundancy or output insufficiency; DEA ineffectiveness suggests the DMU fails to optimize its efficiency, and needs to improve its inputs and outputs.

2.2 Theil index

An important goal of this study is to check if China's HERAEs have significant regional difference. By analyzing the regional difference in China's HERAEs, the authors provided an important basis for the government to formulate differentiated policies on fiscal investment of education.

Theil index has been often adopted to measure the income gap (or inequality) between individuals or regions. Inspired by the entropy in information theory, Theil index is valued between 0 and 1. The closer its value is to 1, the greater the difference between the data. To measure the regional HERAE difference, the Theil index can be defined as:

$$GE_1(z) = \frac{1}{n}\sum_{i=1}^{n}(\frac{z_i}{\mu}\ln\frac{z_i}{\mu}) \tag{2}$$

where, z is the HERAE of a region; n is the number of regions; μ is the mean regional HERAE.

2.3 Kernel density estimation

Our research also attempts to clarify the dynamic evolution law of China's HERAE over time, that is, whether it tends to diverge or converge. In general, the dynamic evolution law of HERAE can be assessed by parametric methods like mixed Gaussian method and Bayesian estimation, or non-parametric estimation methods like kernel density estimation. As a typical non-parametric estimation method, kernel density estimation can fit the accurate distribution of data from the data features and properties.

Kernel density estimation, also called the Parzen window, was proposed by Rosenblatt (1955) and Emanuel Parzen (1962). This approach draws on the principle of the probability theory in solving the distribution density functions of random variables with the set of fixed sample points. This study chooses kernel density estimation to illustrate the distribution density functions of China's HERAEs in 2005-2018, aiming to verify if the regional HERAEs tend to converge or diverge.

Let P be a t-dimensional random vector, and $f(p) = f(p_1, \dots, p_n)$ be the density function of the vector. Suppose n samples form a set of $P_1, P_2, \cdots, P_n$, in which different samples obey independent distribution. Then, the kernel density estimation of $f(p)$ can be expressed as:

$$\hat{f}_h(p) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{p-P_i}{h}\right) \tag{3}$$

where, K(·) is the Epanechnikov kernel function; h is a suitable bandwidth.

2.4 Index system

The HERAE refers to the input and output capacities of higher education, reflecting the sustainable development capacity of higher education. Under the framework of DEA efficiency theory, this paper builds up an index system for the HERAE from two dimensions: inputs and outputs. The inputs mainly include human resources, financial resources, and material resources. Three outputs were determined according to the functions of colleges, namely, talent training, scientific research, and social service. The inputs and outputs are detailed in Table 1.

There are three input indices: human resources, financial resources, and material resources. First, human resources refer to the human inputs of colleges in talent training or technological innovation. The quality of talent training directly depends on the number of full-time teachers. Therefore, human resources were measured by the number of faculty and staff of colleges. Second, the financial resources of colleges are indispensable to talent training and technological innovation. This paper substitutes financial resources with the education expenditure of colleges. Third, the material resources of colleges stand for the stock assets and other assets with long-term use value, which are necessary for the development of college education. Considering the availability of data, this paper measures material resources with area of colleges, fixed asset value of colleges, and year-end number of books of colleges.

There are three output indices: talent training, scientific research, and social service. First, talent training is the primary function of higher education. The number of high-quality talents is a key indicator of the output capacity of higher education institutions. Combining the level of talent training, this paper measures the output level of talent training with the number of graduates from postgraduate school, and the number of graduates from undergraduate school or junior college. Second, colleges are the main subjects of scientific research, and powerful in basic research. Hence, the output level of scientific research was measured by the number of academic papers published by colleges, and the number of scientific works published by colleges. Third, social service is an indispensable function of colleges. The ability of colleges in undertaking social service can be reflected by the number of patent applications.

Table 1. Index system of HERAE

Type	Name	Meaning	Unit
Inputs	Human resources	Number of faculty and staff of colleges	Persons
	Financial resources	Education expenditure of colleges	10,000 yuan
	Material resources	Area of colleges	m^2
		Fixed asset value of colleges	10,000 yuan
		Year-end number of books of colleges	10,000 volumes
Outputs	Talent training	Number of graduates from postgraduate school	Persons
		Number of graduates from undergraduate school or junior college	Persons
	Scientific research	Number of academic papers published by colleges	Each
		Number of scientific works published by colleges	Each
	Social service	Number of patents applied by colleges	Each

2.5 Data sources

For the availability and comprehensiveness of data, the samples were collected from 30 provinces in China between 2005 and 2018. Note that the samples do not include Tibet, Hong Kong, Macao, and Taiwan, because many index data of these provinces are incomplete. The data on all variables were collected from *China Statistical Yearbooks* (2006-2019), *Educational Statistical Yearbooks of China* (2006-2019), *China Educational Finance Statistical Yearbooks* (2006-2019), *Compilation of Higher Education Science and Technology Statistics* (2006-2019), and *China Statistical Yearbooks on Science and Technology* (2006-2019).

