Received: 22 December 2023 | Revised: 20 February 2024 | Accepted: 26 February 2024 | Published online: 1 March 2024

RESEARCH ARTICLE

Green and Low-Carbon Economy
2024, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE42022352

BON VIEW PUBLISHING

Research on the Agglomeration and Spatiotemporal Development of China's Green High-Tech Industries

Bin Zheng[1], Wenfeng Chen[2,*] and Lianshui Li[1]

[1]*Wuxi Taihu University, China*

[2]*Wuxi University, China*

Abstract: Accurate understanding of the spatial and temporal development of the agglomeration of green high-tech industries holds significant importance for the scientific formulation of policies promoting industrial innovation and development. This has attracted increasing attention from scholars. Utilizing nearly a decade's worth of statistical data on China's green high-tech industries, this paper employs methods from spatial geography and other disciplines to analyze the temporal and spatial variations, as well as the agglomeration characteristics of these industries in China. A comprehensive analysis of the development levels of China's high-tech industries and their sub-sectors is conducted through calculations of spatial Gini coefficients, industrial concentration ratios, location quotients, and coefficients of variation. Results indicate that the four key indicators of the development of China's major high-tech industries, namely the number of enterprises, employment figures, operating income, and profits, exhibit linear growth trends. Overall, the agglomeration level of the industry shows a fluctuating downward trend. The regional agglomeration level follows a gradient distribution trend of "eastern region – central region – western region – northeastern region," with a decreasing concentration trend. Regional disparities in the agglomeration level of industries evolve over time, with an increasing concentration in the western and central regions and a decreasing concentration in the eastern and northeastern regions. From a provincial perspective, Guangdong and Jiangsu provinces stand out with significantly higher levels of development in high-tech industries. Furthermore, distinct differences are observed in the development processes of four typical industries. The agglomeration levels, ranked from high to low, are as follows: computer and office equipment manufacturing, electronic information and communication equipment manufacturing, medical device manufacturing, and pharmaceutical manufacturing. The development of the four types of industries has undergone certain transfers and optimizations.

Keywords: key high-tech industries in China, spatiotemporal development, industrial agglomeration, segmented industries

1. Introduction

With the rapid development of economic globalization and industrial technology, high-tech industries have become more important in promoting sustainable economic development, relying on their advantages of intensive in knowledge and technology, low resource consumption, and high added value. High-tech industries are the leading industries in economic growth. Research shows that the output value of high-tech industries in China has reached 16 trillion RMB, accounting for about 15% of the national economic GDP [1]. Therefore, developing high-tech industries is key to China's economic transformation driven by innovation and China's core competitiveness.

In almost 40 years, China's high-tech sector has developed at a breakneck pace. Along the "industrial chain" and "value chain," its development exhibits spatiotemporal features, which are essentially multidimensional evolution processes that continuously expand in depth and breadth. The size of China's high-tech industry is currently comparatively higher than that of sophisticated industries in industrialized nations, but the quality is poorer. China and industrialized nations differ greatly in terms of autonomous innovation, effective use of resources, technology, and product quality. Meanwhile, the pace at which various regions' high-tech businesses are developing varies significantly. As a result, research on the state and determinants of the growth of high-tech industries in various Chinese regions has to be done. The study's findings can offer insightful advice on how to grow high-tech industries in different parts of China in a high-quality manner. This is also crucial for China's 14th Five Year Plan's "accelerating scientific and technological innovation system" to be implemented.

This is a comprehensive, multidimensional, and multi-level study of the spatiotemporal characteristics and dynamic evolution trends of the development level and agglomeration of China's high-tech industries. This study integrated perspectives of economics and geography. On the one hand, we constructed an evaluation model for the development level of China's key high-tech industries and explored multidimensional measurement for industrial agglomeration. We also conducted analysis of the spatiotemporal development of agglomeration level. On the other hand, we studied the differences among various segmented high-tech industries and conducted statistical evaluation of their spatiotemporal distribution and development pattern. The study results can help optimize the spatial layout of China's high-tech industries, as well as formulate targeted

*Corresponding author: Wenfeng Chen, Wuxi University, China. Email: wfchen@cwxu.edu.cn

development strategies and policies. To cover the gaps of previous studies, this study: (1) combined time series models with multiple statistical indicators and applying them to measure the level of high-tech industry agglomeration, which expands the development of industrial agglomeration theory and (2) expand the research on the agglomeration level of high-tech industries from a temporal dimension to a spatiotemporal dimension, showing more perspectives of the evolution process of high-tech industries.

2. Literature Review

As high-tech industries become the core for countries to compete with each other and the foundation for improving national competitiveness, relevant research in China and abroad is gradually increasing. Most of the early studies discussed the development of high-tech industries from the perspective of regional economics and industrial economics. In recent years, with the participation of researchers on geography and study of science, research on the development of high-tech industries from the perspective of geographical economics and study of science has increased.

High technology was first explained as advanced technology used in production processes, mainly referring to the core technologies of the electronic information industry and computer industry at that time [1]. The United States Department of Commerce defines high-tech industries according to two indicators, namely, research and development (R&D) funding intensity and the proportion of scientific and technological staff [1, 2]. The Technology, Trade, and US Economy published by the National Academy of Sciences defines the high-tech industry as an industry with technology as its main product and believes it plays a leading role in the development of the US economy [3]. The UK defines high-tech industries as a group of industries that include new information technology, biotechnology, and other technologies at the forefront of technological progress [4]. The National Bureau of Statistics of China defines high-tech industry as a technology intensive industry with high R&D investment, high product added value, and good international market prospects. It has the characteristics of intelligent, innovative, strategic, and low resource consumption. The standard for the Organization for Economic Cooperation and Development to define high-tech industries is the proportion of R&D funding to total industrial output [5].

The development of high-tech industries is influenced by many factors. Fan & Gu [6] believe that economic foundation, market demand, openness to the global world, industry R&D foundation, independent innovation tendency, government intervention on innovation, and intellectual property protection are key environmental factors. Zhang et al. [7] believe that enterprise size, quality of employees, and government behavior have significant positive impact on high-tech industries. Tian et al. [8] believe that the combination of factors such as employee, technology, talent, and enterprise size, as well as tax preferential policies, has a positive impact on the development of high-tech industries in the region. Liu et al. [9] believe that external technology acquisition is an important factor affecting the quality of innovation in high-tech industries. Zhao and Wang [10] also believe that directly introducing technology such as purchasing domestic technology and introducing foreign technology has a significant promoting effect on industries' innovation efficiency. Other researchers believe that the level of transport infrastructure [11], R&D investment [12], Internet [13], and aging population [14] have significant impacts on high-tech industries.

In recent years, the innovation capacity of China's high-tech industry has shown an overall growing trend, with obvious spatial spillover effects and time accumulation effects [15]. Ruan et al. [16] believe that the innovation efficiency of China's high-tech industry is showing a fluctuating growth trend. Fan & Gu [17] believe that the average innovation efficiency of high-tech industries in China is relatively low, with over half of provinces and cities not reaching the national average level. Cao et al. [18] found that the innovation efficiency of some high-tech industries in the central and western regions has increased rapidly, and their gaps with the eastern region are gradually narrowing. Xu et al. [19] believe the main problem in China's high-tech industry innovation activities is that the technology development efficiency is high while the technology achievement transformation efficiency is low. Both technology development efficiency and technology achievement transformation efficiency are not completely consistent with the local economic development level. Zhang and Yan [20] believe that insufficient innovation investment, stagnant agglomeration level, low participation of R&D institutions, and low profitability of innovation output in high-tech industries are the main reasons for the low synergy between technological innovation and ecological efficiency at present. Li [21] believes that there are general problems in the evaluation system of high-tech enterprises in China, such as weak correlation between industry, university and research, insufficient sustainable development ability, insufficient evaluation indicators, and disconnection between the performance evaluation system and enterprise strategic goals.

