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Study on the factors affecting the competitiveness of biopharmaceutical industry cluster: Evidence from Guangdong and Zhejiang of China

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ABSTRACT

Objective: This study aims to analyze factors affecting the competitiveness of China's biopharmaceutical industry cluster, offering insights for policymakers and stakeholders, while providing Chinese experience and theoretical support for sustainable development of global biopharmaceutical industry clusters.
Methods: Based on relevant data from Guangdong and Zhejiang Provinces in China, the entropy value method was used to evaluate the comprehensive competitiveness of biopharmaceutical industry clusters in Guangdong and Zhejiang provinces respectively, and the principal component regression method was applied to respectively examine factors affecting the competitiveness of biopharmaceutical industry clusters in Guangdong and Zhejiang provinces.
Results: The competitiveness study showed that the comprehensive competitiveness scores of biopharmaceutical industry clusters in Guangdong and Zhejiang both show an upward trend from 2010 to 2020. From 2010 to 2020, the average value of Zhejiang's competitiveness was 0.53 and Guangdong's was 0.41. The influencing factor study showed that the top five factors affecting the competitiveness of biopharmaceutical industry clusters in Guangdong and Zhejiang were the same, namely, the ratio of general public service expenditure to regional GDP, ratio of regional road freight turnover to regional road mileage, proportion of R&D expenditure to total industrial output, ratio of total healthcare expenditure to provincial consumption, and product sales rate.
Conclusion: The results suggested that core factors affecting the competitiveness of China's biopharmaceutical industry cluster center on four aspects: infrastructure, innovation resources, enterprise performance, and market environment. Therefore, the primary strategy is to strengthen infrastructure construction and investment in innovation resources, while balancing enterprise performance with market environment optimization. This study pioneered the research on factors influencing the competitiveness of China's biopharmaceutical industry cluster, providing a new perspective and reference framework for subsequent research in this field.

1. Introduction

Driven by the accelerated aging of the population and increasing public health awareness, the global biopharmaceutical industry has experienced rapid development. As a sunrise industry in the 21st century, biopharmaceutical industry has gradually developed into one of the most promising and competitive high-tech fields. According to data from Yihe Market Consulting, the global pharmaceutical market size is expected to be approximately 119.25 billion US dollars in 2024. It is expected that by 2033, the global pharmaceutical market size will reach 199.01 billion US dollars, with a compound annual growth rate of 5.86% from 2024 to 2033. Meanwhile, the trend of biopharmaceutical industry clustering is obvious, and several world-class industry clusters have emerged worldwide.

In recent years, China's biopharmaceutical industry clusters have developed rapidly, but there is still a certain gap compared with the international advanced level. Internationally leading biopharmaceutical clusters usually have a wider international market and stronger global competitiveness. Famous examples include the Longwood Medical and Academic District in Boston, USA; the Discovery Center in Cambridge, UK; and the Biotech Park in Lyon, France.[1] These biopharmaceutical

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clusters function as magnetic hubs, attracting concentrated capital flows, technological innovation, and talent pools. Although China's biopharmaceutical industry has formed several clusters, such as the Pearl River Delta, Yangtze River Delta, Bohai Rim, and other regions, the competitiveness of biopharmaceutical clusters as a whole is still at the stage of catching up with the international advanced level due to the late start of the biopharmaceutical industry. Therefore, exploring the factors affecting the competitiveness of biopharmaceutical industry clusters has become the focus of our research.

The issue of factors affecting the competitiveness of biopharmaceutical industry clusters has been thoroughly explored by scholars, resulting in a wealth of research results. Cooke[2] identified factors related to the success of bio-industry clusters, including a strong research base, continuously improving organizational innovation, regional infrastructure, availability of funds, and effective policy support. Zhang[3] argued that innovation has the greatest impact on the competitiveness of biopharmaceutical clusters in the Yangtze River Delta region. Powell[4] suggested that technology and capital are the most crucial factors for the growth of the biotechnology industry in regional clusters. Jongholee[5] emphasized the participation of universities, research institutions, and the presence of companies to foster the success of biopharmaceutical industry clusters. Eungdo[6] also suggested that the relationships between biopharmaceutical companies, universities, and research institutions should be tightly enhanced. Chen[7] directly indicated that knowledge spillover plays a crucial role in the innovation of the biopharmaceutical industry, which relies heavily on technology. Together, these studies reveal the multifaceted influences on the competitiveness of biopharmaceutical clusters, but there is less discussion about China.

