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Comprehensive Measurement, Spatiotemporal Evolution, and Spatial Correlation Analysis of High-Quality Development in the Manufacturing Industry

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Abstract: Based on China's provincial panel data from 2007 to 2017, this paper constructs a comprehensive indicator system for high-quality development of manufacturing from eight dimensions. Using the composite entropy weights method, kernel density estimation (KDE) and exploratory spatial data analysis (ESDA) to investigate its spatiotemporal evolution and spatial correlation characteristics. The results show that: (1) The high-quality development of the manufacturing industry shows a steady upward trend, but each dimension (subsystem) is quite different and can be divided into three types: growth type, flat type, and attenuation type. (2) The spatial distribution of the high-quality development of the manufacturing industry is highly consistent with the "Hu Huanyong Line", and the overall layout is "high in the east and low in the west, high in the south and low in the north". Seventy percent of the provinces are below the average level, with large interprovincial differences and significant spatial imbalance. (3) The high-quality development of the interprovincial manufacturing industry shows obvious spatial positive correlation. The hot spots are more active, and the spatial spillover effect is stronger—the Yangtze River Delta is the core, spreading outward in circles, and the main direction of diffusion is "from north to south". In contrast, the cold spot area develops slowly and moves from south to north. Therefore, China should pay more attention to the "Botai Line", which is perpendicular to the Hu Huanyong Line, and formulate differentiated development strategies to promote the coordinated development of the manufacturing industry.

Keywords: high-quality development of manufacturing; spatiotemporal evolution; spatial correlation analysis; sustainable development

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1. Introduction

The report of the Nineteenth National Congress pointed out that China's economy in the new era has shifted from the stage of high-speed growth to the stage of high-quality development. At present, China is still in the late stages of industrialization [1–3]. As the main body of industrial economy [4,5], the foundation of the national economy, and a supporter of the service economy, the development of the manufacturing industry is related to the overall situation of high-quality economic development [6,7]. China's manufacturing industry is "big but not strong, comprehensive but not excellent", and there are still some problems, such as weak independent innovation, high energy consumption, and unreasonable industrial structure. As the primary task of the Central Economic Work Conference, promoting the high-quality development of the manufacturing industry is of great strategic significance to achieve high-quality economic development, accelerate economic transformation and upgrading, and realize the dream of a century-old power [8].

High-quality development is a constantly changing and evolving concept, and people's understanding of it is deepening with the development of social productive forces. In the early stages, the academic understanding of the quality of development was mostly based on a narrow perspective, often taking the efficiency of economic growth as an indicator to measure the quality of development from the perspective of input and output. Therefore, many scholars have used total factor productivity (TFP) [9–13] and green total factor productivity (GTFP) [14–16] as indicators to measure the quality of economic growth. Chen [17] examined the total factor productivity (TFP) as a major source of economic growth in East Asian economies and found that in the end, the importance of technological change in economic growth depends largely on how TFP is defined and measured. Similarly, Saleem et al. [18] endorsed the driving factors behind total factor productivity (TFP) and economic growth in Pakistan. With the development of theoretical research, the research on the quality of economic development has gradually expanded to technological progress [19], institutional innovation, social equity, environmental protection [20,21], and other fields. In the new era, the connotation of high-quality development is more abundant. At present, comprehensive indicators are mainly used to measure high-quality development.

Internationally, many evaluation studies have been carried out in relevant fields, such as the quality of economic growth, the sustainability of economic development, and quality of life. The indicators widely used by the academic community include the Index of Sustainable Economic Welfare (ISEW) [22–26], the genuine progress indicator (GPI) [27–29], the Better Life Index (BLI) [30], and so on. Sánchez et al. [26] calculated the Index of Sustainable Economic Welfare (ISEW) using information from Ecuador for the period 2001–2015 and found that it can better reflect the well-being of a nation than GDP. The Better Life Index, launched by OECD in 2011, contains a detailed overview of the social, economic, and environmental performances of different countries [31]. The focus of indicators has gradually shifted from economic growth and economic development to social development and "all-round human development". In recent years, domestic studies have begun to increase, mainly focusing on high-quality economic development. Measurement perspectives include the Five Development Concept, the Three Reforms [32], and quality indicators of growth [33]. However, there are relatively few achievements specifically aimed at the high-quality development of manufacturing, and most of them focus on the competitiveness, transformation, and upgrading of manufacturing. In 2018, the Chinese Academy of Engineering released the "2018 China Manufacturing Power Development Indicator Report", which mainly constructed the "manufacturing indicator system" from four aspects: scale development, quality and efficiency, structure optimization, and sustainable development. Similarly, the industrial research institute SAIDI took the lead in establishing an indicator system of high-quality development in manufacturing in 2018, which includes seven aspects of technological innovation, structural upgrading, growth rate, factor efficiency, brand building, integrated development, and green manufacturing. Subsequently, scholars also gradually carried out related research on the measurement and evaluation of high-quality development in manufacturing [34]. Li Chunmei measured the development quality of manufacturing from 2003 to 2016 by using the coefficient of variation method from eight dimensions, such as growth rate, efficiency, external dependence, innovation, enterprise quality, product quality, social contribution, and environment [35]. Jiang selected 12 indicators from six aspects: economic benefit, technological innovation, green development, quality brand, integration of industrialization, and high-end development—to construct an evaluation system for high-quality development of manufacturing [36].

Generally speaking, the existing indicator weighting methods include subjective weighting methods and objective weighting methods. The former are based on the relative importance of the indicators through subjective judgment, such as the analytic hierarchy process (AHP), the Delphi method, and the equal weight method; the latter are based on the original information of the indicators, such as clustering analysis, the standard deviation method, and the entropy weights method (EWM) [37]. Subjective weighting methods may be affected by subjective factors, which are biased when assigning weight, so they cannot reflect the composite indicator well. EWM can avoid the inaccuracy of indicator measurements caused by subjective weighting, for which it is widely used in indicator weighting. However, it has its limitations, such as lacking specialist verdict, only considering entropy values, and rank discrimination. Therefore, it is particularly important to choose a more scientific and accurate method. The cross-entropy technique can make up for the shortcomings of EWM and has been widely applied to different machining operations in recent years [38]. In addition, most of the existing studies discuss high-quality economic development or industrial development from a single dimension, such as time series or spatial distribution, and lack of collaborative research on the spatial heterogeneity and spatial evolution mechanisms of high-quality manufacturing development [39]. In their manners of expression, most of them are presented in the form of tables, which is insufficiently intuitive [40]. The emergence of GIS and exploratory spatial data analysis (ESDA) provides an opportunity for rich spatial expression. GIS and exploratory spatial data analysis (ESDA) techniques are employed together to study group-level spatial and social behavior and proved that the compound method possesses high efficiency and effectiveness [41].

1.1. Research Gaps Based on Literature Review

In summary, the literature review shows that there is no consensus on the connotation of high-quality development of the manufacturing industry, and the evaluation indicators used in most studies follow the index system of high-quality economic development, only some of which focus on the manufacturing industry. Secondly, most of the existing evaluation methods are based on traditional statistical analysis and have some limitations, such as not being able to verify and test each other and weak expression in spatial evolution. Finally, there is less literature, collaborative research on the spatial heterogeneity and spatial evolution of high-quality development of the manufacturing industry at the provincial level.

