Research on the Evaluation of China's Major Scientific and Technological Infrastructures

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Abstract. The construction of major scientific and technological infrastructures is the basis for original innovation and scientific and technological breakthroughs and it promotes the transformation and upgrading of industrial structures. However, there are lack of top-level design, R&D support and many problems. Building indicators to measure major infrastructures construction level of science and technology in China, which can guarantee the smooth transformation of scientific and technological achievements and drives the development of the real economy. This paper measures the level of major science and technology infrastructures in various provinces of China and annually level of China from 2011 to 2020. The results suggest that the level of China's major scientific and technological infrastructures has steadily improved however, there are regional differences, the eastern region has a relatively high level of major scientific and technological infrastructures, followed by the central region, but the northeast and western regions have a relatively low level.

Keywords: Major science and technology infrastructures · Principal component analysis · Indicator construction · Evaluation research · Big scientific installations · Technological innovation

1 Introduction

Major scientific and technological infrastructures, also known as "big scientific installations", are planned and constructed by the state and operated by national laboratories or universities, providing an important platform for China to carry out basic and applied research. The construction of major scientific and technological infrastructures plays an important role in solving China's "stuck neck" problems in key scientific and technological fields, promotes the transformation and upgrading of industrial structures, and drives the development of the real economy. In China's "14th Five-Year Plan", it is clearly proposed to promote the optimization and combination of innovation systems guided by national strategic needs, and accelerate the construction of strategic scientific and technological infrastructures such as national laboratories, which is a major strategy to ensure the security of the industrial chain and supply chain.

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The construction of major scientific and technological infrastructures includes the construction of information infrastructures, innovation laboratory infrastructures, innovation achievement transformation and integration facilities, and the construction of other facilities groups (Ge et al., 2020) [1]. Cui et al. (2020) find that the construction of major scientific and technological infrastructures helps to improve regional collaborative development, promote the formation of a data sharing system, promote digital transformation and intelligent upgrading, and provide support for the development of national strategic science and technology [2]. Major scientific and technological infrastructures need to establish a life-cycle management and operation system from the aspects of strategic target positioning, organizational system design, operation guarantee system and international organization cooperation, to ensure the smooth transformation of scientific and technological achievements and enhance China's soft power (Chang et al., 2021) [3].

The earliest major scientific and technological infrastructures in China can be traced back to the "two bombs and one satellite" program in the 1950s (Wu et al., 2021) [4]; Since the 18th National Congress of the CPC, China's scientific and technological innovation, as the first driving force for leading development, has deployed and promoted the implementation of a series of major strategic initiatives, enabling China to achieve major original breakthroughs in the field of frontier science (Chen, 2021) [5]. Yu et al. (2021) found that the major scientific and technological infrastructure of the United States in information technology is currently in the leading position in the world, and in addition, it mainly focuses on particle physics and nuclear physics [6]. France divides research infrastructure into ten scientific fields, such as biological health and digital science, establishes science and technology laboratories and provides technical services for enterprises with the help of business schools, forming an innovative industrial chain (Chen et al., 2022) [7]. In order to cope with the fourth scientific and technological revolution and the crisis and challenge brought by "Brexit", the UK pays attention to the construction of major facilities in data management and other aspects, and plans to build world-class supercomputers (Li et al., 2021) [8].

Chang et al. (2021) found that although China's current scientific and technological infrastructure construction is in the international leading position, there are still problems such as vague goals, repeated construction and imperfect management mechanism [9]. China's state-level scientific and technological infrastructures are concentrated in Beijing, Shanghai and other developed areas, and there are less constructions in the fields of basic science, artificial intelligence and life science, and the functions and locations layout are not reasonable (Luo et al., 2021) [10]. According to Yu et al. (2021), there is a lack of compound professionals in R&D personnel, and no timely and effective mechanism has been formed in the transformation of scientific and technological achievements. In addition, the scientific and technological research and development in each region is relatively independent, and the pattern of joint innovation and open sharing is lacking. The utilization rate of major scientific and technological infrastructure needs to be improved [11].