High level of industrial agglomeration relies on geographical proximity, forming industrial clusters [22]. Yang and Zhao [23] believe that in recent years, China's high-tech industry has developed rapidly but still faces problems such as unbalanced regional agglomeration, excessive interference of policies on external effect of agglomeration, and the local enterprises' concentration on low technology fields. Boschma [24] believes that the level of specialization in different segmented industries is extremely high, and their requirements for software and hardware facilities for development and innovation are also high. When a certain segmented industry in a certain location has received initial investment, some of them will accelerate information resource sharing to reduce the cost in infrastructure construction and related equipment procurement. Li et al. [25] believe that both specialization and diversification of high-tech industries have a significant positive impact on green total factor productivity. The specialization has a greater promoting effect than diversification, and they both have significant spatial spillover effect. Regional studies have shown that high-tech industry agglomeration in the central and western regions significantly improves green total factor productivity, while diversified agglomeration in the eastern region exhibits a significant inhibitory effect due to congestion. With the growing of time, the promotion effect of agglomeration was more prominent from 2016 to 2018, and the spatial effect of diversified agglomeration on green total factor productivity shifted from positive to negative and then to positive. Zhang and Zhong [26] believe that the overall total factor productivity of China's high-tech industries maintained a positive growth from 2011 to 2019, with both technological progress efficiency and technological efficiency contributing to the growth of total factor productivity. The high-tech industries in the central and northeastern regions have made significant progress and all efficiency indicators are good, while the high-tech industries in the eastern region have made significant technological progress, driving their total factor productivity growth [26].

In summary, researchers in China and other countries have conducted extensive studies on the definition, influencing factors, innovation efficiency, and spatiotemporal differences of high-tech industries. These studies have achieved some valuable results, such as clarifying the definition of high-tech industries in China, analyzing their characteristics, and summarizing their development patterns. These achievements provide theoretical support for high-tech research development. However, there are few gaps in current research: firstly, due to differences in measurement, time spans, and other factors, there are inconsistencies in current research results, which reduce the reliability of these results. Secondly, current research extensively focuses on the high-tech industry of the whole China and three major regions. Few research focused on difference in segmented industries or other detailed aspects [27]. Through investigating the distribution pattern and evolution trend of China's high-tech industry, and clarifying its regional agglomeration, we can optimize the spatial layout of regional high-tech industries. What is more, the study results can provide evidence supporting the formulation of development strategies and policies for China's high-tech industry and improve industrial location theory.

3. Materials and Methods

3.1. Data sources

This study defines the concept of high-tech industries based on the Classification of High-tech Industries (Manufacturing Industry) (2017) [28] issued by the Chinese National Bureau of Statistics. Considering the size and authenticity of data sources, this study mainly focused on four key segmented industries in high-tech industries: pharmaceutical manufacturing industry, electronic and communication equipment manufacturing industry, computer and office equipment manufacturing industry, and medical equipment and instrument manufacturing industry.

The data in this paper come from China Statistical Yearbook, China High Tech Industry Statistical Yearbook, and China Science and Technology Statistical Yearbook. Since the golden age of China's high-tech industry development is after 2008, the time span that shows the most typical developmental pattern is 2009–2019, and the spatiotemporal development analysis was conducted with panel data.

3.2. Research methods

The analysis in this paper comprises two primary components. Firstly, it involves an examination of the temporal dynamics of China's high-tech industry. Utilizing interval data spanning over a decade, key metrics including the number of high-tech enterprises, employee count, operating income, and profits are meticulously calculated and analyzed. Inter-annual variations in these indicators serve as the basis for predicting the future development of high-tech industries and establishing statistical models. Secondly, the overall industrial agglomeration trend in China is scrutinized through computations of the spatial Gini coefficient, industry concentration, and location entropy. Adopting a provincial perspective, the analysis measures the spatial distribution change trend of quantitative indicators for high-tech industries and assesses inter-provincial disparities. The second part of the analysis focuses on reflecting the development of different industry categories. It calculates and analyzes the overall growth rate and individual growth rates of the pharmaceutical manufacturing industry, electronic and communication equipment manufacturing industry, computer and office equipment manufacturing industry, and medical equipment and instrumentation industry over the past decade. While growth rates offer insights, they do not capture regional differences and accumulation changes in various industries. To address this, the paper introduces an analysis of the coefficient of variation, concentration proportion, and industry concentration to systematically evaluate the balance degree and accumulation changes across industries. Through these calculations and analyses, the spatial and temporal evolution of China's high-tech industry development is systematically reflected and evaluated.

Concentration ratio of industry. This indicator is measured by the share of the largest provinces (or cities, autonomous regions) in the whole industry on production, employment, income, etc. The formula is

$$CR_n = \sum_{i=1}^{n} X_i \Big/ \sum_{i=1}^{N} X_i \tag{1}$$

where CR_n represents the concentration ratio of industry of the first n regions which contain large high-tech industries. Considering the economic development level of all regions in China, Beijing, Shanghai, Guangzhou, and Shenzhen are the most developed cities, so it may be appropriate to take as 4. The denominator represents the income of high-tech industries across the country. According to statistical data [29], CR_n between 0.4 and 0.5 can be considered as low concentration ratio, between 0.5 and 0.6 represents moderate concentration, and between 0.6 and 1 represents high concentration.

Space Gini Coefficients. Gini proposed the method of using Gini coefficient to calculate the fairness of income distribution. Krugman et al. used the methods of Lorenz curve and Gini coefficient to construct a space Gini coefficient for measuring the degree of spatial distribution equilibrium of industries and used this to study the degree of agglomeration of the US manufacturing industry [30]. The formula is

$$G = \sum_i (S_i - X_i)^2 \tag{2}$$

where G is the space Gini coefficient, S_i is the proportion of the income from high-tech industries in the $i$province (or city, autonomous region) to the national income from this industry, and X_i is the proportion of the growth in income in this province (or city, autonomous region) to the national growth value. Wu and Zhao [30] point out that when $G = 0$, it can be considered that the spatial distribution of industries is balanced. The larger the G (with a maximum value of 1), the higher the degree of industrial agglomeration.

Location quotient. Location quotient is used to measure the spatial distribution of a certain element, which can directly present the role of a certain region in high-level regions. In addition, location quotient can accurately analyze the degree of specialization of a certain industry and reflect the level of agglomeration.

$$LQ_{ij} = (q_{ij}/q_j)/(q_i/q) \tag{3}$$

Among them, LQ_{ij} is the location quotient of the i industry in j region in the whole country, q_{ij} represents the relevant indicators of i industry in the j region (such as output value and income). q_j is the relevant indicators of all industries in the j region. q_i is the relevant indicators of i industries national wide. q is the main income of national industrial enterprises. Bai [29] points out that when the location quotient is greater than 1, it can be considered that the agglomeration capacity of industries in the region exceeds the regional average level.

The coefficient of variation, also known as the standard deviation or dispersion coefficient, is the ratio of the standard deviation to the mean. It measures the degree of variation in observed values, reflecting the distribution balance of industries in the regions. The calculation formula is

$$CV = \frac{\sqrt{\sum_{i=1}^{n}(X_i - u)^2/n}}{u} \quad (4)$$

where CV is the coefficient of variation, n is the samples size, X_i is the sample value, and u is the mean of the samples. The smaller the coefficient of variation, the more balanced the distribution of regional industries.