1.2. Research Questions and Intended Contribution of the Study

Based on the research gap described above, the study has realized the following research questions:

- How can we scientifically understand and reasonably measure the high-quality development of the manufacturing industry?
- What are the dynamic evolution trends and spatial correlation characteristics of high-quality development of the manufacturing industry in each province?
- How can we scientifically judge and solve the defects and problems in the development of the manufacturing industry in various provinces and regions?

Thus, the paper aims to measure the level of high-quality development of the manufacturing industry, explore its constraints, and grasp the current and future development trends through spatial evolution and correlation analysis so as to better formulate different development policies for different regions to further promote the high-quality development and regional coordination of the manufacturing industry.

The intended contribution of the study is as follows: Firstly, innovatively based on the composite entropy weights method, the high-quality development of manufacturing industry at the provincial scale is comprehensively measured from eight dimensions, which is conducive to clarifying the development status and grasping the main constraints of the manufacturing industry. Subsequently, the current situation and potential in each province are clarified by further analyzing the spatiotemporal evolution of the high-quality development of the manufacturing industry using KDE and ESDA methods, and a visual analysis is conducted with the help of ARCGIS10.2. The third is to arouse society's attention to the "Botai Line" in view of the large inter-provincial differences and significant spatial imbalance in the manufacturing industry so as to assist regional coordinated development. This study is of great importance for promoting regional coordinated development as well as narrowing the regional gap.

1.3. Organization of the Paper

The rest of the paper is organized as follows: Section 2 presents materials and methods, including the indicator system, research methods, and data sources; Section 3 describes our empirical results from four aspects and presents our discussion; Finally, the conclusions are presented in Section 4 along with limitations and future scope.

2. Materials and Methods

After clarifying the research objectives, this paper conducts research according to the research paradigm of "pattern–process–mechanism" and the workflow of the paper is shown in Figure 1. Before the comprehensive measurement of the high-quality development of the manufacturing industry, it is necessary to define its concept and connotation so as to make the selected indicators more scientific and reasonable. On this basis, spatiotemporal evolution and spatial correlation analysis of the high-quality development of the manufacturing industry are carried out. This analysis includes four parts, namely: temporal variation characteristics, spatial distribution characteristics, spatial evolution characteristics, and spatial correlation characteristics. These comprise a comprehensive analysis of the high-quality development of the manufacturing industry from static and dynamic perspectives on time and space. The temporal variation characteristics include the changes of the composite indicator and sub-indicators (subsystem indicators), which can make clear the advantages and shortcomings of manufacturing industry development; spatial distribution and spatial evolution characteristics can intuitively show the changes of high-quality development of manufacturing industry in each province, and the spatial correlation characteristics can explore whether the agglomeration effect exists and how the hot spots and cold spots are distributed. In the following subsections, the description of each part is explained.

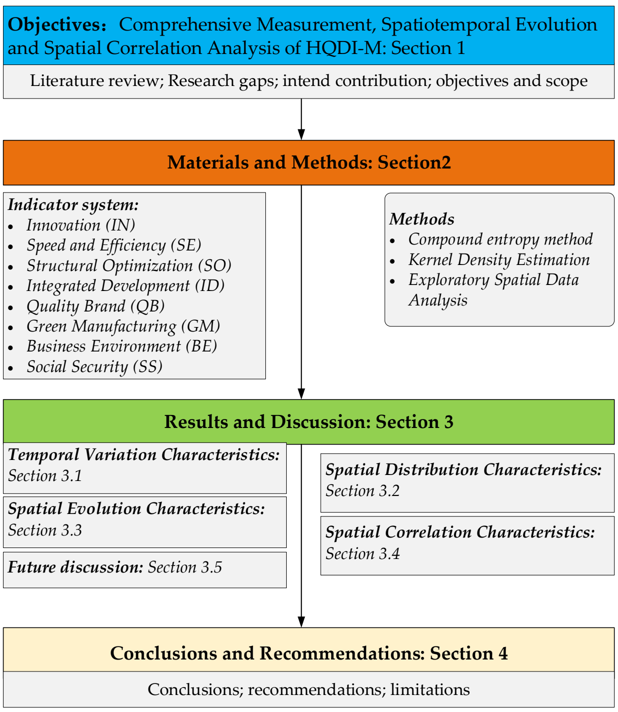

Figure 1. The workflow of the paper.

2.1. Indicator System

Scientific understanding and grasping the theoretical connotation of high-quality development of the manufacturing industry are the premise of this measurement and evaluation. High-quality development of the manufacturing industry is a complex dynamic system which requires comprehensive consideration of all aspects—not only the growth of quantity, but also the continuous optimization of structure; not only economic growth, but also environmental protection and social equity [42]. Considering the practical problems that exist in China's economic development at the present time, this paper holds that the high-quality development of the manufacturing industry should be a more dynamic, innovative, and competitive system with continuous strengthening of innovation (IN), significant improvement of speed and efficiency (SE), continuous upgrading of structural optimization (SO), continuous improvement of integration (ID) and development level, acceleration of green manufacturing (GM), continuous enhancement of quality brand competitiveness (QB), increasingly optimized business environment (BE), and continuous improvement of social security capacity (SS). This paper selects 31 indicators from the above eight aspects to construct a set of indicators suitable for evaluating the high-quality development of the manufacturing industry in provinces (see Table 1).

Table 1. Indicator system of high-quality development of manufacturing.

Dimension	Sub-Indicators	Basic Indicators	Attribute
Innovation (IN)	Innovation environment	X1 Proportion of expenditure on science and technology	+
	Innovation input	X2 Intensity of R&D personnel input in industrial enterprises	+
		X3 Intensity of R&D investment in industrial enterprises	+
	Innovation output	X4 Effective invention patents of R&D expenditure	+
Speed and Efficiency (SE)	Value added rate	X5 output growth rate of manufacturing	+
	Labor efficiency	X6 Total labor productivity of manufacturing	+
	Profitability	X7 main business income profit margin of manufacturing	+
	Asset–liability ratio	X8 Asset–liability ratio of manufacturing	-
Structural Optimization (SO)	Industrial structure	X9 proportion of main business income of high-tech manufacturing	+
	Enterprise structure	X10 Proportion of main business income of large and medium-sized industrial enterprises.	+
	Product structure	X11 Proportion of new product sales revenue	+
	Export structure	X12 Proportion of export delivery value of high-tech manufacturing	+
Integrated Development (ID)	Infrastructure	X13 Internet penetration	+
		X14 Mobile phone penetration	+
		X15 Fixed Broadband Penetration Rate (%)	+
	Application of benefit	X_{16} Proportion of main business income in electronic information sector	+
Quality Brand (QB)	Quality	X17 Qualified rate of manufacturing products	+
		X18 Excellent rate of manufacturing products	+
	Brand construction	X19 Number of China's top 500 manufacturing enterprises	+
Green Manufacturing (GM)	Environmental quality	X20 industrial wastewater discharge of unit added value	-
		X21 industrial SO2 emission of unit added value	-
	Resource utilization	X22 energy consumption per unit of industrial output	-
		X23 Comprehensive utilization rate of general industrial solid waste	+
	Environmental governance	X24 Proportion of investment in treatment of industrial pollution	+
Business Environment (BE)	Market environment	X25 Ratio of Industrial Enterprises with Foreign Investment	+
		X26 Ratio of Employment in Private Manufacturing	+
	Investment environment	X27 Ratio of Total Imports to Foreign-funded Exports	+
	Law environment	X28 The proportion of trade union members in private enterprises	+
Social Security (SS)	Income	X29 Average wage of employees in manufacturing industry	+
	Employment absorption	X30 Proportion of employees employed in manufacturing industry	+
	Tax contribution	X31 Proportion of tax revenue from manufacturing industry	+

2.2. Methods

2.2.1. Compound Entropy Weights Method

The entropy weights method, as the most widely used objective weighting method, can avoid the defects of subjective weighting methods and make the results more objective and truer. However, it has limitations, such as lacking specialist verdict, only considering entropy values, and rank discrimination [38,43]. Meanwhile, some studies have found that the anti-entropy weights method can effectively avoid the sensitivity of the indicator change of the entropy weights method, but it is too unspecialized [44]. After many attempts, this paper selects the compound entropy weights method, which is more reliable and scientific, to calculate the weighted average weight.