In summary, China has to construct a major group of science and technology infrastructures as one path to enhance the core competitiveness of science and technology, but in the area of planning and design, coordination and achievements transformation have many problems. Therefore, by building indicators to measure major infrastructures construction level of science and technology in China, can strengthen the top-level design and show the advantages of major scientific and technological infrastructures clusters to build a country of high-level innovation.

2 Infrastructure Indicators of Major Scientific and Technological Infrastructures

This paper takes 27 provinces and municipalities in China from 2011 to 2020 as the research object, and the 10 indicators of the original data are mainly from CSMAR database and China Statistical Yearbook. To ensure the continuity and availability of data, provinces with incomplete data and missing variables were deleted. In order to avoid the influence of the outliers in the variables on the index construction results, this paper further carried out the tail reduction treatment on all continuous variables at the level of 1% and 99%.

2.1 Selection of Major Scientific and Technological Infrastructure Indicators

The construction level of China's major scientific and technological infrastructures is influenced by many factors, such as manpower, material resources and capital investment, and many factors combine to form a synergistic effect. Therefore, this paper constructs an index to measure the level of major technological infrastructures construction in China from the aspects of R&D support capacity, level of R&D investment, the number of R&D projects and information technology facilities construction.

2.1.1 R&D Support Capacity

Major scientific and technological infrastructures have a long construction period, combined with a single subject and a breadth of interdisciplinary, not only need a innovation ability of scientific research, but also a capacity of application and transformation of the research results (Ge et al., 2021) [12], and need to rely on the function of R&D infrastructures and the equipment of accelerating scientific and technological achievements hatching, Forming a high-speed channel from scientific and technological innovation to the transformation of scientific and technological achievements (Guo et al., 2019). In this paper, the R&D support capacity is selected as the first-level indicator, and the number of R&D institutions and R&D personnel is selected as the second-level indicators to measure the construction level of major scientific and technological infrastructures in China.

2.1.2 Level of R&D Investment

Major infrastructures construction cannot leave the financial support of science and technology, the level of R&D investment has a significant positive correlation with regional innovation ability (Shang et al., 2018), attracting talents and the inflow of new technology can produce "siphonage effect", which encourages research and development institutions, enterprises and universities formed between aggregation (Zhong et al., 2021). In this paper, level of R&D investment is selected as the first-level indicator, and the second-level indicators are the expenditure of R&D funds, the expenditure of new product development funds, the expenditure of technical transformation funds, the expenditure of purchasing domestic technology funds and the expenditure of technology introduction funds to measure the construction level of major scientific and technological infrastructures in China.

2.1.3 The Number of R&D Projects

Major scientific and technological infrastructures are not a single project subject, but a facility cluster composed of multiple projects. Each project relies on each other to form a "$1 + 1 > 2$" synergistic effect and economies of scale, which is an important key to effectively support "scientific and technological infrastructures to advanced manufacturing" (Chen, 2018). In this paper, the number of R&D projects is selected as the first-level indicator, and the second-level indicators is the number of new product development projects to measure the construction level of major scientific and technological infrastructures in China.

2.1.4 Information Technology Facilities Construction

Information technology facilities play a leading and supporting role in the construction of major scientific and technological infrastructures in China. The implementation of information is an important way to enable traditional infrastructures to realize digital transformation (Fan et al., 2022). Information technology combined with Internet and digital technologies such as Blockchain, big data, artificial intelligence into the major science and technology infrastructures, can improve facilities information interaction with each other, optimize the allocation of resources and improve efficiency, help to promote total factor productivity of major science and technology infrastructures (Ba et al., 2022). In this paper, project information technology facilities construction is selected as the first level index, and the second-level indicators are the number of Internet broadband access ports and the number of Internet broadband access users to measure the construction level of major scientific and technological infrastructures.