4. Results

4.1. Development of China's high-tech industry through time

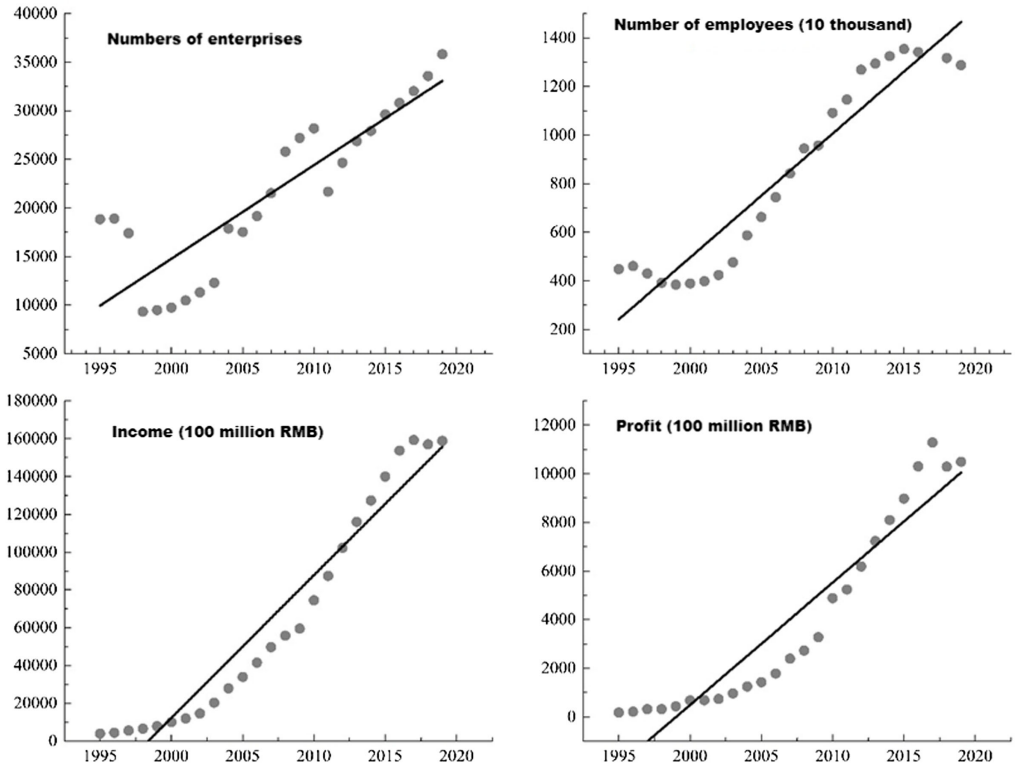
In order to ensure the accuracy of the regression model and increase the time interval in time series analysis, we collected more data to include a larger time span. We investigated the number of industries, the number of employees, income, and profit in China's four key high-tech industries, and the data show that all four factors increased significantly from 1995 to 2019. In 1995, the number of high-tech industries was 18834, with 4.48 million employees, revenue of 391.7 billion RMB, and profit of 17.8 billion RMB. By 2019, there are 35833 high-tech industries with 12.88 million employees, a revenue of 15884.9 billion RMB, and a profit of 1050.4 billion RMB. The average annual growth of high-tech industries is 7.08 million, with an average annual increase of over 350000 employees, an average annual increase of 645.5 billion RMB in revenue, and an annual increase of 43 billion RMB in profits. Over the past 25 years, the number of high-tech industries has increased by 0.9 times, the number of employees has increased by 1.9 times, revenue has increased by 39 times, and profits have increased by 58 times. It should be noted that from 2007 to 2010, industries with an annual income of at least 5 million RMB were counted as high-tech industrial or enterprises, while the standard was adjusted to at least 20 million RMB in 2011, resulting in a decrease in the number of high-tech industries in 2011. See Figure 1 for details.

According to the changes in the four indicators of the high-tech industry between 1995 and 2019, it can be seen that all four indicators have significant positive linear relationships with time. Therefore, it is theoretically possible to establish a univariate regression model of four indicators with the years. SPSS was used to conduct linear regression analysis. Result showed that the coefficient of determination of the linear models for four factors was all greater than 0.6, and the coefficients of determination of the models for the number of employees and income were both greater than 0.9. This represents that the four models fit well. According to the analysis of variance, it can be seen that the p values were all smaller than 0.01, indicating that the linear regression models established by the independent and dependent variables have statistical significance. The linear regression models for the four factors are:

Independent variable (y): year, Dependent variable (x): number of enterprises

$$y = 963.27x - 2 * 106$$

Figure 1
Annual changes in various indicators of Chinese high-tech industries



Independent variable (y): year, Dependent variable (x): number of employees (10000 people)

$$y = 50.986x - 101476$$

Independent variable (y): year, Dependent variable (x): income (100 million RMB)

$$y = 7549.3x - 2 * 107$$

Independent variable (y): year, Dependent variable (x): profit (100 million RMB)

$$y = 503.23x - 1 * 106$$

4.2. Analysis of agglomeration of China's high-tech industry

Table 1 shows that both the space Gini coefficient and the concentration ratio of industry of China's high-tech industry had a continuous decline from 0.66 to 0.55 from 2009 to 2019, with the overall concentration ratio of industry declining by 18%. Although the overall trend is downward, the concentration ratio of industry still reached 0.55 in 2019, which was still at a moderate level of concentration. This may indicate that since 2009, China's high-tech industry has been developing from high concentration to gradual dispersion. The development of space Gini coefficient is similar to the industry concentration ratio.

Table 1
Analysis of China's high-tech industry agglomeration

Year	Concentration ratio of industry CR4	Space Gini coefficient
2009	0.6694065	0.0512664
2010	0.6617774	0.0445424
2011	0.6376137	0.0428747
2012	0.6129105	0.0387500
2013	0.5902258	0.0342367
2014	0.5787323	0.0308573
2015	0.5757477	0.0280925
2016	0.5730837	0.0278917
2017	0.5602897	0.0347735
2018	0.5466379	0.0312604
2019	0.5787323	0.0512664

Location quotient of each region was analyzed. Table 2 shows that the agglomeration in the eastern region remains the highest, with an overall level far exceeding that of other regions. There are significant differences in the developing trends among different regions. However, since 2009, the location quotient in the eastern region has been continuously decreasing, indicating that although still in the lead, the development advantages of eastern region have been gradually reduced in the past decade. This is also the main reason for the gradual distribution of high-tech industry agglomeration across the country. Since 2009, the agglomeration level of high-tech industries in the central and western regions has been continuously increasing, surpassing that of the northeast regions in 2011 and 2012, respectively. This indicates that although the overall agglomeration level of high-tech industries in the western and central regions of China was relatively weak, it still has great space for growth in those areas, which is conducive to the spatially balanced development of China's overall high-tech industry. The overall location quotient of the northeast regions has been in a stepwise decline since 2009 and has been at the bottom of the country since 2011. This reflects the diffusion and spillover of high-tech industries, as well as the decreasing of the growth rate of high-tech industries in the Northeast region.

Table 2
Analysis of regional agglomeration level of China's high-tech industries

Year	Location quotient in the eastern region	Location quotient in the central region	Location quotient in the western region	Location quotient in northeast region
2009	1.490	0.300	0.311	0.716
2010	1.252	0.419	0.401	0.433
2011	1.248	0.472	0.434	0.450
2012	1.261	0.545	0.480	0.440
2013	1.217	0.587	0.540	0.462
2014	1.179	0.624	0.574	0.484
2015	1.143	0.669	0.548	0.503
2016	1.107	0.681	0.574	0.496
2018	1.040	0.713	0.564	0.348
2019	1.039	0.720	0.587	0.330

Table 3 illustrates the degree of provincial agglomeration of China's high-tech industries, which echoes the findings in Table 2 that the distribution of high-tech industry agglomeration was uneven. Under the analysis of location quotient, the agglomeration of high-tech industries in the eastern provinces was significantly higher than that of other regions. The average location quotient of the 10-year data in the eastern region is 1.2, followed by the central region with 0.57, and finally the western and northeastern regions with 0.5 and 0.47, respectively. This indicates that the agglomeration level of high-tech industries in the central, western, and northeastern regions of China did not exceed the regional average level. This indicates poor agglomeration and lack of professional advantages in these areas. The economic development of the eastern provinces was relatively fast. Guangdong, Beijing, Shanghai, and Jiangsu ranked among the top four in terms of location quotient, all exceeding 1.5, which were in the lead in the country in terms of industrial development. On the other hand, the location quotients of Qinghai, Ningxia, Inner Mongolia, Gansu, Xinjiang, and other provinces in the western regions, as well as the three northeastern provinces, were relatively low, indicating significant differences in agglomeration in these provinces. Except for Chongqing and Sichuan, the levels of agglomeration in the western and northeastern regions were significantly lower than that in the eastern and central regions due to regional and economic development levels.