Guangdong Province and Zhejiang Province are the pioneer demonstration areas for biopharmaceutical industry clusters in China. Guangdong has an advantageous geographical location, neighboring Hong Kong and Macao, with numerous ports and convenient foreign trade. Relying on its unique location, Guangdong has successfully built a high-end biopharmaceutical industry cluster in the Guangdong-Hong Kong-Macao Greater Bay Area, which has become an important force in the domestic and international biopharmaceutical field. Zhejiang, on the other hand, is located in the Yangtze River Delta, which is characterized by economic vitality and a strong innovation atmosphere, and has a profound foundation for the biopharmaceutical industry. The biopharmaceutical industry is not only the core pillar of Zhejiang's economy, but also the key engine for its deep integration into the Yangtze River Delta integrated development and the construction of regional industrial clusters. Taken together, Guangdong Province and Zhejiang Province are effective examples that objectively reflect the development status of China's biopharmaceutical industry clusters.

In this study, based on the relevant data of China's Guangdong and Zhejiang biopharmaceutical industry clusters, we constructed an index system for evaluating the competitiveness of biopharmaceutical industry clusters, and calculated the comprehensive competitiveness scores of the clusters by using the entropy value method. Then, we identified and ranked the factors affecting the competitiveness of China's biopharmaceutical industry clusters through principal component regression (PCR) analysis. This study aims to provide a theoretical basis and practical guidance for promoting the high-quality development of China's biopharmaceutical industry cluster and enhancing its international competitiveness, as well as providing a reference for similar developing countries.

2. Materials and methods

2.1. Methods

2.1.1. Entropy value method

The entropy value method is a widely used objective weighting method that can fully utilize the value coefficients of each indicator to measure its contribution to the evaluation results.[1] It effectively overcomes the overlap of information between multiple indicator variables and the subjectivity of determining weights, demonstrating high reliability and accuracy.[8] As the evaluation of competitiveness of biopharmaceutical industry cluster involves a variety of heterogeneous indicators such as industry scale, human and material input, and policy support. Compared with the AHP hierarchical analysis method, which is susceptible to expert experience bias, the entropy value method effectively avoids human subjective interference by calculating the entropy value of indicator information to objectively reflect the degree of data discreteness. Meanwhile, the objective assignment better reflects the regional characteristics of Guangdong and Zhejiang provinces. Therefore, this study adopts the entropy value method to score the comprehensive competitiveness of biopharmaceutical industry clusters in Guangdong and Zhejiang provinces. However, the entropy value method has higher requirements on data, and it is highly sensitive to data noise or outliers, so the possible statistical errors or measurement bias in the original data may lead to weight calculation results deviating from the real situation.

2.1.2. Principal component regression (PCR)

PCR analysis is a regression method that uses principal components as independent variables. When multicollinearity exists among independent variables in a linear regression model, PCR combines multiple original indicators into a few new ones without losing substantial information. By using these new indicators as mutually independent variables for multiple regression, the impact of multicollinearity is mitigated.[9] The PCR includes the following steps: correlation analysis, principal component analysis, and multiple linear regression analysis. This study employed PCR to explore the factors influencing the competitiveness of biopharmaceutical industry clusters in Guangdong and Zhejiang provinces of China.

2.2. Data sources

The data were collected from the "China High-Tech Industry Statistical Yearbook" for the years 2010-2020, as well as the "Guangdong Statistical Yearbook", "Zhejiang Statistical Yearbook", "China Torch Statistical Yearbook", and PrivCo Database. Missing data was handled through averaging or interpolation. Due to the presence of negative values, and in order to eliminate the influence of unit differences, dimensional effects among feature attributes, and ranges of variation, all original data underwent standardization. The "Z" mentioned in the following sections represents the values after data standardization.

