Temporal-spatial analysis of urban education and research efficiency: A case of Yangtze River Delta urban agglomeration, China

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Abstract. Evaluating the efficiency of education and research plays an important role in optimizing resource allocation and promoting sustainable development of science and education. The Yangtze River Delta Urban Agglomeration (YRDUA) is one of the most developed regions in China in terms of economy, science and education, and culture. Quantifying and analyzing its education and research efficiency is of great significance for the development of this urban agglomeration. Therefore, this study applied Data Envelopment Analysis (DEA) to evaluate the education and research efficiency of YRDUA from 2000 to 2021, and applied GIS visualization methods to analyze its spatiotemporal distribution characteristics. The research results indicate that due to the steady implementation of the Yangtze River Delta regional integration strategy, the overall scientific and educational efficiency of the Yangtze River Delta is showing a continuous upward trend. At the same time, the efficiency gap between different cities in the region is showing a narrowing trend, and YRDUA's science and education industry is developing towards a more balanced direction.

Keywords: Education and research efficiency; Data envelopment analysis; Yangtze River Delta; spatial-temporal patterns

1. Introduction

The significance of education and technology in advancing global knowledge and innovation is undeniable. Therefore, assessing the efficiency of both education and technology is pivotal in identifying inadequacies in resource utilization, thereby enhancing resource efficiency and optimizing resource allocation. This, in turn, aids governments in formulating more targeted policies and development plans, fostering continual advancements in education and technology, and contributing to elevating living standards, societal progress, and sustainable development.

Data Envelopment Analysis (DEA) stands out as a suitable method to gauge Education and Research Efficiency (ERE). For instance, Aparicio et al. [1] applied DEA method to measure schools´ efficiency in the United States based on data from participants in Program for International Student Assessment. Duan [2] employed DEA techniques to assess the science and education efficiency of 36 universities in Australia. Jiang et al. [3] applied the DEA approach to examine the research performance of 105 Chinese higher universities based on the EnPAS software. From the domestic regional perspective, Zhou et al. [4] utilized the DEA method to assess the performance of China's Education Science and Technology industry across various areas from 2010 to 2019. Meanwhile, Xiong et al. [5] focused on evaluating the scientific and educational performance specifically within provincial-level universities, concentrating on the humanities and social sciences domains. Moreover, Sun et al. [6] conducted an assessment of higher education efficiency across China’s provinces, covering the period from 2011 to 2020. However, most of these studies primarily focused on school-level or provincial-level analysis, leaving a gap in research at the urban level.

The YRD region is one of the most developed regions in China in terms of economy, technology, and education, with advanced urban infrastructure, abundant human resources, and consistent innovation potential, creating a favorable environment for the rapid development of education and

research. Against the backdrop of rapid global economic development and rapid technological advancements, the development of science and education is an important driving force for sustainable urban development, profoundly affecting the efficiency and competitiveness of cities. Therefore, this study aims to evaluate the education and research effectiveness of the YRDUA and provide scientific support and policy foundations for the development of the YRDUA

2. Methods and materials

Data Envelopment Analysis (DEA) is a linear programming model for evaluating input-output efficiency. It first constructs the production frontier based on the input-output indicators of decision units (DMUs), and then compares each DMU with the frontier to determine the efficiency of different decision units [7]. The range of input-output efficiency is (0,1]. An efficiency score of 1 indicates DEA efficiency, while a score below 1 indicates DEA inefficiency.

$$\begin{aligned} &\min\ \theta_0 \\ &s.t.\quad \sum_j \lambda_j X_j \le X_0 \\ &\qquad \sum_j \lambda_j Y_j \ge \theta_0 Y_0 \\ &\qquad j = 1,\cdots,n \end{aligned} \tag{1}$$

where X_j is input vector，Y_j is output vector，λ_j is the intensity coefficients.