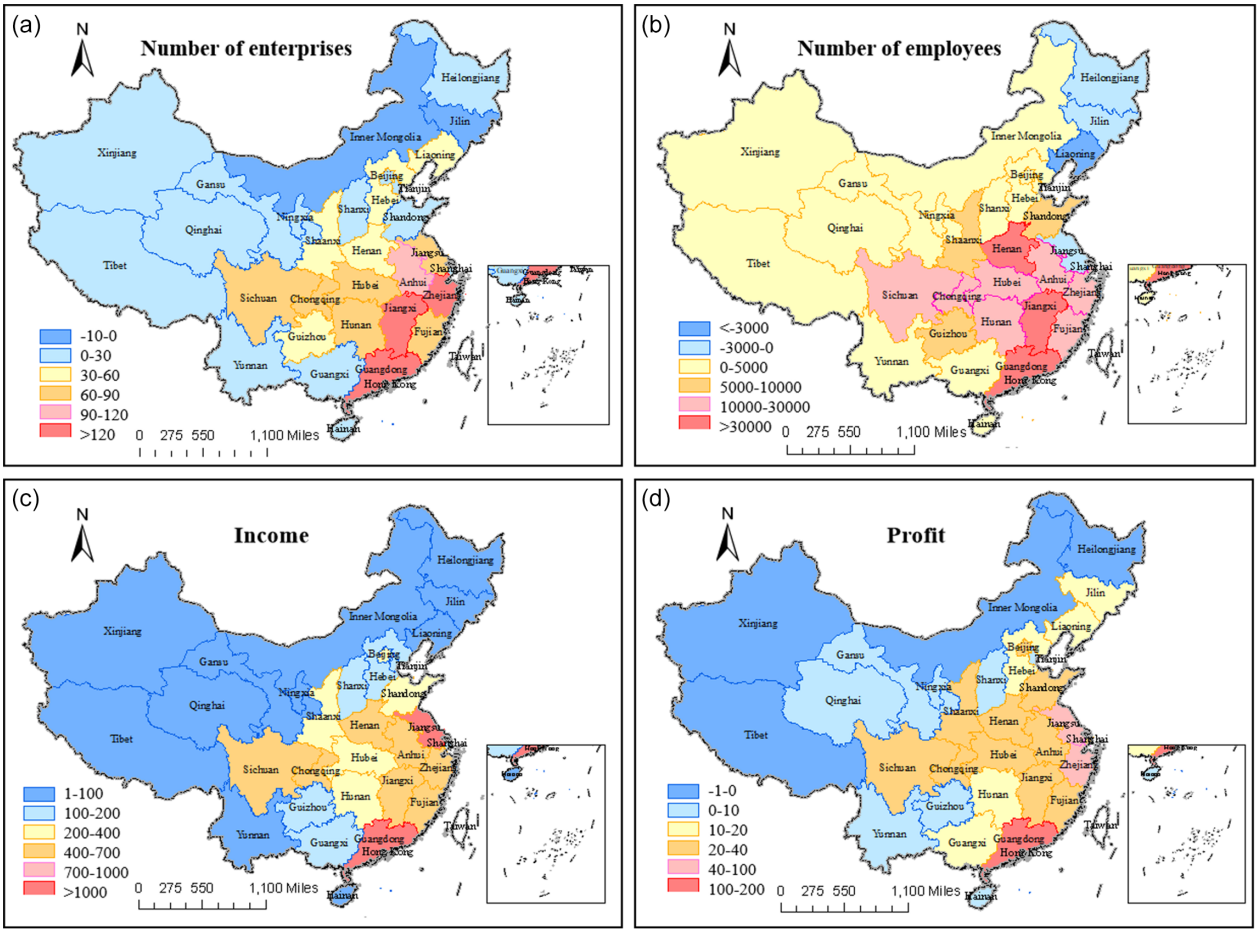
4.3. Spatial change characteristics of China's high-tech industry

Using Arc GIS 10.5, the changes in spatial distribution of four indicators for the development of China's key high-tech industries from 2009 to 2019 were plotted. Figure 2 shows that high-tech enterprises in eastern regions in China had significantly higher level of development than the central and western regions, and the developmental level in the southern region was higher than the

Table 3
Average location quotient of provinces in different regions of China

Eastern region (city)	Location quotient	Central region (city)	Location quotient	Western region (city)	Location quotient	Northeast region (city)	Location quotient
Guangdong	2.3138676	Jiangxi	0.7670304	Chongqing	1.2859150	Jilin	0.5043332
Beijing	1.9310824	Hunan	0.6198217	Sichuan	1.0770633	Liaoning	0.5041077
Shanghai	1.8417393	Hubei	0.5994454	Shaanxi	0.7427481	Heilongjiang	0.3900605
Jiangsu	1.5697762	Henan	0.5912993	Tibet	0.6676519		
Tianjin	1.2222951	Anhui	0.5144296	Guizhou	0.6148016		
Fujian	0.8994946	Shanxi	0.3461115	Guangxi	0.5240735		
Hainan	0.6814951			Yunnan	0.2854626		
Zhejiang	0.6699675			Qinghai	0.2489440		
Shandong	0.5777791			Ningxia	0.1868028		
Hebei	0.2677874			Inner Mongolia	0.1650987		