2.3. Variable selection

2.3.1. Explained variable

The comprehensive competitiveness score of the biopharmaceutical industry clusters in Guangdong and Zhejiang is set as the explained variable (Y), which is calculated using the entropy value method with various levels of indicators, including 1 primary indicator, 4 secondary indicators, and 13 tertiary indicators, as shown in Table 1. Drawing on previous findings,[10,11] this study, based on principles of systematicity, scientific rigor, objectivity, and operability, combined the professional, distinctive, and green characteristics of the biopharmaceutical industry. We predominantly focused on the low-carbon perspective to establish an evaluation index system for the competitiveness of biopharmaceutical industry clusters in China, covering scale, management, green technology innovation, and growth. Scale competitiveness refers to the resource capabilities of the biopharmaceutical industry, including human, material, and financial resources; managerial competitiveness measures the operational capabilities of the industry, primarily reflected in indicators such as revenue and profit; green technology innovation competitiveness refers to breakthroughs in green technology; and growth competitiveness reflects the potential of the industry.

Table 1
Evaluation index system for the competitiveness.

Primary indicators	Second indicators	Tertiary indicators	Unit	Property
Competitiveness of the biopharmaceutical clusters	Scale	Number of enterprises	Number	+
		Average number of employees	Ten thousand	+
		Year-end total asset	100 million yuan	+
	Managerial competitiveness	Operating revenue	100 million yuan	+
		Total profit	100 million yuan	+
	Green innovation	R&D expenditure/energy consumption	Ten thousand yuan/ten thousand ton	+
		Employees/energy consumption	Person/ten thousand ton	+
		Patents/energy consumption	Per ten thousand ton	+
		Sales revenue of new products/energy consumption	Ten thousand yuan/ten thousand ton	+
	Growth	Employee's growth rate	%	+
		Annual average growth rate of operating revenue	%	+
		Growth rate of new projects	%	+
		Growth rate of patents	%	+

2.3.2. Explanatory variables

Based on relevant studies, this article selected 13 indicators as explanatory variables, including the proportion of R&D expenditure to total industrial output (X_1), R&D personnel full-time equivalent (X_2), number of research institutions (X_3), ratio of regional road freight turnover to regional road mileage (X_4), ratio of general public service expenditure to regional GDP (X_5), regional GDP (X_6), ratio of total healthcare expenditure to provincial consumption (X_7), general public R&D budget of local governments (X_8), amount of venture capital (X_9), growth rate of industrial output in clusters (X_{10}), overall labor productivity (X_{11}), product sales rate (X_{12}), and corporate income tax (X_{13}). Please refer to Table 2 for details.

This article categorizes the determinants of the competitiveness of the biopharmaceutical industry cluster into internal and external factors. In terms of internal factors, the three main factors selected for continued consideration in this study are infrastructure, innovation resources, and enterprise performance. Specifically, infrastructure is a solid guarantee for economic development. Improving the infrastructure will create a favorable environment for enterprises within the cluster and solidify the foundation for industrial development. Palei[12] also presented similar views on the practical significance of infrastructure. This article selected two indicators, transportation and general public service expenditure, to measure whether the state of infrastructure construction affects the overall competitiveness of the cluster. Innovative resources are the driving force of the biopharmaceutical industry, facilitating the assessment of growth potential and the examination of the core competitiveness. This article primarily explored three indicators: scientific and technological personnel, the number of scientific and technological institutions, and R&D expenditure. We further discussed whether technological innovation is the main factor influencing cluster competitiveness. The development of industrial clusters cannot be separated from enterprises. Considering the actual situation that the growth of the Chinese pharmaceutical manufacturing industry has encountered various obstacles, we speculated that enterprise performance can assess the economic achievement in their business scope. Specifically, indicators such as the growth rate of the industrial output of the cluster, the labor productivity of all employees, and the product sales rate will be selected to show the performance of the enterprise.

Table 2
Factors of competitiveness.