Firstly, the original data must be standardized. The standardization method is commonly used for dimensionless indicators, but it eliminates the difference in the variation degree of each indicator and cannot accurately reflect the information contained in the original data. In contrast, the weighted average method can retain the information of the variation degree of each indicator well. Therefore, we use the mean and linear methods to standardize the indicators. Next, the indicators must be weighted. In the entropy value method, the information entropy value of each indicator is calculated according to the standardized data, then the weight is calculated according to the entropy value. $x_{ij}{}'$, ei, z_i respectively represent the standardization value, information entropy value, and information utility value of i, and w_{i1} represents the entropy weight of each indicator.

$$ei = -\frac{1}{In(n)} \sum_{j=1}^{n} x_{ij}^{*} In x_{ij}^{*} \ , \ x_{ij}^{*} = x_{ij}{}' / \sum_{j=1}^{n} x_{ij}{}' \tag{1}$$

$$w_{i1} = z_i / \sum_{i=1}^{m} z_i \ , \ z_i = 1 - ei \tag{2}$$

In the anti-entropy value method, the inverse entropy of each indicator is first calculated according to the standardized data of the original indicator, and then the weight is calculated according to the anti-entropy. $x_{ij}{}'$, hi, z_i respectively represent the standardization value, anti-entropy, and the diversity factor of i, and w_{i2} represents the anti-entropy weight of each indicator.

$$hi = \sum_{j=1}^{n} x_{ij}^{*} In(1 - x_{ij}^{*}) \ , x_{ij}^{*} = x_{ij}{}' / \sum_{j=1}^{n} x_{ij}{}' \tag{3}$$

$$w_{i2} = z_i / \sum_{i=1}^{m} z_i \ , \ z_i = 1 - hi \tag{4}$$

The final weight under the compound entropy weights method is:

$$W = 0.5 * (w_{i1} + w_{i2}) \tag{5}$$

Through all the above formulas, the weight of each indicator can be calculated on the basis of standardized data, and the high-quality development index of manufacturing (HQDI-M) can be obtained through linear weighted calculation.

2.2.2. Kernel Density Estimation

Kernel Density Estimation, as a non-parametric estimation, is a spatial analysis method based on the distribution characteristics of the research object [45]. It can directly reflect the degree of dispersion and agglomeration of variables in space, and is often used to analyze spatial imbalance and dynamic evolution process.

$$f(x) = \frac{1}{Nh} \sum_{i=1}^{N} \left(\mathrm{K}\left(\frac{x - x_i}{h}\right) \right) \ , \ \int K(x)dx = 1 \ , \ K(x) > 0 \tag{6}$$

$f(x)$, N, h, K respectively represent the probability density function, sample size, bandwidth, and kernel function. The common forms of kernel functions include triangular kernel function, Epanechnikov kernel function, and Gaussian kernel function. This paper selects Gaussian kernel function, for it is widely used by researchers.

2.2.3. Exploratory Spatial Data Analysis

Exploratory spatial data analysis (ESDA) is a statistical method which can explore spatial relevance and aggregation based on spatial data [46]. Exploratory spatial data analysis (ESDA) is an extension of exploratory data analysis, as it explicitly focuses on the particular characteristics of geographical data. It is an increasingly popular geographic information science (GIS)-based technique that allows users to describe and visualize spatial distributions; identify atypical locations or spatial outliers; discover patterns of spatial association, clusters, or hot spots; and suggest spatial regimes or other forms of spatial heterogeneity. ESDA has two types of methods; the first type is the Global Moran Index, which is an indicator to measure spatial difference and the degree of spatial correlation. *Moran′ s I* represents the overall trend of the spatial correlation in the study area, and its possible values are -1 to 1. $I > 0$ indicates positive spatial correlation, and the closer it is to 1, the higher the degree of clustering with similar attributes. $I = 0$ indicates irrelevance; that is, high-quality development has spatial randomness and no spatial correlation.

$$Moran's\ I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{7}$$

The second type of ESDA is hot spot analysis (*Getis-Ord Gi**). Compared to the Global Moran Index, *Getis-Ord Gi** can judge local spatial correlation features more accurately so as to identify hot and cold spots in space. Its calculation formula is:

$$G_i^*(d) = \sum_{i=1}^{n} W_{ij}(d) X_i / \sum_{i=1}^{n} X_i \tag{8}$$

$G_i^*(d)$ must be standardized for comparative analysis.

$$Z\ (G_i^*) = \frac{G_i^* - E(G_i^*)}{\sqrt{var(G_i^*)}} \tag{9}$$

$Var(G_i^*)$ and $E(G_i^*)$ are variances and mathematical expectations of G_i^*, respectively. If $Z(G_i^*)$ is positive and statistically significant, it indicates that the value around i in this area is relatively high. That is, the agglomeration distribution of high value space is a hot spot; otherwise, it is a cold spot. X_i is the HQDI-M of i province. W_{ij} is the spatial weight matrix, the value of which is 0 if it is spatially nonadjacent. Otherwise, it is 1.

2.3. Data Sources

The research period of this paper is from 2007 to 2017, and the subjects are 30 provinces in China, excluding Tibet, Hong Kong, Macau, and Taiwan due to the availability of data. The original data are from the *China Statistical Yearbook*, *China Industrial Economic Statistics Yearbook*, *China Science and Technology Statistics Yearbook*, *China Tax Statistics Yearbook*, *Statistical Yearbook of Scientific and Technological Activities of Industrial Enterprises*, *China Environmental Statistics Yearbook*, *China Energy Statistics Yearbook*, *China Business Statistical Yearbook*, and statistical bulletins of various provinces from 2007 to 2018.

3. Results and Discussions

According to the classical paradigm of economic geography research, this section performs multiangle and all-round empirical analysis of the level of high-quality development of the manufacturing industry from static and dynamic time and space perspectives, including static spatial distribution characteristics, dynamic spatiotemporal evolution characteristics. In the meantime—based on the first law of geography—everything is interrelated, and the closer things are, the easier it is to communicate through the flow of people and information. Thus, this section also tries to analyze the hot spots and cold spots of high-quality development of the manufacturing industry from the perspective of spatial relevance.

3.1. Temporal Variation Characteristics

Firstly, the overall level of high-quality development of the manufacturing industry has steadily improved, showing a fluctuating trend of rising first, then falling, and then rising (Figure 2). HQDI-M was 0.6994 in 2007 and 0.9649 in 2017 with an average annual growth rate of 3.27%. The periods with higher growth rates were 2012–2013 and 2015–2016. The growth rate in 2012–2013 was 6.05%. The main reason is that many significant events related to manufacturing quality occurred during this period. For example, in 2012, the Ministry of Industry and Information Technology and other four ministries jointly issued the *Catalogue of Guidance for Independent Innovation of Major Technical Equipment* and the 12th Five-Year Plan for the Development of the High-end Equipment Manufacturing Industry, which accelerated the development of the manufacturing industry to a certain extent and injected new impetus into the next stage of development. The growth rate from 2015 to 2016 was 8.87%, much higher than that in other years, mainly because the State Council issued "Made in China 2025" in May 2015 to comprehensively promote the implementation of the strategy of manufacturing power. In summary, the promotion of high-quality development of the manufacturing industry is obvious, but there is still much room for improvement.