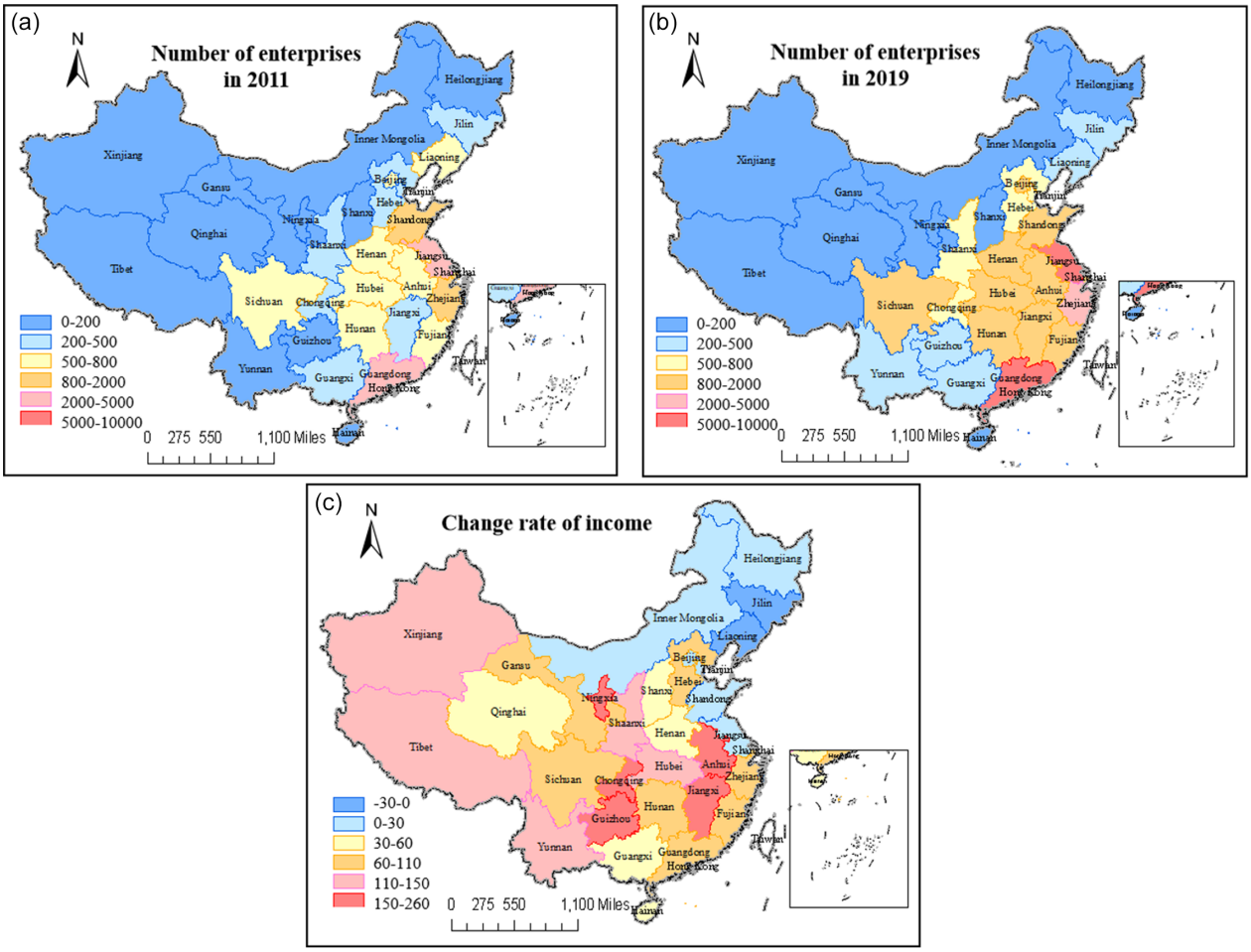
Figure 2
Regional distribution of growth in four indicators for the development level of China's high-tech industry from 2009 to 2019



northern region. This characteristics in spatial change has significantly changed in recent years: In 2009, there were 27218 high-tech industries across the country, including 19919 in the eastern region, accounting for 73.2%, 3293 in the central region, accounting for 12.1%, 2351 in the western region, accounting for 8.6%, and 1655 in the northeast region, accounting for 6.1%. In 2019, there were 35833 high-tech industries across the country, including 23736 in the eastern region, accounting for 66.2%, 6863 in the central region, accounting for 19.2%, 4260 in the western region, accounting for 11.9%, and 974 in the northeast region, accounting for 2.7%.

Figure 3 shows that in the past decades, the growth rate of high-tech industries in Guizhou, Anhui, Jiangxi, and Ningxia has been relatively high, followed by Yunnan, Tibet, Xinjiang, Hubei, and Shanxi, which also had high growth rates. However, the growth rates in Liaoning and Jilin were very low, even showing signs of

Figure 3
Regional distribution of changes in high-tech industries in China compared to 2011 in 2019



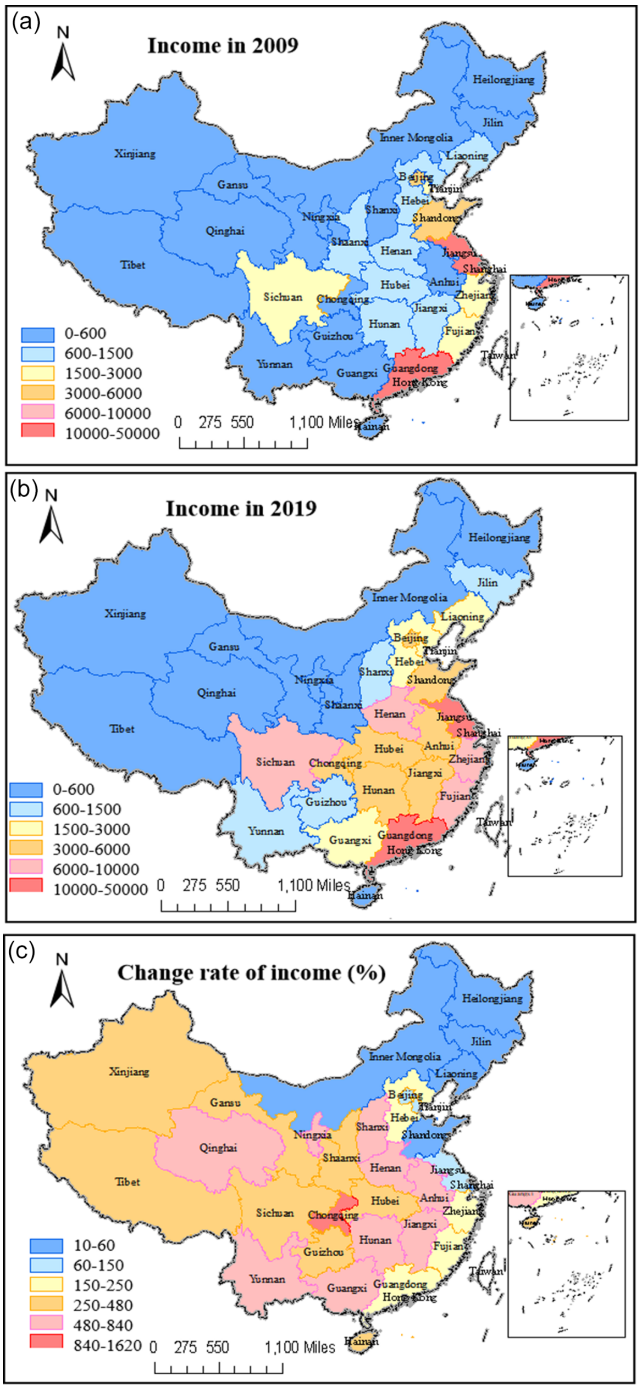
reducing. Overall, the number of high-tech industries in the eastern region has always been higher than that in the western region. However, the number of high-tech industries in the western region has been rapidly increasing. The number of high-tech industries in the southern and central provinces was also increasing, while the number in the northern provinces of China has not increased significantly.

In 2009, provinces can be divided into several groups in terms of the numbers of high-tech industries: Guangdong Province and Jiangsu Province were in the first group, with 5603 and 4542 high-tech industries, respectively. In Guangdong Province, domestically funded enterprise accounted for 48.6%, state-owned enterprises accounted for 0.6%, Hong Kong, Macao and Taiwan invested enterprises accounted for 31.5%, and foreign invested enterprises accounted for 19.9%. However, there were differences in Jiangsu Province, with domestically funded enterprises accounting for 52.5%, state-owned enterprises accounting for 0.7%, Hong Kong, Macao, and Taiwan invested enterprises accounting for 16.1%, and foreign invested enterprises accounting for 31.5%. Nearly 50% of high-tech enterprises in these two provinces were Hong Kong, Macao, and Taiwan invested enterprises and foreign invested enterprises. The provinces in the second group were Zhejiang, Shandong, and Shanghai, with 3094, 1907, and 1536 high-tech industries, respectively. The provinces in the third group were Liaoning, Beijing, Henan, Anhui, Hubei, Sichuan, and Fujian. In 2019, the first group was still composed of Guangdong (9542) and Jiangsu Province (5111), while the second group was only composed of Zhejiang Province (3150). For the third group, Liaoning was excluded, while Jiangxi and Hunan were added. It consisted of Shanghai, Beijing, Shandong, Anhui, Hubei, Sichuan, Jiangxi, Hunan, and Fujian in 2019.