The paper categorizes indicators into input and output categories. The selected input indicators comprise public financial expenditure on education (X1) and public financial expenditure on science and technology (X2). Meanwhile, the output indicators consist of the number of enrolled students (Y1), the number of employed educational staff (Y2), and the number of patents granted (Y3). These choices stem from the significance of public financial investment in education and science and technology as pivotal indicators of the development input in the field of education and science. Concerning the selection of output indicators, the educational staff numbers reflect the strength of teaching resources in schools, ensuring sustainable development in the field of education. The number of enrolled students indicates the scale of educational institutions in cultivating students. Moreover, the quantity of granted patents reflects the output of scientific and technological achievements. The data for this study are sourced from the "China Urban Statistical Yearbook" spanning from 2001 to 2022.

3. Results and discussion

Based on the fundamental principles of the DEA model, we employed the DEAP2.1 software to evaluate the efficiency of education and research (ERE) across 27 cities within the YRDUA for the years 2000, 2007, 2014, and 2021, as illustrated in Fig. 1.

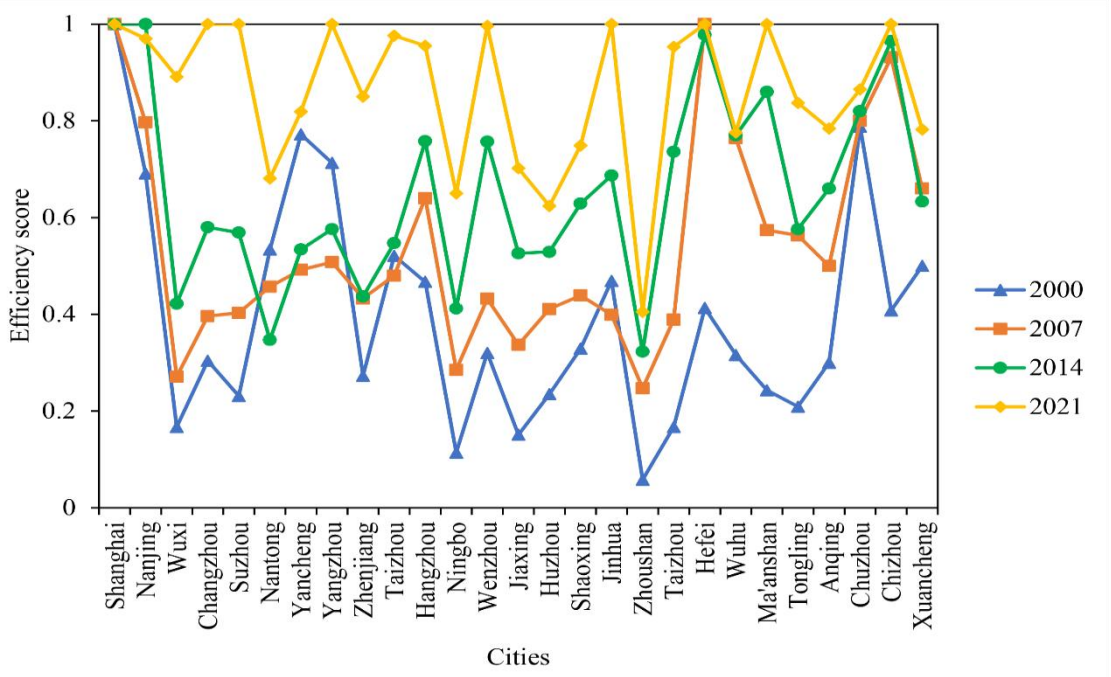

Fig. 1 Trends of ERE scores in 27 cities in YRDUA

Examining the temporal trend reveals an upward trajectory in the overall efficiency levels within the YRD region. Starting from 0.396 in 2000, the efficiency gradually increased to 0.534 in 2007, followed by 0.646 in 2014, culminating at 0.862 by 2021. While a few cities such as Shanghai and Nanjing demonstrate high efficiency in the input-output dynamics of education and technology, the majority of cities within the YRD fail to achieve effective efficiency levels. Nevertheless, over time, there is a noticeable gradual increase in efficiency among cities with initially lower efficiency values. Simultaneously, the efficiency gap between different cities is narrowing. For instance, the efficiency in education and technology in Hangzhou rose from 0.467 in 2000 to 0.955 in 2021. Similarly, Suzhou's efficiency surged from 0.231 in 2000 to a perfect score of 1.000, indicating DEA effectiveness. This trend aligns with the progressive implementation of regional integration in the YRD, the evolving strategy of emphasizing education and technology for national development, and the maturation of governmental plans and market regulations, collectively shaping the current configuration of resources in education and technology within the region.