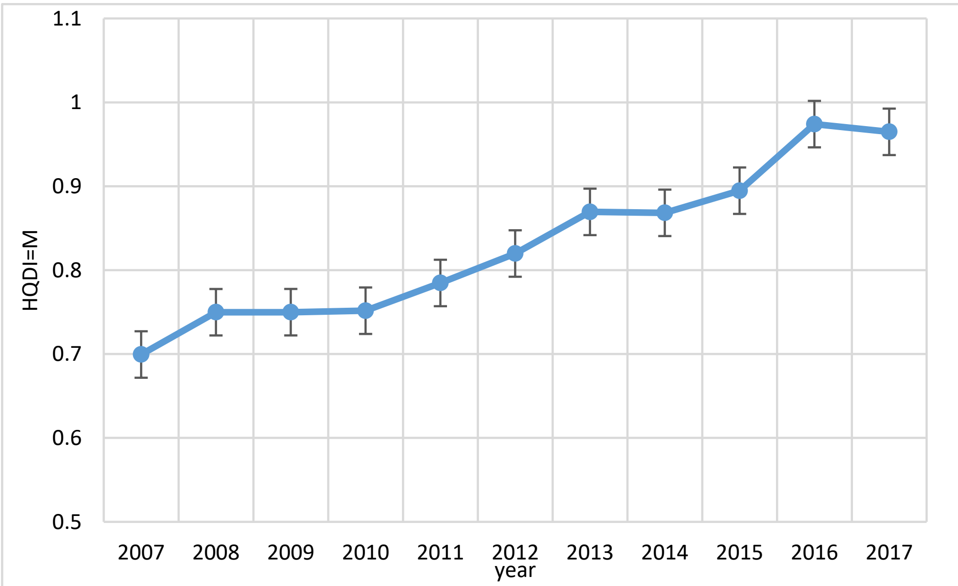

Figure 2. The HQDI-M from 2007 to 2017 in China.

Secondly, this paper calculates the average value of HQDI-M subsystem indicators from 2007 to 2017 and selects 2007, 2010, 2013, and 2017 as time breakpoints to draw radar charts (Figure 3). From 2007 to 2017, the subsystem indicator of HQDI-M varies greatly and can be generally divided into three types: growth subsystem, flat subsystem, and attenuation subsystem.

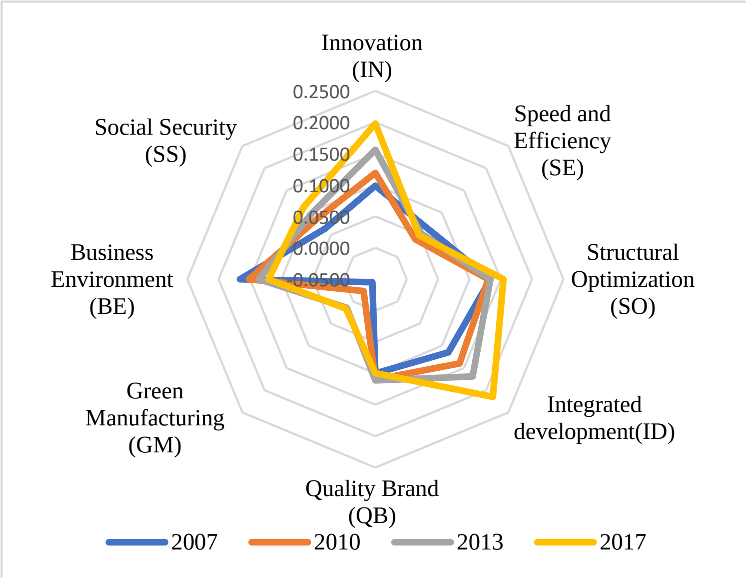

Figure 3. Subsystem indicator of HQDI-M from 2007 to 2017.

Growth subsystems, which included innovation (IN), integrated development (ID), green manufacturing (GM), social security (SS), and structural optimization (SO), grew rapidly or steadily from 2007 to 2017, and the growth rate was IN > ID > GM > SS > SO. IN is constantly increasing. The evaluation value increased from 0.0989 in 2007 to 0.198 in 2017, which played an important role in promoting the high-quality development of the manufacturing industry. (1) From the perspective of breakdown indicators, the four indicators of IN all show an increasing trend. The innovation environment plays a leading role, but the growth is slow. Innovation output grew the fastest thanks to the continuous investment of R&D personnel and R&D funds in the manufacturing industry. It is worth noting that in terms of innovation investment, R&D personnel investment is much higher than R&D expenditure investment, which must be increased, especially in basic research. (2) The ID evaluation value increased from 0.115 in 2007 to 0.215 in 2017, and the growth rate accelerated year by year, indicating that integration is entering a new stage of deepening application, reform, and transformation. (3) The evaluation value of GM increases from −0.043 to 0.0164, which indicates that the manufacturing industry pays more and more attention to environmental protection. Specifically, the steady development of green manufacturing has benefited from the continuous improvement of environmental quality and resource utilization, while the investment in industrial environmental governance has decreased in recent years. (4) SS was further improved. Wages in the manufacturing sector continue to grow rapidly according to the breakdown. In contrast, the employment absorption and tax contribution of the manufacturing industry are basically stable. With the deepening of aging and the reduction of young labor force, it may affect the supply and demand structure of the labor market, labor mobility, and labor participation rate, thus reducing the social security capacity of the manufacturing industry. (5) SO sees a steady rise, in which product structure plays a leading role. In contrast, the industrial structure and enterprise structure are relatively stable, and the export structure is slightly optimized.

Flat subsystem. The values of such indicators are basically stable or fluctuate slightly. The overall change in speed efficiency (SE) is small. Except for the improvement of labor productivity, other indicators are relatively stable or show a downward trend. The evaluation value of quality and brand (QB) dropped from 0.1 in 2007 to 0.09 in 2017. The brand construction of China's manufacturing industry still lags behind.

Attenuation subsystem. Business environment (BE) decreased from 0.166 in 2007 to 0.12 in 2017. The investment environment and legal environment are relatively stable, but the proportion of foreign-invested industrial enterprises and private enterprises continues to decline, indicating that the market environment must be further optimized.

3.2. Spatial Distribution Characteristics

In this paper, the average value of HQDI-M from 2007 to 2017 was calculated and divided into five grades using the natural breakpoint method (Figure 4). Like clustering, the natural breakpoint method maximizes the similarity within each group and the dissimilarity between groups. Its advantage over clustering is that it makes the range and number of elements in each group as close as possible [47]. The results show that the distribution is consistent with the "Hu Huanyong Line", and the spatial imbalance is significant. According to specific statistics, the high-quality development level of the manufacturing industry in nine provinces (High Quality Areas, Medium-High Quality Areas) is higher than the average level (0.82967), while that in 21 provinces (Medium Quality Areas, Medium-Low Quality Areas, Low Quality Areas) is lower; that is, 70% of the provinces are lower than the average level, and most of them are distributed on the west side of the "Hu Huanyong Line" with significant spatial imbalance.