Factors	Explanation
Innovative resources	Number of research institutions
	R&D personnel equivalent (ten thousand per year)
	R&D/industrial output
Infrastructure	The proportion of general public services expenditure to regional GDP
	Regional road freight turnover/regional road mileage
Market environment	Regional GDP (in 100 million yuan)
	The ratio of personal health expenditure to total residential consumption in the province (%)
Financing channels	Corporate income tax (in 100 million yuan)
	Amount of venture capital investment (in 100 million yuan)
	Local general public budget on science and technology (in 100 million yuan)
Enterprise performance	Product sales rate (%)
	Total labor productivity (%)
	Growth rate of gross output in industrial clusters (%)

In terms of external factors, this study mainly involves the market environment and financing channels. The importance of the market environment as a potential factor affecting the competitiveness of biopharmaceutical industry clusters cannot be ignored. This indicator is measured by regional GDP and the ratio of personal health expenditure to total residential consumption in the province. Higher regional GDP means stronger economic strength and broader market space. This provides greater market potential for the pharmaceutical industry. The proportion of personal health expenditure to total residential consumption directly reflects the importance local residents attach to health and the strength of investment in health care. This indicator also reflects the potential scale of market demand.

In addition, the growth of the biopharmaceutical industry cluster requires significant financial support. Zhang[13] believed that effective funding plays a determining role in industrial R&D investment. A well-developed financing mechanism can meet the further development of clusters. Combining with the current situation of slowing investment in China, the funding support mechanism of the cluster is speculated as a factor affecting competitiveness. Therefore, this study innovatively introduces this research indicator. There are multiple ways for financing in the biopharmaceutical industry, among which venture capital is very important. Tax policies are a key factor affecting the investment and financing capabilities of enterprises.[14] In order to support the development of small and medium-sized enterprises(SMEs), the Chinese government has introduced a number of policies, among which the SMEs can benefit a lot from tax preferential policies.[15] Therefore, we incorporated corporate income tax indicators into the financing channel measurement system, using this indicator to indirectly reflect whether China's macroeconomic policies can guide the financing channels and methods. The market environment will also be discussed as a potential factor affecting cluster competitiveness. This indicator can reflect the competitiveness of products of the cluster. This article calculated the impact of regional macroeconomic conditions and market demand on the cluster. In conclusion, we identified infrastructure, innovative resources, business performance, financing channels, and market environment as the five key elements influencing the competitive strength of the biopharmaceutical industry clusters in China, and specific indicators related to these elements are selected for detailed measurement.

3. Results

3.1. Comprehensive competitiveness score

The comprehensive competitiveness score of the biopharmaceutical industry clusters is used to measure and compare the strengths of different biopharmaceutical clusters in a number of aspects. The comprehensive competitiveness scores of biopharmaceutical industry clusters in Guangdong and Zhejiang provinces from 2010 to 2020 were calculated by entropy value method (Table 3). The higher score suggests the greater competitiveness of the biopharmaceutical industry cluster in that province. From 2010 to 2020, the comprehensive competitiveness scores of biopharmaceutical industry clusters in Guangdong and Zhejiang both show an increasing trend. The average score of Zhejiang is 0.53, and the average score of Guangdong is 0.41. It can be seen that there is not much difference in the average competitiveness scores of the biopharmaceutical clusters of the two provinces from 2010 to 2020, which suggests that they are comparable in terms of competitiveness in the biopharmaceutical industry. This relatively balanced competitive situation provides a good research basis for us to study in depth the general factors affecting the competitiveness of China's biopharmaceutical industry clusters.

3.2. Correlation analysis

Correlation analysis is a method of determining the degree of correlation between variables. The data results are shown in Appendix A (Figures A.1 and A.2). By analyzing the correlation analysis of the variables of Guangdong and Zhejiang separately, it is found that the correlation coefficients between the variables of Guangdong and Zhejiang are mostly greater than 0.8, which indicates that there is a strong correlation between the explanatory variables of Guangdong and Zhejiang individually, that is, there is a high degree of multicollinearity between the variables of each province. PCR is considered an effective method for addressing multicollinearity.[16] Therefore, this article adopted PCR to analyze the factors of the competitiveness of the biopharmaceutical industry clusters in Guangdong and Zhejiang.