In summary, according to the above analysis this paper selects 4 first-level indicators and 10 s-level indicators to measure the construction level of major scientific and technological infrastructures in China. The indicators system is as shown in Table 1.

2.2 Principal Component Analysis Method to Construct the Evaluation Index

In order to avoid that the weight caused by subjective assignment method does not have objectivity and partial information overlap, this paper adopts the idea of dimensionality reduction and uses the principal component analysis method in objective assignment method to construct evaluation index. On the basis of reducing the original information loss, the principal component analysis method can make multiple linear transformation of the original series of indicators to calculate the index weight, and then recombine to form a new representative comprehensive index system.

Table 1. Indicators system of construction level of major scientific and technological infrastructures in China

First-level Indicators	Second-level indicators	Component index
R&D support capacity	The number of R&D institutions	X_1
	The number of R&D personnel	X_2
Level of R&D investment	The expenditure of R&D funds	X_3
	The expenditure of new product development funds	X_4
	The expenditure of technical transformation funds	X_5
	The expenditure of purchasing domestic technology funds	X_6
	The expenditure of technology introduction funds	X_7
The number of R&D projects	The number of new product development projects	X_8
Information technology facilities construction	The number of Internet broadband access ports	X_9
	The number of Internet broadband access users	X_{10}

Table 2. KMO test and Bartlett's test

KMO test and Bartlett's test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.836
Bartlett's Test of sphericity	Approx Chi-Square	4025.852
	df	45
	Sig.	0.000

2.2.1 Data Standardization Processing and Applicability Test

In this paper, SPSS26.0 software is used to standardize the original data by Z-score method to form new variables, so as to avoid the deviation in weight calculation caused by the inconsistent measurement units of the original data. Secondly, KMO test and Bartlett sphericity test were used to test the applicability of the variables. The test results are shown in Table 2. The KMO value is 0.836, indicating a strong correlation between variables. The significance of Bartlett's sphericity test is $0.000 < 0.05$. Therefore, the above two tests indicate that the variables are correlated and can be analyzed by principal component analysis.

Table 3. Explanation of total variance of principal components

Explanation of total variance						
Initial eigenvalue				Extract the sum of squared loads		
Principal	Aggregation	Percentage of variance	Accumulation %	Aggregation	Percentage of variance	Accumulation %
1	7.371	73.712	73.712	7.371	73.712	73.712
2	1.147	11.469	85.181	1.147	11.469	85.181
3	0.876	8.755	93.937			
4	0.305	3.052	96.989			
5	0.126	1.264	98.252			
6	0.094	0.936	99.189			
7	0.033	0.327	99.516			
8	0.030	0.295	99.811			
9	0.016	0.164	99.975			
10	0.003	0.025	100.000			

2.2.2 Principal Components Extraction

The principal components are extracted according to the principle of eigenvalue greater than 1, as shown in Table 3. The two principal components extracted in this paper are denoted as Y_1 and Y_2, the variance contribution rate is 73.712% and 11.469% respectively, and the cumulative contribution rate is 85.121%, indicating that the two principal components fully retain the information of 10 indicators. It is enough to represent the index system of the construction level of major scientific and technological infrastructures. The load matrix of principal components is shown in Table 4.

2.2.3 Principal Components Calculation

The eigenvector coefficients of principal components are calculated as shown in Formula (1):

$$\textbf{\textit{Eigenvector coefficients}} = \frac{\textbf{\textit{The load matrix of principal components}}}{\sqrt{\textbf{\textit{Principal components eigenvalues}}}} \tag{1}$$

After obtaining the eigenvector coefficients of the principal components, the function expressions of the two principal components can be calculated as follows:

$$\begin{aligned} Y_1 = {} & 0.348 * X_1 + 0.349 * X_2 + 0.359 * X_3 + 0.360 * X_4 + 0.312 * X_5 + 0.116 * X_6 \\ & + 0.301 * X_7 + 0.360 * X_8 + 0.292 * X_9 + 0.288 * X_{10} \end{aligned} \tag{2}$$