Figure 4 shows that in terms of income, the first group of provinces with incomes exceeding one trillion RMB were Guangdong Province and Jiangsu Province in 2009. The province with highest income was Guangdong Province, with 1575.8 billion RMB, followed by Jiangsu Province with 1278.2 billion RMB. The second group with incomes exceeding 300 billion RMB were Shanghai (578.6 billion RMB), Shandong (454.9 billion RMB), and Beijing (301.9 billion RMB). The third group with incomes exceeding 100 billion RMB included Zhejiang (256.9 billion RMB), Fujian (1948 billion RMB), Tianjin (191.8 billion RMB), Sichuan (158.3 billion RMB), Liaoning (129.4 billion RMB), and Hubei (129.4 billion RMB).

In 2019, there were still Guangdong and Jiangsu who had incomes exceeding one trillion RMB, with 4672.3 billion RMB and 2396.4 billion RMB, respectively. The ranking of provinces in the second groups with incomes exceeding 500 billion RMB has changed. It includes Zhejiang (838.4 billion RMB), Sichuan (158.3 billion RMB), Shanghai (743.8 billion RMB), Fujian (656.3 billion RMB), Henan (611.8 billion RMB), Shandong

Figure 4
Regional distribution of income changes in high-tech enterprises in China compared to 2009 in 2019



(591.1 billion RMB), Beijing (585 billion RMB), Chongqing (577.7 billion RMB), and Anhui (523.3 billion RMB). The provinces that had income exceeding 100 billion RMB include Hubei (443.3 billion RMB), Hunan (401.5 billion RMB), Shaanxi (322.5 billion RMB), Tianjin (272 billion RMB), Liaoning (192.9 billion RMB), Hebei (157.6 billion RMB), Guangxi (153.6 billion RMB), and Guizhou (115 billion RMB). We can see that both Guangxi and Guizhou have entered the 100 billion RMB income group in 2019. In the past 11 years, high-tech enterprises in Chongqing have the highest income growth rate, followed by Shanxi, Anhui, Hunan, Jiangxi, Henan, Guangxi, Yunnan, and Qinghai.

4.4. The spatiotemporal development of segmented industries in China's high-tech industry

Table 4 shows the development rate of the four key segmented industries of China's high-tech industry from 2009 to 2019. It can be seen that the number of enterprises, income, and profits have all increased, indicating the good development of China's high-tech enterprises. According to the absolute value, the electronic and communication equipment manufacturing industry had the largest increase in the number of enterprises, employees, income, and profits, while the number of employees in the computer and office equipment manufacturing industry has decreased. There was significant difference in the development rates among China's segmented high-tech industries, with the electronics and communication equipment manufacturing industry developing the fastest. Although more than 10 years ago, this industry already had the highest number of enterprises and employees, the development rate of this industry in the past 10 years was still the fastest. It was the industry with the highest number of high-tech enterprises and employees, and the highest profit in 2019. This relies on that China's communication services was closely related to social production and daily life. With the development of 5G and the construction of the Internet of Things, the explosive growth appeared in the communication industry.

Table 4
Development rate of some segmented industries in China's high-tech industry from 2009 to 2019

Industry	Number of enterprises	Number of employees	Income (100 million RMB)	Profit (100 million RMB)
Pharmaceutical manufacturing	8.6%	21.99%	162.8%	220.3%
Electronic and communication equipment manufacturing	48.9%	58.04%	251.6%	302.6%
Computer and office equipment manufacturing	35.3%	−22.5%	25.45%	36.1%
Medical equipment and instruments	11.22%	25.9%	134.3%	184.2%

Table 5 shows the growth rate of individual high-tech enterprises. The individual high-tech enterprises in pharmaceutical manufacturing industry had the highest growth rate, followed by the enterprises in electronic and communication equipment manufacturing industry and medical equipment and instruments. The growth rate of the computer and office equipment manufacturing industry even shows negative values, which suggests regression. The computer and office equipment manufacturing industry has shown a decrease in both numbers of employees and income, which may due to the following reasons: (1) a lack of integrated circuit chip technology in China. The equipment for production relies on imports. (2) There was insufficient technological innovation in this industry in China, with 57% of technology imported from abroad. (3) The industry was

Table 5
Growth rate of individual high-tech enterprises in China

Industry	Number of employees/per company	Income (100 million RMB)/per company	Profit (100 million RMB)/per company
Pharmaceutical manufacturing	12.3%	141%	186.7%
Electronic and communication equipment manufacturing	6.1%	136%	180%
Computer and office equipment manufacturing	−42.7%	−7.2%	0%
Medical equipment and instruments	13.2%	116.4%	157.1%

underutilized and approximately 50% of its production capacity was wasted.

As shown in Table 6, based on the coefficient of variation, the electronic and communication equipment manufacturing industry has the largest regional distribution difference among the four segmented industries, with a mean coefficient of variation over 2. This indicates that the high-tech enterprises in this industry had significant regional differences. Meanwhile, this field has the highest income and profit. The pharmaceutical manufacturing industry has a relatively low coefficient of variation, and the coefficient of variation of the computer and office equipment manufacturing industry has been decreasing year by year. This indicates that the two industries have diffused among regions. Overall, the coefficient of variation in high-tech industries is relatively large, which relies on the high regional difference in the electronic and communication equipment manufacturing industry.

Table 7 shows the proportion of the number of enterprises, employees, income, and profits in the national high-tech industries of the four major segmented industries. To further study the development pattern and concentration ratio of the industries, Table 8 lists the top four provinces for their income from industries and their concentration ratio in 2009 and 2019. By comparing the data in 2009 and 2019, we can find that: (1) the proportion of four indicators of the pharmaceutical manufacturing industry has declined slightly, but it is not obvious. The top four provinces of income have not changed. The concentration ratio of this industry has declined slightly, and the overall pattern of low agglomeration has not changed. (2) The electronic communication and equipment manufacturing industry has always been dominated in the high-tech industry in various indicators and achieved significant growth. In 2019, all four indicators accounted for over 50% of the overall high-tech industry in China. Guangdong and Jiangsu were still the top two in terms of income, while Zhejiang and Fujian have successively replaced Beijing and Shandong to be in the third and fourth place. The overall concentration ratio of this industry has dropped from 0.71 to 0.63. It can be seen that the concentration ratio of the electronic communication and equipment manufacturing industry has high level of agglomeration, but the concentration ratio of the industry tends to decline with the change of the spatial pattern. (3) There was no significant change in the proportion of the number of the enterprises in the computer and office equipment manufacturing industry. However, there has been a significant decline in the number of employees, income, and profit. Among them, the proportion of the number of employees has decreased by 42%, and the proportion of profits has decreased by 58%, indicating a significant decrease in per capita labor output and an overall disadvantage in industry development. Further research on

Table 6
The coefficient of variation of operating income in China's high-tech industry from 2009 to 2019

	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019
Overall high-tech industry	1.906	1.901	1.829	1.745	1.688	1.648	1.642	1.655	1.776	1.725
Pharmaceutical manufacturing	0.938	0.988	0.993	1.057	1.101	1.091	1.121	1.135	0.980	0.938
Electronic and communication equipment manufacturing	2.223	2.189	2.125	2.010	2.011	1.976	2.013	2.026	2.167	2.102
Computer and office equipment manufacturing	1.885	1.903	1.853	1.777	1.668	1.598	1.433	1.420	1.409	1.452
Medical equipment and instruments	1.626	1.714	1.894	1.996	2.033	2.052	1.998	2.049	1.639	1.473

Table 7
The proportion of various indicators in China's four industries

	Proportion of the number of enterprises		Proportion of the number of employees		Proportion of income		Proportion of profit	
Industry	2009	2019	2009	2019	2009	2019	2009	2019
Pharmaceutical manufacturing	25.01	20.63	16.76	15.20	15.26	15.04	30.32	30.30
Electronic and communication equipment manufacturing	47.14	53.33	53.26	62.58	47.79	63.01	39.94	50.20
Computer and office equipment manufacturing	6.16	6.33	17.05	9.83	27.59	12.98	14.86	6.31
Medical equipment and instruments	20.88	17.64	9.53	8.92	7.15	6.28	12.14	10.77