3.3. Principal component analysis

As can be seen from the total variance explanation tables (Table B.1 and B.2 in Appendix B) for Guangdong and Zhejiang, both provinces have two common factors with initial eigenvalues greater than one. Meanwhile, the cumulative contribution rate of the eigenvalues is 88.95% for Guangdong and 87.72% for Zhejiang, indicating that both provinces contain most of the information of the original variables. Second, combining the respective fragmentation plots of Guangdong and Zhejiang (Figures A.3 and A.4 in Appendix A), it can be seen that the connecting lines between component 1 and component 2 are steeper in both provinces, indicating that they contain more information, while the connecting lines after component 3 in both provinces tend to be flat, indicating that the subsequent components contain less information. Therefore, we extracted the first two principal components of Guangdong Province and Zhejiang Province respectively to represent the original explanatory variables for the subsequent regression analysis.

Table 4 shows the component score coefficient matrix of the two principal components F1 and F2 in Guangdong Province. As shown in Table 4, ZX_1, ZX_2, ZX_3, ZX_6, ZX_7, ZX_8, ZX_9, ZX_{10}, ZX_{11}, and ZX_{13} in Guangdong Province have larger loadings on the 1st principal component, which can be interpreted as the 1st principal component reflecting innovation resources, market environment, financing channels, and enterprise performance. And ZX_4, ZX_5, and ZX_{12} have larger loadings on the 2nd principal component, which can be interpreted as the 2nd principal component reflecting infrastructure and enterprise performance. Taken together, F1 and F2 are the main public factors affecting the competitiveness of the biopharmaceutical industry clusters in Guangdong Province. The two principal component expressions of Guangdong Province are shown in equations (1) and (2).

$$F1 = 0.10*ZX_1 + 0.10*ZX_2 + \cdots + 0.10*ZX_{13} \quad (1)$$

$$F2 = 0.01*ZX_1 + 0.09*ZX_2 + \cdots - 0.07*ZX_{13} \quad (2)$$

Table 5 shows the component score coefficient matrix of the two principal components F1' and F2' in Zhejiang Province. As shown in Table 5, ZX_1', ZX_2', ZX_3', ZX_4', ZX_6', ZX_7', ZX_9', ZX_{11}', ZX_{12}', and ZX_{13}' have larger loadings on the 1st principal component, which can be interpreted as the 1st principal component reflecting innovation resources, infrastructure, market environment, financing channels and enterprise performance. While ZX_5', ZX_8', and ZX_{10}' have larger loadings on the 2nd principal component, the 2nd principal component reflects infrastructure, financing channels, and enterprise performance. Taken together F1' and F2' are the main public factors affecting the biopharmaceutical industry clusters in Zhejiang Province. The two principal component expressions of Zhejiang Province are shown in equations (3) and (4).

$$F1' = 0.10*ZX_1' + 0.10*ZX_2' + \cdots + 0.10*ZX_{13}' \quad (3)$$

$$F2' = 0.00*ZX_1' + 0.01*ZX_2' + \cdots + 0.02*ZX_{13}' \quad (4)$$

3.4. Multiple linear regression analysis

Multiple linear regression analysis for Guangdong Province was conducted with principal components F1 and F2 as explanatory variables and ZY as a dependent variable. The results show that $R = 0.95$, $R^2 = 0.91$, and adjusted $R^2 = 0.89$, indicating that the model fits well. The results are shown in Table 6. Finally, we derived the regression equation expression (5) for Guangdong Province:

Table 3
Comprehensive competitiveness score.

Year	Zhejiang	Guangdong
2010	0.28	0.16
2011	0.17	0.17
2012	0.32	0.28
2013	0.32	0.24
2014	0.36	0.29
2015	0.45	0.35
2016	0.47	0.35
2017	0.52	0.44
2018	0.61	0.48
2019	0.77	0.58
2020	1.02	0.76

Table 4
Coefficient matrix of Guangdong component scores.

Components	F1	F2
ZX_1	0.10	0.01
ZX_2	0.10	0.09
ZX_3	0.10	0.04
ZX_4	0.03	−0.34
ZX_5	0.05	0.34
ZX_6	0.10	−0.03
ZX_7	0.09	0.09
ZX_8	0.10	−0.04
ZX_9	0.09	−0.17
ZX_{10}	−0.07	0.07
ZX_{11}	0.09	−0.10
ZX_{12}	0.03	0.34
ZX_{13}	0.10	−0.07

Table 5
Coefficient matrix of Zhejiang component scores.