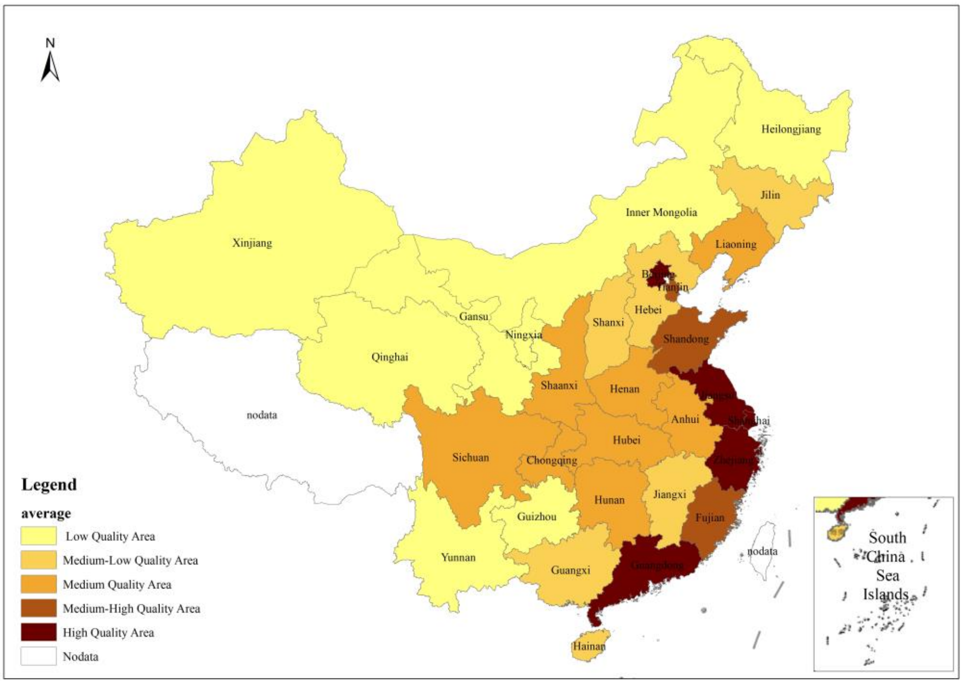

Figure 4. Spatial distribution of HQDI-M over the past 11 years.

In order to further explore the performance of each province in the subdivision dimension, the average value of HQDI-M from 2007 to 2017 was calculated and divided into five grades by natural breakpoint method.

- High Quality Areas include Jiangsu (1.50050), Shanghai (1.45101), Zhejiang (1.45016), Guangdong (1.43349), and Beijing (1.41999). The performance of these five provinces in green manufacturing, speed efficiency, and social security is relatively balanced. In terms of business environment, Jiangsu and Zhejiang are the best, followed by Shanghai and Guangdong. Due to the relevant policies restricting the general manufacturing industry and the high comprehensive cost in recent years, Beijing's overall performance is poor, but it has performed well in integration development, innovation development, and structural optimization. Zhejiang ranks first in brand building, followed by Jiangsu and Beijing.
- Medium-High Quality Areas include Tianjin (1.25390), Shandong (1.09084), Fujian (1.00381) and Chongqing (0.88740). Tianjin has performed well in all aspects. Shan-

dong's brand building is the best, but the problems of structural optimization and integrated development are prominent. Chongqing has a high level of structural optimization and integrated development, but green manufacturing and business environment must be further optimized.

- Medium Quality Areas include Hubei (0.82264), Anhui (0.82220), Sichuan (0.81549), Liaoning (0.80384), Henan (0.75833), Hunan (0.75158), and Shaanxi (0.73955). The development of all aspects in Hubei is relatively balanced, and there are no obvious shortcomings. Anhui, Sichuan, and Liaoning are in the leading positions in innovation, structural optimization, and business environment, respectively. However, the problem of structural optimization in Liaoning is more serious. For Hunan and Shaanxi provinces, it is necessary to further optimize their business environment; Shaanxi in particular must further strengthen its brand building.
- Medium-Low Quality Areas include Hebei (0.72391), Jiangxi (0.71087), Jilin (0.68196), Hainan (0.65600), Guangxi (0.59409), and Shanxi (0.59360). Hebei's brand building is good, but there are some shortcomings in speed benefit, structure optimization, and green manufacturing. The business environment of Jiangxi and Jilin is better, but the structural optimization of Jilin is prominent. Shanxi has a good integration of development and structural optimization.
- Low Quality Areas include Guizhou (0.55103), Inner Mongolia (0.52601), Yunnan (0.51699), Heilongjiang (0.51409), Qinghai (0.46165), Ningxia (0.45561), Gansu (0.45113), and Xinjiang (0.44855). The shortcomings of Guizhou, Heilongjiang, and Yunnan are business environment, speed and efficiency, and integrated development. Ningxia's business environment is relatively good, but its performance in speed and efficiency and green manufacturing is poor. Gansu's speed and efficiency and comprehensive development levels must be further improved.

3.3. Spatial Evolution Characteristics

This paper selects HQDI-M in 2007, 2010, 2013, and 2017 and draws the corresponding nuclear density distribution map (Figure 5) to reflect the overall evolution characteristics of the high-quality development of China's manufacturing industry.

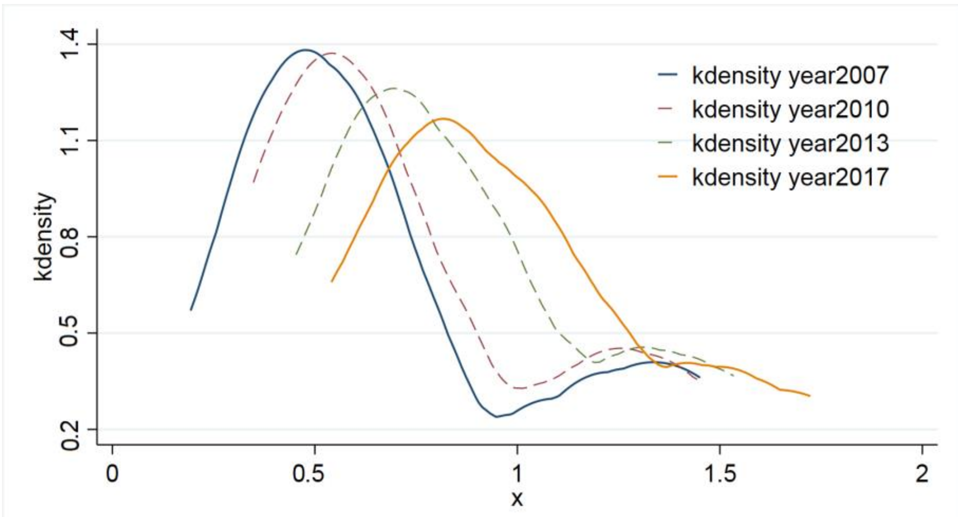

Figure 5. Nuclear density curve of HQDI-M in 2007, 2010, 2013, and 2017.

From the perspective of location, the nuclear density curve of HQDI-M from 2007 to 2017 has been shifted to the right as a whole, indicating that the level of high-quality development of the manufacturing industry has been steadily improved. The area of the low value region decreases, and the area of the high value region increases, indicating that the overall HQDI-M shows a steady upward trend, which is consistent with the previous analysis results. In terms of kurtosis, the nuclear density curve changes from a narrow peak to a broad peak, and the kurtosis decreases continuously, indicating that the spatial non-equilibrium increases. The right drag phenomenon shows that the high-quality development of the manufacturing industry in some provinces has been significantly improved. From the shape, the nuclear density curve of HQDI-M shows a "bimodal" distribution, the peak value of the main wave decreases obviously, and the secondary wave decreases slightly, indicating that there may be cold and hot spots. That is to say, provinces are spatially dependent and accompanied by spatial spillover benefits.