Table 8
Concentration ratio of operating income indicators in the four industries

Industries	2009		2019	
	Top 4 provinces and cities in terms of income	Concentration ratio	Top 4 provinces and cities in terms of income	Concentration ratio
Pharmaceutical manufacturing	Shandong, Jiangsu, Zhejiang, Guangdong	0.40	Jiangsu, Shandong, Guangdong, Zhejiang	0.37
Electronic and communication equipment manufacturing	Guangdong, Jiangsu, Beijing, Shandong	0.71	Guangdong, Jiangsu, Zhejiang, Fujian	0.63
Computer and office equipment manufacturing	Guangdong, Jiangsu, Shanghai, Shandong	0.84	Guangdong, Jiangsu, Sichuan, Chongqing	0.65
Medical equipment and instruments	Jiangsu, Zhejiang, Guangdong, Shandong	0.58	Jiangsu, Guangdong, Zhejiang, Shanghai	0.58

concentration ratio shows that Guangdong and Jiangsu, the top two provinces in terms of income, have not changed. Meanwhile, Sichuan and Chongqing have developed rapidly, replacing Shanghai and Shandong as the third and fourth place. The main reason may be related to the spatially transfer of this industry. The concentration ratio of industry of computer and office equipment manufacturing is high, but it also declined the most compared to other industries. The concentration ratio of this industry reached 0.84 in 2009 and 0.65 in 2019. (4) The proportion of medical equipment and instrumentation industry has declined slightly, which may indicate that the importance of this industry has not changed much in the national high-tech industries. The top three provinces with highest incomes were still Jiangsu, Guangdong, and Zhejiang, but the fourth was replaced by Shanghai. The overall concentration ratio is high for this industry and has not changed significantly with the development of spatial pattern.

5. Conclusions and Policy Recommendations

5.1. Conclusions

This study conducted empirical research on the agglomeration level and spatiotemporal development of China's key high-tech industries. The results show that:

(1) With the growing of time, there was a linear growth pattern in the development of China's key high-tech industries. The development of China's high-tech industry was proposed and started by experts in the mid-1980s. In the 1990s, the high-tech industry in China began to rise and entered a period of rapid development. Analyzing the development of four major high-tech industries in 31 provinces, cities, and autonomous regions across China from 2009 to 2019, including pharmaceutical manufacturing, electronic communication equipment manufacturing, electronic computer and office equipment manufacturing, and medical equipment and instrument manufacturing, the growth rates of these industries were far higher than the growth rate of China's GDP of the same period. Although the number of enterprises and employees has not increased much (more than doubled), income and profits have increased by five and six times. At the same time, due to the government's encouragement of individual entrepreneurship in the 1980s and the transformation of some state-owned enterprises in the 1990s, the development speed of high-tech industries was very high and the benefits were good. At the same time, the individual growth of each high-tech enterprise was also very fast. Although the average number of employees per enterprise increased only by less than 20%, income increased by 3.7 times, and profits increased by 2.8 times in the past 11 years. This indicates that the transformation and upgrading of the enterprise have been successful, with a significant increase in income and profit despite a slow increase in the number of employees.

(2) In terms of spatial distribution, there were significant differences in the agglomeration of China's high-tech industry in different regions. The development level of China's high-tech industry in the eastern region was significantly higher than that in the central and western regions. The development level in the southern region was higher in the northern region. According to the level of the indicators of different high-tech industries, China's high-tech industries can be divided into several groups, reflecting the regional differences. The regional differences have similarities with that in the late 1990s and are close to the condition in 2009. However, there was a significant difference in regional distribution in 2019 [31]. Meanwhile, although there were many high-tech enterprises in the eastern region, in the past decade, the number of high-tech enterprises in the western region has rapidly increased, gradually increasing its share in China. The number of high-tech enterprises in the southern and central provinces has increased, while the number of high-tech enterprises in the northern provinces of China has decreased.

(3) The development of China's key segmented high-tech industries was also imbalanced. From the analysis of the development of four major high-tech industries: pharmaceutical manufacturing, electronic communication equipment manufacturing, electronic computer and office equipment manufacturing, and medical equipment and instrument manufacturing, the electronic and communication equipment manufacturing industry has developed the fastest, with the coefficient of variation showing the largest inter provincial differences. The pharmaceutical manufacturing industry ranks the second, followed closely by the medical equipment and instrument manufacturing industry. The electronic computer and office equipment manufacturing industry, in terms of the number of employees, income, and profit, was not as good as other high-tech enterprises. Moreover, due to the development of various provinces, there was also great inter provincial competition, which is consistent with the research of Su et al. [27]. In terms of the growth rate of individual high-tech enterprises, the pharmaceutical industry had the highest growth rate, followed by the electronic and communication equipment manufacturing industry and the medical equipment and instruments manufacturing industry. The development of the computer and office equipment manufacturing industry was slow, and even showed regression. This relied on the withdrew of some foreign-funded enterprises from China due to the impact of the 2008 economic crisis. The

computer and office equipment manufacturing industry is the most sensitive to international economic changes.

5.2. Business and management practices

Based on the above findings, we propose the following business and management implications and theoretical implications:

- According to the significant differences in the agglomeration of China's high-tech industries in different regions, we should discover the development potential of regions with low agglomeration level of high-tech industry, utilizing their regional advantages. Specifically, the eastern region with higher agglomeration levels should further innovate the development path of high-tech industries, construct the support systems for technology research, development, and service, and actively develop leading high-tech manufacturing industries both domestically and internationally. The central and western regions should break administrative barriers, strengthen policy coordination, carry out the transfer of high-tech industries, and accelerate the construction of high-tech industry clusters. The northeast region should improve the construction of corresponding infrastructure and adopt mechanisms such as policy incentives and interest compensation to absorb innovative resources such as high-tech talents and diversified fundings, so as to improve the agglomeration level of high-tech industry. In addition, the construction of metropolitan areas and city clusters for high-tech industries has been strengthened, and cities and provinces have been encouraged to actively integrate into regional innovation clubs. Through the extension and layout of high-tech industrial chains, the innovation space spillover effect of high-tech industrial agglomeration will be brought into full play, leading to the development of surrounding cities and provinces.
- According to the characteristics of different industries, we should innovate institutional arrangements, leverage industry characteristics, and enhance the agglomeration level of key-segmented high-tech industries in China. For the pharmaceutical manufacturing industry, measures such as optimizing government assistance and introducing "seed type" innovative enterprises can be taken to improve the distribution of industries. In the medical equipment and instrument manufacturing industry, we should increase investment in technology R&D and develop intelligent production. For the electronic information and communication equipment manufacturing industry and the computer and office equipment manufacturing industry, it is necessary to accelerate the R&D of core technologies with independent intellectual property rights, realizing the transformation from high-tech products to products with high added value. In addition, the Government, as well as enterprises, is encouraged to rationalize industrial layout and improve technological innovation development planning. Enterprises will be guided to participate more actively in domestic and international market competition. They can keep abreast of market trends, promote technological improvement through commercial activities such as product sales, purchasing, and customer feedback, and achieve technological breakthroughs in "neck-breaking" areas of high-tech industrial development through exchanges, learning, and competition between the local high-tech industry and leading international technology industries.

5.3. Theoretical implications

According to the theory of industrial layout location, it is known that in the process of economic growth, the so-called growth poles are formed when certain dominant sectors or enterprises or industries with innovation ability are clustered in certain specific regions or cities, so that the economy of this specific region develops faster than that of the neighboring regions. Therefore, by studying the distribution pattern and evolution trend of China's high-tech industries and clarifying their regional agglomeration, this paper can not only optimize the spatial layout of regional high-tech industries, but also the results of the study can provide a basis for the formulation of strategies and policies for the development of China's high-tech industries, and also improve the theory of industrial location.