In addition, education expenditure of colleges and fixed asset value of colleges both contain price factors. To eliminate the inflation impact, the former was deflated to the constant price with 2005 as the base period, using the educational consumer price index (CPI); the latter was deflated to the actual value with 2005 as the base period, using the fixed asset price index.

3 Results and Discussion

3.1 Measured results on HERAE

Based on the index system of HERAE, the data on inputs and outputs were imported to maxDEA. Then, the HERAEs of China in 2005-2018 were measured by super-efficiency DEA model. For convenience, Table 1 presents the mean HERAE of each province in the sample period. It can be seen that China had a large provincial difference in HERAE.

During the sample period, 21 provinces, including Beijing, Shanghai and Henan, had a mean HERAE equal to or greater than 1. The HERAEs of these provinces are DEA effective, that is, the education resources have been allocated in the optimal manner. On the contrary, Shaanxi, Hainan and the other seven provinces had a mean HERAE smaller than 1. The HERAEs of these provinces are DEA ineffective, calling for further improvement to education inputs and outputs in these places.

Hence, the higher education resources are allocated satisfactorily in most province of China, but not so satisfactory in a few provinces, waiting for further improvement.

Table 2. HERAEs of each province in China, 2005-2018

Province	2005	2006	2007	2008	2009	2010	2011	Average
Beijing	1.739	1.651	1.779	1.784	1.682	1.750	1.626	1.638
Shanghai	1.765	1.643	1.554	1.611	1.475	1.321	1.397	1.418
Henan	1.667	1.876	1.702	1.603	1.461	1.234	1.129	1.365
Qinghai	1.220	1.466	1.446	1.352	1.161	1.517	1.520	1.257
Jiangsu	0.899	0.881	0.929	0.960	1.020	1.130	1.305	1.221
Shanxi	1.237	1.258	1.264	1.299	1.278	1.240	1.195	1.182
Zhejiang	1.037	1.111	1.296	1.362	1.305	1.262	1.169	1.168
Liaoning	1.002	0.970	1.139	1.038	1.198	1.242	1.313	1.140
Anhui	0.957	0.934	0.924	1.142	1.111	1.470	1.035	1.107
Guangxi	0.952	1.184	1.117	1.078	1.194	1.048	1.090	1.088
Ningxia	1.089	1.030	0.836	0.815	0.949	1.357	1.110	1.087
Hubei	1.188	1.138	1.249	1.036	1.010	1.025	1.070	1.085
Jilin	1.039	1.251	1.052	1.126	1.023	1.057	0.988	1.065
Gansu	1.049	0.966	1.033	1.072	1.123	1.097	1.088	1.055
Hebei	1.081	0.983	1.061	1.076	0.996	1.032	1.051	1.047
Hunan	0.932	0.863	0.893	0.952	1.038	1.052	1.049	1.040
Tianjin	1.083	1.275	1.015	0.987	0.966	0.921	1.039	1.023
Guizhou	1.496	1.213	1.128	1.109	1.058	0.971	0.868	1.010
Chongqing	0.879	0.947	0.855	0.945	0.990	1.011	1.008	1.005
Guangdong	0.792	0.856	0.930	0.920	0.923	0.973	1.006	1.001
Sichuan	0.973	0.985	1.021	1.007	1.065	1.040	0.979	1.000
Heilongjiang	1.044	0.912	0.940	1.092	0.916	1.009	0.992	0.980
Shaanxi	1.009	1.010	0.962	0.924	0.893	0.952	0.986	0.978
Hainan	0.811	0.706	0.769	0.906	0.950	0.887	0.873	0.965
Inner Mongolia	0.878	0.890	0.901	0.867	0.916	0.875	0.958	0.963
Yunnan	0.841	1.048	0.966	0.988	0.937	0.864	0.988	0.959
Shandong	0.872	0.895	0.896	0.894	0.947	1.009	0.964	0.943