In order to further explore the dynamic evolution process of high-quality development of interprovincial manufacturing, this paper draws the distribution map of HQDI-M in 2007, 2010, 2013, and 2017 (Figure 6).

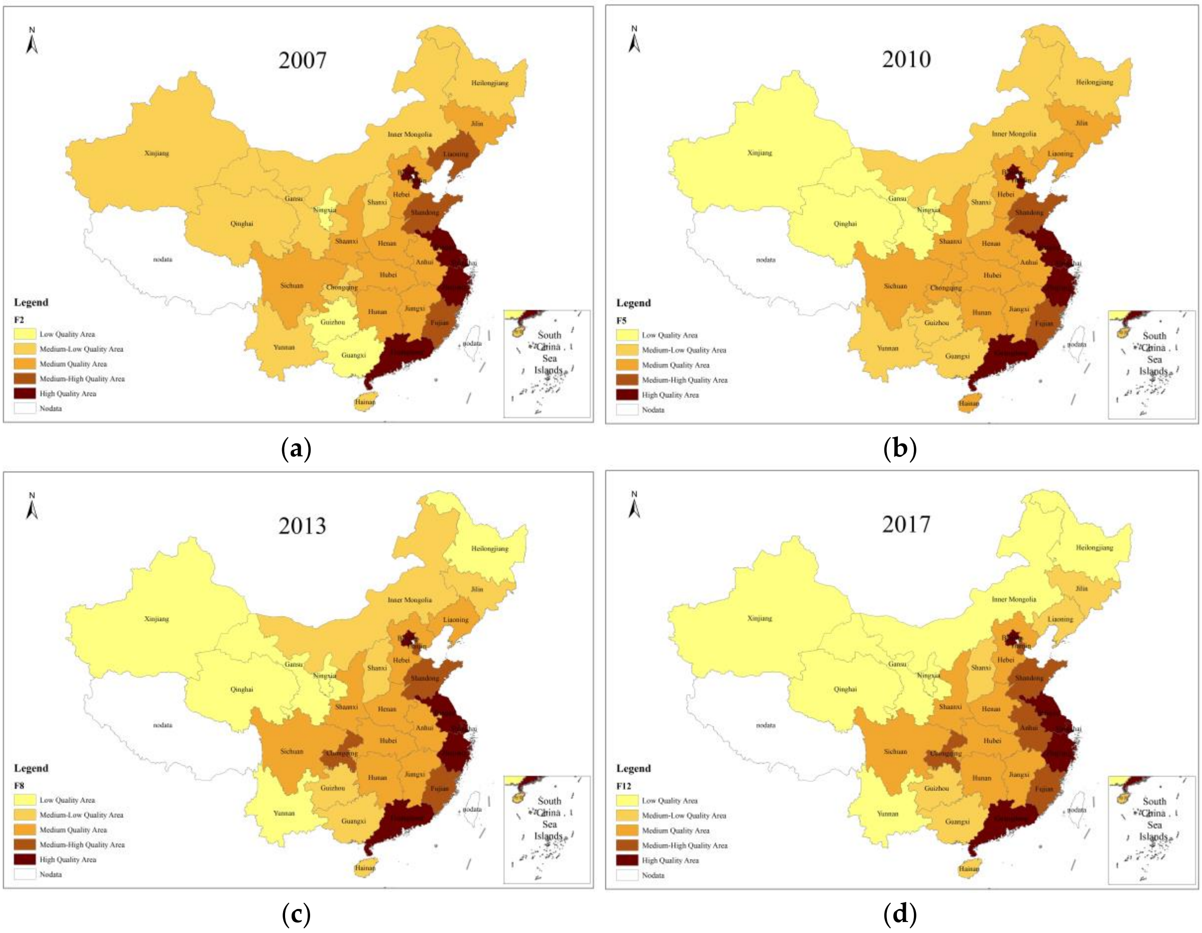

Figure 6. Spatial Evolution of HQDI-M (**a**) 2007; (**b**) 2010; (**c**) 2013; (**d**) 2017.

In 2007, the high-quality development of the manufacturing industry showed the characteristics of gradient decline from coastal to inland. Six High Quality Areas are distributed in coastal areas, mainly in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei urban agglomeration. The level from high to low is Guangdong, Beijing, Shanghai, Jiangsu, Tianjin, and Zhejiang. There are three Medium-High Quality Areas, namely Shandong, Fujian, and Liaoning. There are 18 Medium Quality Areas and Medium-Low Quality Areas (accounting for 60%), which are mainly distributed in the central and western regions.

In 2010, High Quality Areas had no change except for their ranking, which is Shanghai, Jiangsu, Beijing, Zhejiang, Guangdong, and Tianjin. The Yangtze River Delta improved significantly, while Beijing-Tianjin-Hebei declined slightly. The Medium-High Quality Areas were reduced to two (Shandong and Fujian), and Liaoning was relegated to Medium Quality Areas. The most obvious changes are the Medium-Low Quality Areas and Low-Quality Areas, among which Xinjiang, Gansu, and Qinghai have retreated to Low Quality Areas, forming a "western lowland". In contrast, Guizhou and Guangxi have been upgraded to Medium-Low Quality Areas.

In 2013, the number of High-Quality Areas decreased to five (Jiangsu, Zhejiang, Guangdong, Shanghai, and Beijing), and Tianjin fell back to being a Medium-High Quality Area. It can be seen that the development momentum of the Yangtze River Delta is still strong, but the decline in Beijing and Tianjin is relatively obvious. In the Medium-High Quality Areas, the development level from high to low is Tianjin, Shandong, Chongqing, Fujian. Of particular note is Chongqing, which has a faster development speed. It is worth noting that the high-quality development level of Jilin and Heilongjiang in Northeast China has relatively declined and they have returned to being Medium-Low Quality Areas and Low-Quality Areas, respectively.

In 2017, the spatial imbalance of HQDI-M increased, showing a pattern of "north–south differentiation". There was no significant change in High Quality Areas. The number of Medium-High Quality Areas has increased to five, namely Chongqing, Tianjin, Shandong, Anhui, and Fujian. Chongqing continues to develop at a high speed, once surpassing Tianjin and Shandong and occupying first place. In the future, Anhui will make great strides forward and usher in sustained and rapid development. Low Quality Areas increased significantly, and most of them were concentrated in the north. It can be seen that the differentiation between the north and the south is prominent.

3.4. Spatial Correlation Characteristics

The first law of geography points out that everything is interrelated, and the closer things are, the easier it is to communicate through the flow of people, logistics, and information. Is there spatial correlation and agglomeration in the high-quality development of manufacturing industry in each province? What kind of regularity does it show? To explore this issue, this paper calculated the Global Moran 'I using ARCGIS (Table 2). The Global Moran 'I is positive and significant, which meets the requirements of a z-value test, indicating that there is a significant positive spatial correlation and the agglomeration phenomenon of manufacturing industry development is prominent and spatial dependence is enhanced.

Table 2. Global Moran' I of HQDI-M from 2007 to 2017.