Acknowledgments

We thank International Science Editing (http://www.internationalscienceediting.com) for editing this manuscript.

Funding Support

This work was funded by the National Natural Science Foundation of China's general project "Research on Intelligent Manufacturing Models and Paths Integrating the Digital Economy" (No. 72372121).

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the authors.

Author Contribution Statement

Bin Zheng: Conceptualization, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Wenfeng Chen:** Methodology, Investigation, Resources, Data curation, Supervision. **Lianshui Li:** Conceptualization, Software, Visualization, Supervision, Funding acquisition.

References

[1] Li, J. (1999). *On the prosperity of science and technology in the country*. China: Social Science Academic Press.

[2] Zhou, G., Li, Y., & Li, P. (2016). How to properly define the statistical scope of China's high tech manufacturing industry. *Statistics and Information Forum*, *31*(9), 43–48. https://doi.org/10.3969/j.issn.1007-3116.2016.09.008

[3] National Academy of Sciences. (1978). *Technology, trade, and the US economy*. Retrieved from: https://nap.nationalacademies.org/catalog/19951/technology-trade-and-the-us-economy

[4] Hippel, E. V. (1988). *The sources of innovation*. UK: Oxford University Press.

[5] Guo, W. (1991). *Dictionary of modern industrial economics*. China: Citic Press.

[6] Fan, D., & Gu, X. (2020). Multiple models for improving the efficiency of technological innovation in high tech industries: An innovation environment perspective. *Science and Technology Progress and Countermeasures*, *37*(18), 52–59.

[7] Zhang, X., Cao, Z., & Xu, S. (2021). The heterogeneity of the impact of innovation quality on the efficiency of green innovation in high tech industries: A threshold effect based on industrial agglomeration. *Technology Management*, *41*(18), 10–17. https://doi.org/10.3969/j.issn.1000-7695.2021.18.002

[8] Tian, X., Guo, X., & Yang, G. (2021). Research on the impact of factor agglomeration on the development of innovation ability in high tech industries. *Research Management*, *42*(9), 61.

[9] Liu, Y., Wang, W., & Quan, H. (2021). External technology acquisition, regional institutional environment, and innovation quality of high-tech industries. *Journal of Yunnan University of Finance and Economics*, *37*(10), 84–98.

[10] Zhao, X., & Wang, H. (2019). Research on the impact of technology sources on the innovation efficiency of high tech industries. *Modernization of Management*, *39*(4), 31–35.

[11] Li, S., Xu, M., & Lin, Z. (2021). Research on the impact of international knowledge spillovers on the innovation performance of high tech industries under the effect of R&D human capital. *Journal of Management*, *18*(9), 1354.

[12] Li, T., Liang, L., & Li, Y. (2021). Professional agglomeration, human capital mismatch, and innovation performance in high tech industries: Taking the pharmaceutical manufacturing industry as an example. *Research Management*, *42*(4), 131–137. https://doi.org/10.19571/j.cnki.1000-2995.2021.04.014

[13] Yang, S., & Li, L. (2021). Internet development and innovation efficiency improvement – Empirical evidence from China's high tech industry operations. *Research and Management*, *30*(3), 190–198. https://doi.org/10.12005/orms.2021.0095

[14] Liu, C. (2021). Population aging and innovation efficiency of high tech industries – Empirical analysis based on regulating mesomeric effect. *Yunnan Social Sciences, 40*(3), 93–102, 188. https://doi.org/10.3969/j.issn.1000-8691.2021.03.013

[15] Wan, Q., Yuan, L., & Jiang, Z. (2020). Research on the impact of R&D factor flow on the innovation capability of high tech industries – Also on the regulatory role of economic policy uncertainty. *Soft Science*, *34*(10), 1–6. https://doi.org/10.13956/j.ss.1001-8409.2020.10.01

[16] Ruan, W., Liu, X., & Wu, C. (2020). Research on the innovation efficiency of China's high tech industries – Retesting the "Spillover Effect Hypothesis" of foreign investment. *Modernization of Management*, *40*(2), 41–45. https://doi.org/10.19634/j.cnki.11-1403/c.2023.01.012

[17] Fan, D., & Gu, X. (2020). Research on multiple modes for improving technological innovation efficiency of high-tech industry—Based on the perspective of innovation environment. *Technological Progress and Countermeasures*, *37*(18), 52–59. https://doi.org/10.6049/kjjbydc.2020040586

[18] Cao, L., Liu, Z., Ma, Z., & Ma, S. (2020). Research on innovation efficiency of high-tech industries in provinces and regions along the "the Belt and Road" – Based on the modified generalized DEA model. *Journal of Inner Mongolia University (Natural Science Edition)*, *51*(5), 471–478. https://doi.org/10.13484/j.nmgdxxbzk.20200504

[19] Xu, H., Zhao, L., & Zhu, L. (2019). Research on the spillover effect of innovation efficiency of China's high-tech industries from the perspective of innovation value chain. *Journal of Shanghai University (Social Sciences Edition)*, *36*(5), 67–77. https://doi.org/CNKI:SUN:SHDS.0.2019-05-007

[20] Zhang, L., & Yan, Z. (2019). Research on the synergy between technological innovation and ecological efficiency in high tech industries – Taking Shandong province as an example. *Journal of Dalian University of Technology (Social Science Edition)*, *40*(5), 36–43. https://doi.org/10.19525/j.issn1008-407x.2019.05.005

[21] Li, Y. (2020). Research on the performance management evaluation system of high tech enterprises. *Guidelines for Public Investment, 26*(14), 60–61.

[22] Warda, P. (2012). Innovation system frontiers: Cluster networks and global value – By Brian Wixted. *Papers in Regional Science*, *91*(1), 235–236. https://doi.org/10.1111/j.1435-5957.2011.00411.x

[23] Yang, S., & Zhao, X. (2019). Industrial agglomeration: The driving force for the development of high tech industries in China. *Academic Exchange, 34*(5), 94–103, 192. https://doi.org/10.3969/j.issn.1000-8284.2019.05.010

[24] Boschma, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies*, *39*(1), 61–74. https://doi.org/10.1080/0034340052000320887

[25] Li, J., Xia, M., & Yuan, Q. (2021). Research on the impact of high tech industry specialization and diversification agglomeration on green total factor productivity. *Statistics and Information Forum*, *36*(4), 42–50.

[26] Zhang, Z., & Zhong, W. (2021). Calculation of high quality development efficiency of high tech industries and analysis of regional differences. *Statistics and Decision Making*, *37*(8), 14–17.

[27] Su, H., Liu, W., & Liu, S. (2017). Research on the development law and differences of China's high tech industry. *Contemporary Economy, 32*(33), 144–148.

[28] Li, Z., & Guo, J. (2022). Analysis of the spatiotemporal evolution trend of high-tech manufacturing agglomeration level in the Yangtze River economic belt. *Journal of Hunan University of Technology (Natural Science Edition)*, *35*(4), 55–61.

[29] Bai, W. (1994). Empirical study on China's industrial concentration ratio. *China Industrial Economy*, *11*, 45–50.

[30] Wu, X., & Zhao, G. (2017). China's spatial Gini coefficient: Measurement, improvement, and trends. *Statistics and Decision Making*, *24*(5), 604–608. https://doi.org/10.13546/j.cnki.tjyjc.2017.03.001

[31] Tang, G., & Xu, W. (2004). Research on the spatiotemporal evolution characteristics and spatial layout of China's high-tech industry growth. *Economic Geography*, *24*(5), 604–608. https://doi.org/10.3969/j.issn.1000-8462.2004.05.008

How to Cite: Zheng, B., Chen, W., & Li, L. (2024). Research on the Agglomeration and Spatiotemporal Development of China's Green High-Tech Industries. *Green and Low-Carbon Economy*. https://doi.org/10.47852/bonviewGLCE42022352