Jiangxi	0.802	0.927	1.072	0.830	0.830	0.801	0.922	0.890
Xinjiang	0.855	0.797	0.799	0.923	0.778	0.744	0.825	0.872
Fujian	0.719	0.775	0.786	0.793	0.803	0.826	0.791	0.788

Table 3. HERAEs of each province in China, 2005-2018 (Continue)

Province	2012	2013	2014	2015	2016	2017	2018	Average
Beijing	1.636	1.443	1.653	1.579	1.553	1.537	1.517	1.638
Shanghai	1.279	1.264	1.295	1.304	1.325	1.301	1.320	1.418
Henan	1.191	1.112	1.133	1.232	1.325	1.242	1.207	1.365
Qinghai	1.567	1.244	1.047	1.026	0.973	1.012	1.045	1.257
Jiangsu	1.512	1.283	1.530	1.330	1.367	1.460	1.481	1.221
Shanxi	1.141	1.110	1.140	1.166	1.110	1.080	1.032	1.182
Zhejiang	1.157	1.153	1.150	1.219	1.084	1.023	1.028	1.168
Liaoning	1.121	1.015	1.114	1.194	1.182	1.208	1.226	1.140
Anhui	1.094	1.127	1.149	1.161	1.183	1.121	1.092	1.107
Guangxi	1.170	1.082	1.166	1.041	1.086	1.017	1.012	1.088
Ningxia	1.165	1.206	1.361	0.981	1.061	1.232	1.031	1.087
Hubei	1.021	1.017	1.047	1.072	1.127	1.107	1.079	1.085
Jilin	1.094	1.110	1.167	1.061	1.020	0.941	0.975	1.065
Gansu	1.111	1.137	1.155	1.048	1.036	0.947	0.911	1.055
Hebei	1.032	1.063	1.031	1.023	0.983	1.115	1.127	1.047
Hunan	1.007	1.012	1.015	1.121	1.112	1.256	1.263	1.040
Tianjin	1.070	0.999	1.119	0.995	0.934	0.953	0.969	1.023
Guizhou	0.977	0.876	0.897	0.797	0.937	0.876	0.938	1.010
Chongqing	1.082	1.020	1.027	1.042	1.019	1.038	1.202	1.005
Guangdong	1.027	0.998	1.053	1.083	1.162	1.138	1.150	1.001
Sichuan	0.974	0.940	0.980	1.038	1.051	0.975	0.972	1.000
Heilongjiang	0.981	1.053	0.972	1.044	0.903	0.897	0.959	0.980
Shaanxi	0.956	0.988	0.982	1.028	1.043	0.980	0.975	0.978
Hainan	1.059	1.440	1.140	0.987	1.000	1.087	0.894	0.965
Inner Mongolia	0.968	1.044	1.048	1.128	1.071	0.948	0.983	0.963
Yunnan	0.918	0.926	0.959	0.966	1.021	0.993	1.012	0.959
Shandong	0.944	0.896	0.906	0.920	1.112	0.990	0.953	0.943
Jiangxi	0.814	0.838	0.867	0.922	0.947	0.992	0.901	0.890
Xinjiang	0.918	0.919	0.982	1.010	0.883	0.868	0.907	0.872
Fujian	0.813	0.825	0.801	0.791	0.798	0.782	0.729	0.788

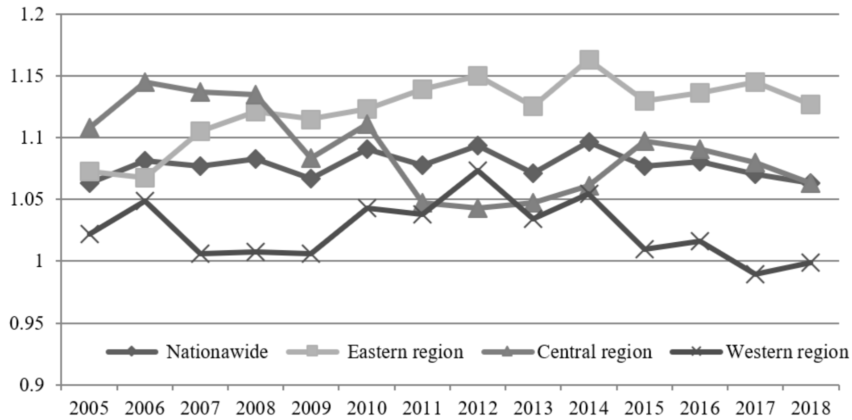

Fig. 1. HERAE trends of China and eastern, central, and western regions

To highlight regional difference, China was further divided into the eastern region (Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan), the central region (Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan), and the western region (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang).