Components	F1′	F2′
ZX_1'	0.10	0.00
ZX_2'	0.10	0.01
ZX_3'	0.09	0.02
ZX_4'	0.09	0.12
ZX_5'	0.04	0.40
ZX_6'	0.10	−0.03
ZX_7'	0.09	−0.17
ZX_8'	−0.03	0.37
ZX_9'	0.08	−0.07
ZX_{10}'	−0.05	0.30
ZX_{11}'	0.09	−0.06
ZX_{12}'	−0.09	−0.16
ZX_{13}'	0.10	0.02

Table 6
Regression analysis of Guangdong.

model	B	Standard error	Beta	t	p	VIF
Constant	0.00	0.10	–	0.00	1.00	–
F1	0.95	0.11	0.95	8.97	0.00	1.00
F2	0.10	0.11	0.10	0.97	0.36	1.00

Table 8
Ranking of factors.

Rank	Province	
	Guangdong	Zhejiang
1	X_5	X_5
2	X_4	X_4
3	X_1	X_1
4	X_7	X_{12}
5	X_{12}	X_7
6	X_2	X_2
7	X_8	X_{10}
8	X_{13}	X_8
9	X_3	X_{13}
10	X_6	X_3
11	X_{11}	X_6
12	X_9	X_{11}
13	X_{10}	X_9

$$Y = 0.09600000*X_1 + 0.00200000*X_2 + 0.00000220*X_3 + 0.11100000*X_4 + 0.18100000*X_5 + 0.00000106*X_6 + 0.03900000*X_7 + 0.00008400*X_8 + 0.00000002*X_9 - 0.00237815*X_{10} + 0.00000052*X_{11} + 0.03100000*X_{12} + 0.00004749*X_{13} \quad (5)$$

Similarly, multiple linear regression analysis was performed for Zhejiang Province. The results show that $R = 0.96$, $R^2 = 0.91$, adjusted $R^2 = 0.89$, indicating a good model fit. The results are shown in Table 7. Finally, we derived the regression equation expression (6) for Zhejiang Province:

$$Y' = 1.70300000*X_1' + 0.00100000*X_2' + 0.00000200*X_3' + 5.34500000*X_4' + 15.52000000*X_5' + 0.00000100*X_6' + 0.00400000*X_7' + 0.00008400*X_8' + 0.00000008*X_9' + 0.00100000*X_{10}' + 0.00000013*X_{11}' + 0.00500000*X_{12}' + 0.00003100*X_{13}' \quad (6)$$

3.5. Ranking of factors

Based on the coefficients of the respective multiple linear regression equations for Guangdong and Zhejiang provinces, the rankings of the affecting factors are shown in Table 8. The results indicate that the top five factors affecting the competitiveness of the biopharmaceutical industry clusters in the two provinces are the same, namely the ratio of regional road freight turnover to regional road mileage (X_4), ratio of general public service expenditure to regional GDP (X_5), proportion of R&D expenditure to total industrial output (X_1), ratio of total healthcare expenditure to provincial consumption (X_7), and product sales rate (X_{12}). Among the indicators, X_5 and X_4 denote the infrastructure, X_1 represents the innovative resources, X_{12} relates to the enterprise performance, and X_7 describes the market environment.

Table 7
Regression analysis of Zhejiang.

Model	B	Standard error	Beta	t	p	VIF
Constant	0.00	0.10	–	0.00	1.00	–
F1′	0.94	0.10	0.94	9.03	0.00	1.00
F2′	0.18	0.10	0.18	1.78	0.11	1.00

4. Discussion

4.1. The impact of infrastructure on the competitiveness of biopharmaceutical industry clusters

The results of this study showed that the proportion of general public service expenditures to regional GDP (X_5) and the volume of regional road freight turnover per mileage of regional roads (X_4) have significant impacts on the competitiveness of the biopharmaceutical industry clusters in Guangdong and Zhejiang provinces, particularly government fiscal behaviors and regional transportation networks. General public service expenditures have been policy-biased, providing funding support for the construction of biopharmaceutical industrial parks and laying a material foundation for clustered development. Fu[17] believed that the government is the main provider of public goods and services, supporting manufacturing in industrial clusters and playing an effective role in infrastructure. Vernay[18] argued that governments play a crucial role in regulating industrial clusters. Zhang[19] pointed out that the modern transportation industry plays a significant role in industrial clusters. The development of transportation brings convenience, which is conducive to achieving the "information networking" of the biopharmaceutical industry chain, further promoting the clustering development of industries. Based on the commonality of research results between Guangdong Province and Zhejiang Province, it is indicated that in the current development process of China's biopharmaceutical industry cluster, it is necessary to strengthen infrastructure layout, optimize the development environment of the industry cluster, and promote the scientific development of the biopharmaceutical industry cluster. In addition, the