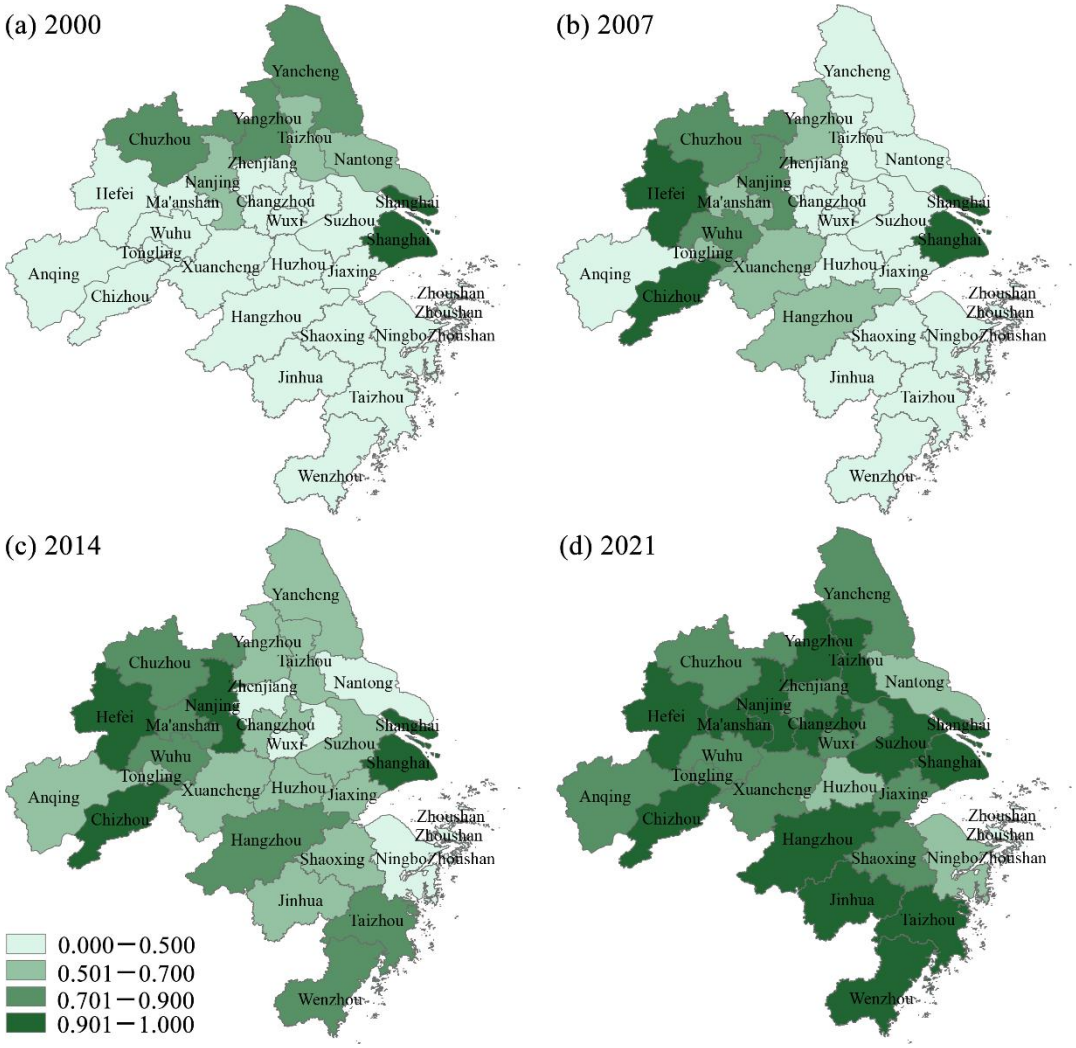

Fig. 2 Spatial distribution of ERE in YRDUA

The efficiency scores exhibit considerable disparity across cities within the YRD region. Fig. 2 depicts the spatial distribution maps of ERE in 2000, 2007, 2014, and 2021 generated using ArcGIS 10.2. These maps provide a visual aid for a more intuitive analysis of the spatiotemporal distribution of ERE. Regarding the distribution of educational and technological efficiency among cities, economically developed areas such as Shanghai, Nanjing, Suzhou, Hangzhou, and Hefei demonstrate higher efficiency values, with most of them achieving DEA effectiveness. Conversely, cities with comparatively lower economic development exhibit lower efficiency scores, such as Zhoushan (0.405), Nantong (0.681), Ningbo (0.65), and Huzhou (0.624). These cities encounter issues related to input redundancy and insufficient output in their educational and technological endeavors, indicating resource wastage. Consequently, these cities are in need of further reform and development stages in their educational and technological sectors. They can benefit from learning and implementing development strategies observed in more successful cities, thereby enhancing their resource allocation efficiency and elevating their levels of educational and technological development. Concerning the spatial distribution of education and technology efficiency within the YRD, an overall trend emerges indicating a gradual decrease in efficiency from coastal areas towards inland regions. However, by comparing efficiency distributions across different years, it becomes evident that the efficiency gap among cities within the YRD is progressively narrowing over time.

The integrated development of the YRD not only improves the education and research efficiency of cities within the region, but also narrows the gap in the development of science and education between different cities. Specifically, (1) With its geographical and policy advantages, the YRD has attracted a large amount of investment in research and development, education, and innovation