Figure 1 presents the HERAE trends of China and eastern, central, and western regions. There was a certain disparity in the HERAE trends of China and the three regions. During the sample period, the nationwide HERAE remained stable without significant oscillation; the HERAE in eastern region increased with fluctuations; the HERAE in central region first declined and then increased, exhibiting a U-shaped curve; in contrast, the HERAE in western region first increased and then decreased, showing an inverted U-shaped curve.

The three regions had certain difference in HERAE. During the sample period, the HERAEs in eastern region averaged at 1.123, above the national average of 1.078; those in central region averaged at 1.089, similar to the national average; those in western region averaged at 1.025, below the national average. In general, eastern region had the highest HERAE, followed in turn by central region, and western region. These results show that the eastern region should emphasize on the fairness of education resource allocation, while central and western regions must improve the level of allocation.

3.2 Regional difference in HERAE

To further illustrate the regional difference in HERAE trend, the Theil indices for the HERAEs of China and eastern, central, and western regions in 2005-2018 are provided in Figure 2. It can be seen that the Theil indices for the HERAEs of China and eastern, central, and western regions were all declining in the sample period, indicating the narrowing gap between China and the three regions in terms of HERAE.

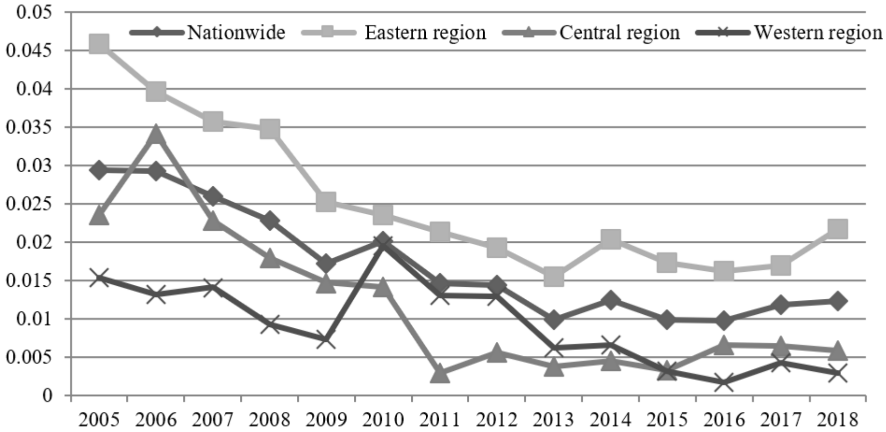

Fig. 2. Theil indices for the HERAEs of China and eastern, central, and western regions in 2005-2018

Specifically, the Theil index of eastern region dropped by 52.17% in the sample period; that of central region shrunk by 75%; that of western region plunged by 80%. Hence, the HERAE gap narrowed the fastest in western region, followed in turn by central region and eastern region.

In addition, the multiyear average Theil index of eastern region was as high as 0.025, while that of central and western regions was merely 0.012 and 0.009, respectively. This means eastern region faces the largest internal gap in HERAE, although it boasts the highest HERAE. The central region keeps a moderate HERAE level and internal HERAE gap. The western region has the smallest internal HERAE gap and the lowest HERAE.

3.3 Dynamic evolution of HERAE

To reveal the dynamic evolution of China's HERAEs, the HERAEs in 2005, 2008, 2011, 2014, and 2018 were estimated by kernel density estimation (3), and plotted into Figure 3, where the x- and y-axes are HERAE and kernel density. The kernel density curves of the five years show that the HERAE distribution in each province only had a single peak, indicating that China's HERAEs were polarized in time. With the passage of time, the peaks of the kernel density curves gradually rose, and the right tails slowly moved toward the left. This means the provincial HERAEs continued to concentrate and tended to be stable. The results show that the polarization of regional HERAEs slowly declined, and exhibited a clear convergence.