government should further expand general public service expenditures, improve infrastructure construction such as energy supply, comprehensive management, and transportation networks in China's biopharmaceutical industry cluster, improve the basic public service system, and fully leverage transportation as a pioneer in the development of the biopharmaceutical industry cluster.

4.2. The impact of innovative resources on the competitiveness of the biopharmaceutical industry cluster

The results indicated that the proportion of R&D expenditure to the total industrial output (X_1) has a significant impact on the biopharmaceutical industry clusters, suggesting that the intensity of R&D investment is a crucial factor influencing the competitiveness of biopharmaceutical industry clusters. This may be due to the substantial R&D investment attracting numerous enterprises to enter the industry, gradually expanding the scale, and thus forming a competitive cluster. The Chinese government needs to increase its support for innovation in biopharmaceutical technology, such as through continuous support, linkage support, supplementary support, and other methods, to promote the deepening and meticulous cultivation of advantageous areas and key links in the industrial chain in the biopharmaceutical industry park, guide innovation resources to cluster in the biopharmaceutical industry, create platform carriers for innovation resource aggregation, and strengthen the cultivation of scientific and technological innovation talents in enterprises within the industrial cluster. Enterprises should adhere to the use of industry university research to drive the transformation of achievements, utilize investment promotion, joint construction, and other methods to transform the intellectual resources of prestigious universities into industrial innovation resources, connect the collaborative innovation chain of "government, universities, enterprises, and research institutes", promote the implementation of major achievements, and ultimately enhance the technological innovation and research and development capabilities of industrial clusters.

4.3. The impact of enterprise performance on the competitiveness of biopharmaceutical industry clusters

Product sales rate is an indicator of the extent to which industrial products meet social needs, reflecting the market competitiveness of products and the ability of enterprises to influence the market. Compared to Guangdong, the impact of product sales rates on a regional level is more significant in Zhejiang. This may be related to the rapid development of e-commerce in Zhejiang, which has driven the sales of products related to the biopharmaceutical industry, further enhancing market competitiveness and highlighting the overall cluster competitiveness. Focusing on demand response is also the core concern for promoting good performance growth of enterprises. With the increasing demand for health security, the Chinese government should improve the quality of domestic supply, support social forces to provide multi-level and diversified products and services, meet the personalized and diversified consumption needs of residents, and stimulate their consumption willingness and market vitality. The enterprise also needs to constantly adjust the development strategic direction, actively contact the current "digital" and "Internet" development trend to improve market competitiveness, such as building the biopharmaceutical industry cluster e-commerce platform, exhibition platform, and other public marketing channels, increasing product publicity and promotion, strengthening the regional biopharmaceutical product brand construction, and promoting the aggregation of biopharmaceutical product elements and value enhancement.

4.4. The impact of market environment on the competitiveness of the biopharmaceutical industry cluster

The prominent impact on the competitiveness of the biopharmaceutical industry cluster mainly manifests in the ratio of residents' medical and healthcare expenditure to total consumption (X_7). Yang[14] proposed that the central and eastern regions of China currently have a relatively better healthcare system, with abundant and higher quality medical services. Therefore, residents in these provinces are better covered by the healthcare system, subsequently enabling residents to invest more in personal healthcare. In comparison to Zhejiang, residents in Guangdong spend proportionally more on healthcare, possibly due to the comprehensive urban and rural medical insurance system that enables residents to easily reimburse medical expenses, thus effectively reducing medical burden and subsequently improving quality of life. Meanwhile, with population aging, the demand for medical services is expected to rise gradually, suggesting a greater need for high-quality and convenient medical services, as well as a broad prospect for healthcare market. This will help propel the transformation and upgrading of China's biopharmaceutical industry, thus enhancing the competitiveness of industrial clusters. The government should establish and improve the basic medical and health system to serve people's health. Promote the basic medical insurance and major illness insurance system for urban and rural residents, strengthen the management of medical insurance funds, and improve the efficiency of the use of medical insurance funds. Strengthen the construction of the medical and health service system, accelerate the expansion and balanced layout of high-quality medical resources. Strengthen the supervision of the quality and safety of pharmaceutical products, control pharmaceutical prices and medical insurance expenditures, reduce the medical burden on citizens, and improve the quality and efficiency of medical services. We attach great importance to reducing the burden of outpatient medical expenses on insured persons and comprehensively strengthening outpatient medical security.