Table 4. The load matrix of principal components

The load matrix of principal components		
Principal indicators	Y_1	Y_2
X_1	0.944	0.013
X_2	0.947	0.015
X_3	0.975	−0.019
X_4	0.978	−0.140
X_5	0.846	−0.411
X_6	0.314	0.643
X_7	0.818	−0.449
X_8	0.976	−0.009
X_9	0.792	0.392
X_{10}	0.783	0.435

As can be seen from Formula (2), in principal component Y_1, the absolute coefficient of the expenditure of new product development funds (X_4), the number of new product development projects (X_8), the expenditure of R&D funds (X_3), the number of R&D personnel (X_2) and the number of R&D institutions (X_1) account for the main weight. Therefore, in the construction of major scientific and technological infrastructures, a reasonable allocation of resources in terms of project development and R&D investment will lead to a better construction level.

$$\boldsymbol{Y_2 = 0.036 * X_1 + 0.042 * X_2 - 0.054 * X_3 - 0.401 * X_4 - 1.181 * X_5 + 1.848 * X_6 - 1.291 * X_7 - 0.025 * X_8 + 1.126 * X_9 + 1.252 * X_{10}} \tag{3}$$

As can be seen from Formula (3), in the principal component Y_2, the absolute coefficients of the expenditure on purchasing domestic technology funds (X_6), the expenditure on technology introduction funds (X_7), the number of Internet broadband access users (X_{10}), the expenditure on technological transformation funds (X_5) and the number of Internet broadband access ports (X_9) account for the main weight. Therefore, in the construction of major scientific and technological infrastructure, a reasonable allocation of resources in technology input and information technology input will lead to a better construction level.

As shown by formula (4), the two principal components Y_1 and Y_2 are respectively multiplied by the variance contribution rate, and the comprehensive index Y is the measure index of the major scientific and technological infrastructures construction level in China.

$$\boldsymbol{Y = 0.737 * Y_1 + 0.115 * Y_2} \tag{4}$$

3 Evaluation of Major Science and Technology Infrastructures in China

3.1 Major Scientific and Technological Infrastructures Evaluation in Provinces of China

The average of Y value in 27 provinces and cities from 2011 to 2020 to compare the level of major scientific and technological infrastructures construction in each province in 10 years, as shown in Table 5. Due to the standardized processing of the original data, the negative Y value does not mean that the investment in scientific and technological infrastructures will reduce the construction level, but the size of Y value only represents the level of major scientific and technological infrastructure construction.

In recent years, China has taken the construction of major scientific and technological infrastructures as the focus and growth point to drive the construction of a scientific and technological power. Beijing, Shanghai and the Guangdong-Hong Kong-Macao Greater Bay Area have become the cluster places of scientific and technological innovation construction, improving the regional innovation capacity and technological strength. Can be seen from Table 5, major infrastructures of science and technology of Guangdong province is 7.26, the highest level of Guangdong province the government actively promote the bay area of important science and technology infrastructure cluster, local talent environment improved significantly, is conducive to the landing of high-tech industry, the industry has played a positive role in promoting transformation and upgrading, promote the development of the real economy. Followed by Jiangsu Province and Zhejiang Province, the levels of major basic scientific and technological facilities were 3.796 and 1.586, respectively. Among the top 10 provinces, only Henan and Hubei province are in the central region, only Sichuan Province is in the western region, and the rest are in the eastern region.