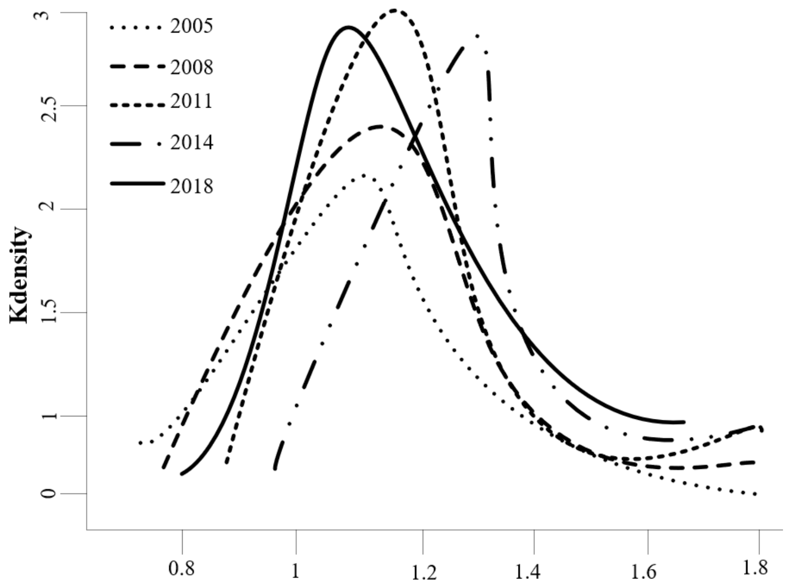

Fig. 3. Kernel density curves of HERAEs

4 Conclusion and Policy Recommendations

Based on a self-designed index system for HERAE, this paper measures the HERAEs of 30 provinces from China with the super-efficiency DEA model, and then discussed the regional difference and dynamic evolution law of HERAEs. The main conclusions are as follows:

1. China's HERAEs had significant provincial difference. In most provinces, the higher education inputs and outputs were effective. But some provinces were backward in HERAE, lagging far behind the advanced provinces.
2. There was a certain difference in the HERAE trend between eastern, central, and western regions. In the sample period, eastern region had the highest HERAE, followed in turn by central and western regions.
3. By the differential change of HERAE, eastern region sees the largest gap in HERAE, and the smallest decrease of the gap; central region keeps a moderate HERAE level and internal HERAE gap; western region witnesses the smallest internal HERAE gap and the largest decrease of the gap.
4. Kernel density estimation shows that, the HERAE distribution in each province only had a single peak, indicating that China's HERAEs were polarized in time. With the passage of time, the polarization of regional HERAEs slowly weakened.

Based on the above conclusions, several suggestions were made for China to improve its HERAE.

First, the government should formulate differentiated policies on higher education development. With abundant higher education resources, the eastern region needs to focus on the following aspects to elevate the HERAE: improving the institutional mechanism of higher education, strengthening the introduction of talents, and guiding various education resources to support, complement, and rely on each other, creating a benign development situation. For central and western regions, the lack of education resources is the main bottleneck of the development of higher education. For this reason, the local governments must provide preferential policies and fund support to higher education investment.

Second, different regions should step up exchanges and cooperation in the field of higher education. Apart from mining their own potential of education development, the colleges in central and western regions should further cooperate and exchange with their counterparts in the eastern region in talent cultivation, scientific research, and social service, and remove the said bottleneck of higher education development with the aid of the rich education resources in the eastern region.

Third, China should optimize the allocation structure of higher education resources between regions. According to the actual situation of higher education resource allocation in different regions or provinces, China should rationalize the existing allocation structure of higher education resources, making it efficient, fair, and scientific. In this way, the economic underdeveloped areas could develop education more rapidly, and solve the Matthew effect in inter-regional higher education development, which ultimately leads to efficiency and fair coordinated development of higher education in China.

Fourth, China should further strengthen supervision of higher education resource allocation. Currently, the higher education development in China is not well supervised. The relevant government departments are recommended to enhance supervision of higher education resource allocation, implement integrated management of higher education resources, and prevent redundant investment in higher education resource allocation. Further, the government must confirm the distribution channels and users of higher education funds, and ensure that the limited funds are spent on the most critical areas, thereby maximizing the HERAE.

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7 Authors

Dalai Ma, PhD in Applied Economics, was graduated from School of Economics and Business Administration, Chongqing University, and works as associate professor at School of Management, Chongqing University of Technology. He is a seasoned researcher of the evaluation of educational development efficiency. Email: madalai@163.com

Xuefeng Li, Master of Education, was graduated from School of Public Affairs, Chongqing University, and works as a lecturer at Faculty of Education, Yunnan Normal University. He is a seasoned researcher of the evaluation of educational development efficiency. Email: forfamilyisme@163.com

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