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Moran I	0.213	0.232	0.214	0.225	0.223	0.185	0.198	0.189	0.203	0.204	0.187
E(I)	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345	−0.0345
(I)	3.3003	3.5448	3.3076	3.4431	3.4054	2.9124	3.0829	2.9729	3.1552	3.1689	2.9315
p value	0.00096	0.00039	0.00094	0.00057	0.00066	0.00358	0.00204	0.0029	0.0016	0.00153	0.00337

Global spatial autocorrelation is used to analyze whether there are clustering characteristics in the whole spatial range of geographic data. However, it cannot accurately point out the specific clustering area, and the instability of local state will be ignored, so it is necessary to detect and analyze the specific clustering area and its changing trend. According to the significance levels of the indicators, the different regions are divided into six types: Core Cold Spot, Sub-Core Cold Spot, Edge Cold Spot, Edge Hot Spot, Sub-Core Hot Spot and Core Hot Spot (Figure 7).

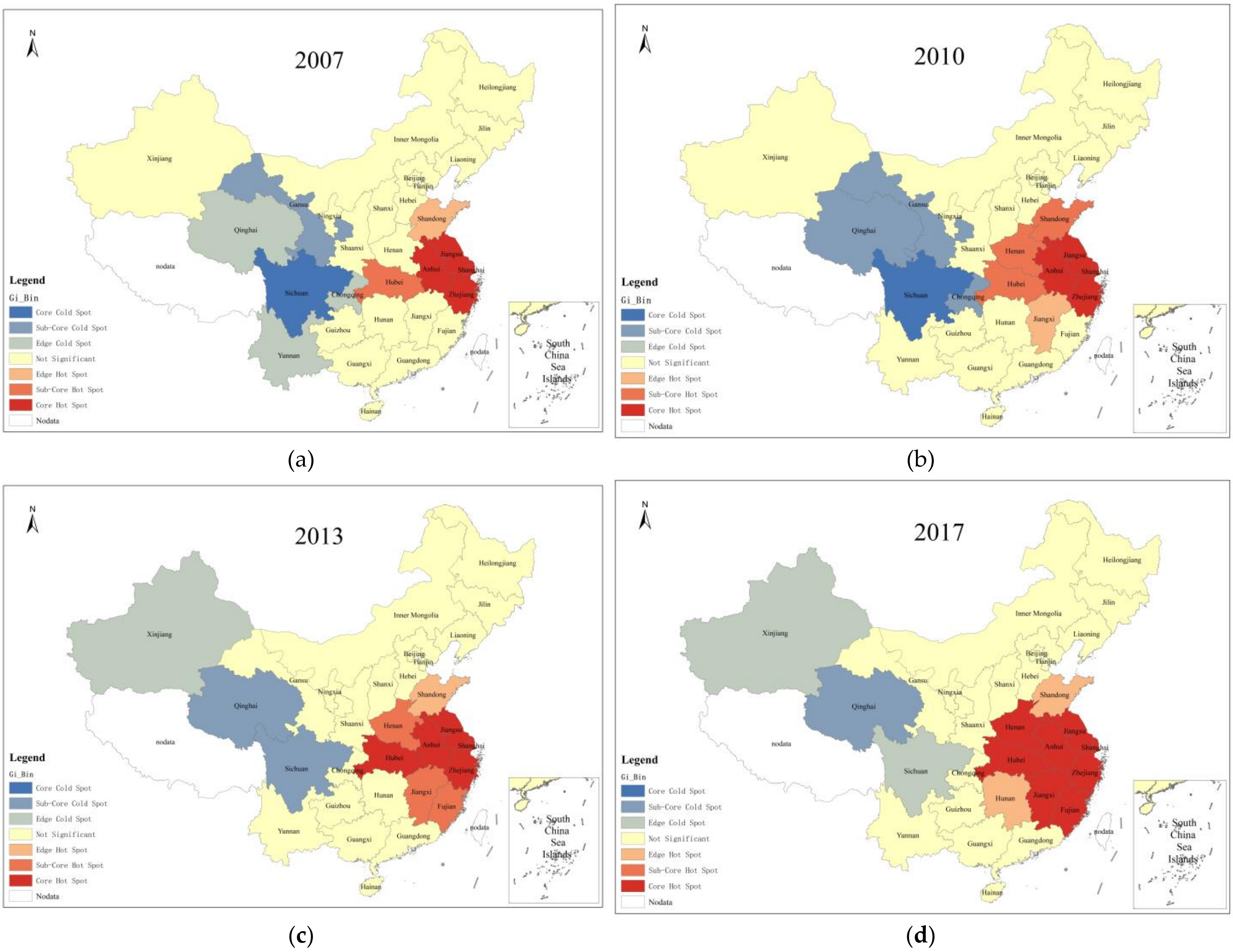

Figure 7. Spatiotemporal evolution pattern of cold and hot spots (**a**) 2007; (**b**) 2010; (**c**) 2013; (**d**) 2017.

Judging from the overall distribution of cold and hot spots, two different agglomeration areas are formed in space: one is the "low-low" cold spots composed of Xinjiang, Qinghai, Gansu, and Sichuan, which are located in the remote west, with vast territory and sparse population. At the same time, the development of industrialization is relatively slow and lacks the motive force of innovation. The other is the "high-high" hot spots composed of Zhejiang, Jiangsu, Fujian, Anhui, and Hubei, which are mainly distributed along the southeast coast and spread outward with the Yangtze River Delta urban agglomeration as the core.

In terms of quantity change, the number of hot spots has increased rapidly from five provinces to 10 provinces, and the diffusion effect has gradually increased; in particular, the Core Hot Spot has increased from four provinces to eight provinces, indicating that the spatial spillover effect of manufacturing development has gradually enhanced. The number of cold spots has steadily decreased from five provinces in 2007 to three provinces in 2017, indicating that the overall development of the manufacturing industry has improved.

From the perspective of the spatial evolution of cold and hot spots, the diffusion direction of hot spots has changed from "coastal–inland" to "north–south". In addition to Jiangsu, Zhejiang, and Shanghai, Anhui has been in the Core Hot Spot for 11 consecutive years, and its HQDI-M has continuously improved not only due to the continuous improvement of its innovation level, but also due to the radiation effect of Jiangsu and Zhejiang. In 2013, the development of Hubei entered the Core Hot Spot. Especially after the Eleventh

Five-Year Plan, Hubei has resolutely implemented the policy of "revitalizing the province by industry". The development of the manufacturing industry has showed a good trend of improving quality and optimizing structure. In 2017, Henan, Fujian, and Jiangxi gradually evolved into Core Hot Spots, which will continue to move southward and westward in the future, and the spatial spillover effect will be gradually enhanced. Instead, the cold spot continues to move northward. Yunnan and Chongqing have withdrawn from the cold spot one after another, especially Chongqing, which has jumped from 19th to 6th in the past 11 years mainly because of the rapid development of the manufacturing industry and the continuous optimization of business environment in recent years. In addition, Sichuan has gradually withdrawn from the Sub-Core Cold Spot to the Edge Cold Spot, and the high-quality development of the manufacturing industry has steadily improved. It is expected to gradually withdraw from the cold zone in the future.

3.5. Futher Discussion

Heterogeneity of Subsystem indicators. The subsystem indicators of HQDI-M are divided into three types: growth subsystem, flat subsystem and attenuation subsystem. Three indicators in particular require more attention, which include innovation, brand quality and business environment. In terms of innovation, R&D expenditure, especially in basic research, must still be strengthened. Basic research is the foundation of promoting the subversive development of science and technology. China's manufacturing industry has achieved remarkable results in terms of scale and complexity, but due to the neglect of investment in basic research, China's original achievements must be strengthened. Meanwhile, the brand construction of China's manufacturing industry is still lagging behind, and there is a contradiction between the large number of brands and low market awareness as well as the problems of low added value and weak competitiveness.