4.5. The impact of financing channels on the competitiveness of the biopharmaceutical industry cluster

According to our model, the impact of financing channels on the competitiveness of the biopharmaceutical industry cluster is relatively small. Specifically, indicators such as corporate income tax, venture capital amounts, and local government general public budget expenditures on scientific and technological support do not rank very high. This differs from the conclusions of most scholars, who believe that financing channels are an important factor influencing the growth and maturity of the biopharmaceutical industry cluster.[20] This may be due to several reasons. First, the PCR analysis reduces not only the multicollinearity between variables, but also the dimensionality of influencing factors. The limitation is that, the common factors obtained through dimension reduction cannot extract all the information of the variables, and there may be deviations from actual economic situation when interpreting coefficients. Second, the pharmaceutical industry is characterized by the difficulty of developing new drugs, large R&D investment, long investment and payback cycles, and high financial risks. Therefore, the impact of financing on the competitiveness of the biopharmaceutical industry cluster will not be immediately apparent, but with a certain lag. Compared with western developed countries, the financing channels for the China's biopharmaceutical industry are limited, and the financing efficiency is relatively lower.[21] Current studies found that pharmaceutical companies preferably obtain finance through both equity and debt. Furthermore, financial institutions with government backgrounds are noted for more complex procedural systems, leading to longer financing periods and higher costs.[22] Third, both Guangdong and Zhejiang have established relatively complete industrial chains and financial systems based on their geographical and policy advantages. With a diversified industrial structure, innovative technological capabilities, and rich talent reserves, the financing costs are relatively lower, and financing channels are more diverse. Therefore, the impact of financing channels is relatively subordinate. The government can alleviate the burden on enterprises and enhance their financing capabilities through structural tax reduction and fee reduction policies, such as continuing to implement value-added tax retention and refund, advanced manufacturing

enterprise value-added tax additional deduction, and other measures. The government should vigorously develop the corporate bond market, reduce administrative intervention, and establish sound debt protection mechanisms such as asset collateral and credit guarantees. Enterprises need to conduct a comprehensive and accurate assessment of their own funding needs, including short-term operating capital needs and long-term investment needs, establish diversified financing channels, optimize debt structure, such as arranging debt terms reasonably and controlling debt costs.

5. Conclusion

This study explored the factors affecting the competitiveness of China's biopharmaceutical industry clusters, providing a Chinese reference for the development of biopharmaceutical industry clusters worldwide. The results of the study indicate that the primary strategies for enhancing the competitiveness of biopharmaceutical industry clusters are the consolidation of infrastructure and the continuous follow-up of innovative resources. It is important to balance between enterprise performance and market environment. It is worth noting that the factors influencing industrial competitiveness in Guangdong and Zhejiang are highly instructive. The experience of the two provinces can inspire the sustainable development of biopharmaceutical industry clusters worldwide. However, the limitation of this article is that the sample size is relatively small, and only two representative regions are selected. In terms of future research directions, we can sustainably expand the scope of investigation, such as including areas with weaker development levels in the biopharmaceutical industry to compare with this original analysis, preliminarily testing with various research methods, and ultimately selecting appropriate and objective research methods to further improve this study and obtain more reliable research results and more valuable inspiration.

CRediT authorship contribution statement

Qiu Zhang: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mandong Huang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Xiaoxin Huang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation. **Lu Gan:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis. **Yiling Li:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Huiying Huang:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis.

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Declaration of competing interest

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Supplementary data

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