driven industries, improved the infrastructure of regional internal medicine and education, and thus promoted the progress of scientific research, technological innovation, and education quality. (2) The integration of the YRD provides a favorable environment for the gathering and exchange of capital, talent, education, technology and other resources between cities, expanding extensive cooperation, knowledge sharing, and resource utilization among cities, thereby improving their education and research capabilities. (3) The policy framework and supporting measures of the overall planning and design of the YRD help prevent malicious competition and resource waste between cities, promote effective allocation of scientific and educational development resources between cities, and improve resource utilization efficiency and fairness.

4. Conclusions and policy implications

This study used DEA to evaluate the education and research efficiency within YRDUA from 2000 to 2021, and applied GIS visualization technology to explore its spatiotemporal evolution characteristics. The results indicate that the overall education and research efficiency of cities in the YRD is on the rise. Meanwhile, the efficiency gap between different cities has narrowed.

Based on the above research conclusions and combined with the characteristics of each city, design policy recommendations tailored to local conditions to promote the development of science and education.

(1) Identify regional characteristics and design differentiated development strategies. Due to the diverse characteristics of cities within the YRD, when formulating development strategies for science and education, it is necessary to consider local subtle differences and advantages and design differentiated development strategies.

(2) Learn from successful experiences and imitate feasible development paths. Shanghai, Nanjing, Hangzhou and other regions have shown high input-output efficiency in the field of science and education, and are successful examples. Therefore, other relatively backward regions can combine their own advantages, draw on the advanced experience of developed cities, and imitate and formulate feasible paths for scientific and educational development.

(3) Strengthen regional exchanges and promote coordinated development between regions. Capital, technology, talent, education and other resources are important factors in promoting the development of science and education. Through industrial cooperation, the establishment of platforms for sharing successful practices, lessons learned, and innovative methods can promote knowledge exchange and cooperation among different regions within YRD, and promote the overall development of science and education in the Yangtze River Delta.

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