The top 10 provinces are Guangxi Zhuang Autonomous Region, Yunnan Province, Guizhou Province, Inner Mongolia Autonomous Region and Gansu Province in the

Table 5. Major scientific and technological infrastructures evaluation in provinces of China

Province	Y	Rank	Province	Y	Rank	Province	Y	Rank
Guangdong	7.265	1	Hebei	−0.232	10	Tianjin	−0.915	19
Jiangsu	3.796	2	Anhui	−0.233	11	Shanxi	−0.934	20
Zhejiang	1.586	3	Beijing	−0.324	12	Heilongjiang	−0.944	21
Shandong	1.186	4	Hunan	−0.384	13	Yunnan	−0.957	22
Sichuan	0.255	5	Liaoning	−0.577	14	Guizhou	−1.040	23
Fujian	0.085	6	Jiangxi	−0.597	15	Jilin	−1.052	24
Shanghai	0.017	7	Shaanxi	−0.613	16	Inner Mongolia	−1.093	25
Henan	−0.066	8	Chongqing	−0.771	17	Gansu	−1.152	26
Hubei	−0.203	9	Guangxi	−0.871	18	Hainan	−1.281	27

western region, Shaanxi Province in the central region, Heilongjiang and Jilin Province in the northeast region, Tianjin Province in the eastern region and Hainan province in the bottom of the list with a score of -1.281. In recent years, China has actively laid out the national science and technology strategy in the central and western regions, such as the “East and West” digital infrastructure, and promoted a steady increase in the level of major basic science and technology facilities in the central and western regions.

In summary, in terms of geographical location, there are regional differences in the level of major scientific and technological infrastructures in China. The eastern region has a high level of major scientific and technological infrastructures, followed by the central region, and the Northeast and western regions have a low level of major scientific and technological infrastructures.

3.2 The Evaluation of Annually Major Scientific and Technological Infrastructures in China

The Y value of major basic scientific and technological infrastructures in 27 provinces in China was averaged annually to measure the level of major basic scientific and technological infrastructures in each year. Since the data have been standardized, the negative mean Y value does not mean that the investment level of major scientific and technological infrastructures in China decreased in that year. The mean Y value results of each year are shown in Table 6 and Fig. 1.

During the 11th Five Year Plan, China planned and laid out major national scientific research infrastructures, it can be seen from Table 6 and Fig. 1, China’s major technology infrastructures level is 0.701 in 2011, the level of major scientific and technological infrastructures in China increased continuously every year, and it reached 0.904 in 2020. The 19th National Congress of the CPC proposed to accelerate the building of a manufacturing power and the development of advanced manufacturing, and promote the integration of cloud networking, big data, and artificial intelligence technologies with

Table 6. The evaluation of annually major scientific and technological infrastructures in China

Year	Y	Rank
2011	−0.701	10
2012	−0.539	9
2013	−0.441	8
2014	−0.351	7
2015	−0.184	6
2016	0.012	5
2017	0.155	4
2018	0.494	3
2019	0.651	2
2020	0.904	1

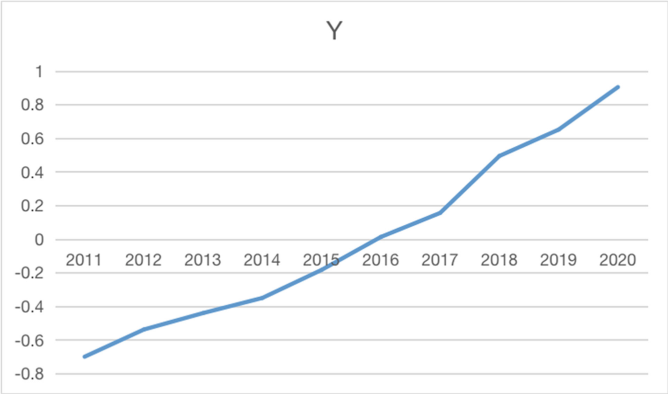

Fig. 1. Chart of trend of major technological infrastructures in different years in China

the real economy. As can be seen from Table 6 and Fig. 1, the growth rate of China's major scientific and technological infrastructures has increased significantly since 2017. In recent years, China has promoted the layout of major science and technology infrastructures, and continued to invest in the design, construction and use of major science and technology infrastructures. Therefore, it can be expected that the level of major science and technology infrastructures in China will be further improved in the next few years.

4 Conclusion

This paper attempts to measure the level of major scientific and technological infrastructures in China. This paper novelty using principal component analysis to construct the evaluation index and measuring the level of major science and technology infrastructures in various provinces of China and annually level of China from 2011 to 2020.