Business environment, as the main component of institutional quality, can affect the status of the global value chain. Good business environment has more convenient procedures, open supervision, and efficient services, which will help enterprises to improve their technological level, expand the volume of international trade, and enhance the international competitiveness of the manufacturing industry, while a poor business environment will bring pressure to the development of enterprises. Creating a stable, fair, transparent, legalized, and predictable business environment is still the primary task of fostering new competitive advantages in attracting foreign investment and accelerating the high-quality development of the manufacturing industry.

Uncoordinated development among provinces. Distribution is consistent with the "Hu Huanyong Line", and the spatial imbalance is significant. The phenomenon of agglomeration has become increasingly prominent; high-quality areas are mainly concentrated in three major urban agglomerations and coastal provinces, while low-quality areas are mainly distributed in Inner Mongolia, Xinjiang, and other northwest regions. By analyzing the reasons, it is found that the development speed in the north, such as in Beijing and Tianjin, has slowed down. This is especially true in Tianjin, where the brain drain is serious and the level of human capital has declined in recent years, while southern provinces like Chongqing and Anhui, as "rising stars", have developed rapidly with continuous improvement of business environment and innovation. In the meantime, the center of mass gradually moves southward, gradually evolving from the gradient difference between east and west to the differentiation between north and south. That is to say, China's regional pattern has changed from the east–west gap to the north–south gap. The southern provinces will play an increasingly important role in leading the high-quality development of the manufacturing industry in the future, and Jiangsu, Zhejiang, Shanghai, and Guangdong will continue to occupy the "highland". In order to narrow the gap with the south, more attention is needed to focus on innovation, brand building, and business environment to improve the high-quality development level of the manufacturing industry in the north so as to promote regional coordinated development.

Club-convergence of HQDI-M. In terms of spatial distribution, provinces with similar performance are significantly concentrated on the map, which presents that the diffusion direction of hot spots has changed from "coastal–inland" to "north–south". Furthermore, the spatiotemporal dynamic evolution demonstrates an obvious club convergence phenomenon in which the hot spot is centered on the Yangtze River Delta and the cold spot is centered on the northwest. Geographical proximity plays a vital role in social economic development. Additionally, spatial agglomeration has become a significant feature of economic development within a given area by promoting knowledge spillover. An explanation for the club convergence of HQDI-M might be that the similar economic structure in the neighboring cities accelerates the frequent flow of production factors and that a set of similar economic policies has been adopted by different local governments for socioeconomic development. Therefore, the adjacent cities illustrate a clustering phenomenon. The club convergence of HQDI-M is likely to be related to the construction of digital economy. That is, the south and coastal provinces, with better digital infrastructure and policy support, are conducive to attracting highly skilled labor and capital from the surrounding provinces.

4. Conclusions and Recommendations

4.1. Conclusions

This paper constructs a comprehensive and systematic indicator system from eight dimensions to measure the HQDI-M of 30 provinces in China from 2007 to 2017 and analyzes its spatiotemporal evolution and spatial correlation characteristics. The main conclusions of this study are as follows: Firstly, the high-quality development level of the manufacturing industry has steadily improved from 2007 to 2017, and the growth rate was faster in 2012 and 2015. The change characteristics of subsystems can be divided into three types (growth type, flat type, and attenuation type), and business environment and innovation are the main factors restricting the development of the manufacturing industry at present and in the future. Thus, the business environment should be further optimized in the future to stimulate market vitality. Secondly, the spatial distribution of high-quality development of the manufacturing industry is highly consistent with the "Hu Huanyong Line", generally showing a distribution pattern of decreasing gradient from southeast to northwest, with great differences among provinces, 70% of which are below the average level and distributed on the left side of the "Hu Huanyong Line". That is to say, the spatial imbalance is significant, and the advantages and disadvantages of different provinces are not the same. Thirdly, the high-quality development of manufacturing has evolved from "spatial relative equilibrium" to "spatial disequilibrium", and its centroid has gradually shifted southward. That is, from the gradient difference between east and west to the differentiation between north and south. Jiangsu, Zhejiang, Shanghai, and Guangdong will continue to occupy the "high ground", while the leading role of Beijing and Tianjin will continue to weaken. Chongqing and Anhui, as "rising stars", have developed rapidly. HQDI-M levels in the northeast will continue to decline. Finally, there is an obvious positive spatial correlation in the high-quality development of the manufacturing industry. The hot spots with the Yangtze River Delta as the core are developing actively and spreading outward in a circular manner. The spillover effects of Anhui, Chongqing, Hubei, Henan, and Fujian have gradually increased, forming a "new highland". In contrast, the development of the cold spot is relatively slow, moving gradually from south to north.

4.2. Recommendations

At this stage, attention should be paid to the leading role of high-quality development in the manufacturing industry and bid farewell to "inertial thinking". For scholars and policy advisers, it is necessary to keep pace with the times in theory and methods and to shift from traditional "rapid growth" economic theory to new "high-quality" methods and practices. Special attention should be paid to the interdisciplinary integration of this field.

In addition, different regions should plan the future development direction of the manufacturing industry according to their constraints and development advantages. (1) At the national level, innovation and business environment have gradually become the most prominent problems affecting the high-quality development of the manufacturing industry. The improvement of innovation ability should be placed in a more important position so as to play its leading role in economic development. In the meantime, business environment should be further optimized to strengthen regional sharing. (2) At the regional level, the key to narrowing the gap is to strengthen the integrity implementation of innovation strategy. The focus of the work in the western region is to continue to optimize the layout of the industrial structure, develop resource-based industries, and at the same time strengthen the prospective layout of advanced manufacturing industries to promote advanced development of the industrial structure. For northeast China, the institutional environment should be further optimized and the relationship between the government and the market should be straightened out to ensure a fair and efficient market environment. At the same time, it is of great importance to pay attention to the accumulation of human capital so as to jointly promote the balanced development of the manufacturing industry.

Finally, provincial synergy optimization should be actively implemented from a global perspective to enhance the geographical diffusion effect. Based on the fact that the distribution of high-quality development level of manufacturing industry is highly consistent with the “Hu Huanyong Line”, all sectors of society must pay more attention to the “Botai Line” perpendicular to the “Hu Huanyong Line”. It is an important demarcation line to promote the coordinated development of east and west and north and south, and it can effectively solve the problem of insufficient imbalance. At the national level, it is necessary to formulate a policy of coordination and linkage along the line and fully release the multiple potential functions of the “Botai Line” through various methods, such as spatial spillover of innovative achievements, interactive exchange of resource allocation, and experience sharing of market mechanisms so as to actively explore new ways to break through Hu Huanyong Line and narrow the gap of high-quality development of the manufacturing industry.

Due to the limitations of the research scope, length, and data availability, this study still must be improved. The spatial characteristics of high-quality development of the manufacturing industry can be explored from a smaller scale, such as the scale of cities and counties, so as to put forward more region-specific policy recommendations. Additionally, in view of the fact that the spatial imbalance of the manufacturing industry is significant, it is urgent for us to explore the influencing factors and the theoretical mechanism behind it. These studies can not only provide reference for economic development, but also provide policy reference for the coordinated development of regions.

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