The paper has three major findings. First, the cluster places of scientific and technological innovation construction, such as Guangdong province, Jiangsu Province and Zhejiang Province have the top level of major scientific and technological infrastructures. Second, there are regional differences in the level of major scientific and technological infrastructures in China. The eastern region has a high level of major scientific and technological infrastructures, followed by the central region, and the Northeast and western regions have a low level of major scientific and technological infrastructures. Third, the level of major scientific and technological infrastructures in China increased continuously every year and it can be predicted that the level will be further improved in the next few years.

In summary, the level of major science and technology infrastructures is improving steadily year by year, but there is still a problem of unbalanced and insufficient development from the regional level. Aiming at the above problems, this paper further discusses how to layout the major scientific and technological infrastructures construction in China, and form the new development pattern of east and west coordinated development.

5 Suggestions

5.1 Strengthen the Top-Level Design and Optimize the Layout of Facilities

Major science and technology infrastructures are a long-term and systematic project, not only need continuing to pour money into financial capital, more need to strengthen the top-level design, make full use of its advantages in system optimize the industrial layout and production factors flow, improve the efficiency of resource utilization, according to "stuck neck" technology breakthroughs made in key areas, improve the core competitiveness, this will provide the solid foundation to form a strong manufacturing power. Establish and improve the major transformation of scientific and technological infrastructures safeguard mechanism, promote the construction of integration of "Industry-university-research", the formation of the synergistic effect in enterprise, government and universities, establish the national laboratory of science and technology, cultivate capable of interdisciplinary talents, promote the formation of globally competitive infrastructures cluster, forming new development pattern, help to realize high quality development in China.

5.2 Promote Coordinated Development

The construction of major scientific and technological infrastructures is not the construction of one city or one province, but the construction of a strong scientific and technological country with remarkable comprehensive ability. Because of the various provinces strategic positioning and resources endowment is different, the eastern region has accumulated experience and advantages of science and technology development in the past, to take the initiative to give play to the role of lead and take the lead, the western region to play new energy natural resources advantage, such as wind power and solar. East together with the Midwest to form regional coordinated development, reasonable layout of major infrastructure framework and system of science and technology, restructuring and optimizing the allocation of resources, Accelerate the core technology to apply for industrial transformation, carry out the new development concept, and provide support and guarantee for the construction of major scientific and technological infrastructures group.

5.3 Improve the Personnel Training Mechanism

Human resource is the most important factor of the major scientific and technological infrastructures construction, and the knowledge and technology owned by innovative talents will bring "spillover effect", which is the cornerstone of promoting scientific and technological research and social progress. Relying on the resource advantages of the state key laboratories and universities, we will improve the environment for scientific and technological innovation, establish a perfect personnel training system, jointly cultivate compound professionals, give play to the enthusiasm of talents in the construction of facilities, and implement the strategy through science and education and strengthening the country through talent. We will improve the mechanism for transforming scientific and technological achievements, define the scope of intellectual achievements' property rights, protect the rights and interests of researchers, stimulate the enthusiasm of talents for innovation, empower scientific and technological achievements to the real economy, and bring into play the value of major scientific and technological infrastructures.

5.4 Strengthen International Cooperation

New Science and technology revolution and industry revolution are accelerating, from economic globalization to the science and technology globalization, the development of science and technology cooperation with the international top scientific research laboratory promote the world to construct international big science plan, which will implement a global strategy of scientific and technological cooperation featuring openness, inclusiveness, joint contribution and shared benefits. In the new era of international cooperation and on the basis of scientific and technological innovation, make full use of the world's major scientific infrastructures cluster and technological innovation resources, learning advanced science and technology and the development path, their own experience, consummates our country science and technology innovation system, and promote our country science and technology development and transformation, improve the international competitiveness of core technology, the construction of high level technologies, Achieve science and technology collaboration and breakthrough.

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