

## Research Article

# Analysis of the Coupling Coordination and Spatiotemporal Evolution of High-Tech Industrial Technological Innovation and Regional Economic Development

Xu-Mei Yuan , Fu-Li Wei , Hui Li , and Ying An 

*School of Economics and Management, Yanshan University, Qinhuangdao, Hebei, China*

Correspondence should be addressed to Fu-Li Wei; [weifuli0317@163.com](mailto:weifuli0317@163.com)

Received 28 May 2022; Revised 8 August 2022; Accepted 22 August 2022; Published 28 September 2022

Academic Editor: Hassan Zargarzadeh

Copyright © 2022 Xu-Mei Yuan et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Improving the coordination between technological innovation in high-tech industries and regional economic development is an important measure for all provinces (cities) to implement the innovation-driven development strategy. Based on the analysis of the mechanism of high-tech industrial technological innovation and regional economic development, this paper constructs the measurement index system of high-tech industrial technological innovation and regional economic development, and the chain network DEA model, entropy weight method, coupling coordination model, and exploratory spatial data analysis technology are comprehensively used to empirically analyze the technological innovation efficiency of high-tech industries, regional economic development level, and the coupling coordination relationship between them and the spatiotemporal evolution trend in 24 provinces (cities) of China from 2009 to 2018. The results show that (1) there are significant differences in the average level of technological innovation efficiency of high-tech industry in each stage, which is the most prominent in the technology research and development stage, followed by the industrialization stage, and finally in the technology transformation stage. (2) The degree of coupling and coordination between high-tech industrial technological innovation and regional economic development is increasing year by year, which is in the adaptation stage of high-tech industrial technological innovation and regional economic development. (3) From the perspective of spatial pattern, there is a positive spatial autocorrelation between the coupling coordination degree of high-tech industrial technological innovation and regional economic development. The number of provinces (cities) with low coupling coordination degree is much larger than that with high coupling coordination degree, showing a serious imbalance of regional heterogeneity and forming two spatial aggregation areas of “high-high” diffusion effect and “low-low” low-speed growth.

## 1. Introduction

Under the new normal, China's economic growth is at a critical stage of transformation from being driven by factors of production and investment to being driven by innovation, and innovation has become a new engine driving development. The 19th National Congress of the Communist Party of China (CPC) made an important judgment on China's economic development that “it has shifted from a stage of high-speed growth to a stage of high-quality development,” and promoting high-quality economic development has become an important strategy for China's development in the new era. High-tech industry is an

important front of economic and technological competition; its technological innovation activities promote the upgrading of industrial structure, improve labor productivity and economic development quality, and have an irreplaceable role. In this context, how to coordinate the development of high-tech industrial technological innovation and regional economy has become an urgent problem to be answered.

Joseph first put forward the theoretical view of innovation in 1912, insisting that technological innovation is the driving force and source of economic growth [1]. In the early 1990s, Romer proposed that technological progress brought by technological innovation is an endogenous variable to

promote economic growth [2]. Later, a number of scholars conducted empirical studies on the impact of technological innovation on economic development. For example, Torres-Preciado et al. used spatial data analysis to empirically analyze the impact of technological innovation on regional economic growth in Mexico during 1995–2007 and found that technological innovation had a positive impact on regional economic growth [3]. Adak used econometric methods to study and found that technological progress and innovation have a significant impact on Turkey's economic growth [4]. Koshovets and Ganichev took the Russian high-tech industry as the research object and concluded that the technology development capacity of the high-tech industry plays an important role in promoting international market development and productivity increase [5]. Chen et al. found that the impact of technological innovation on urban green development in China's Yellow River Basin is spatially heterogeneous [6].

In China, relevant researches mainly focus on the impact of technological innovation on regional economic development and the interaction between technological innovation and regional economic development. On the one hand, in terms of the impact of technological innovation on regional economic development, many literature mainly discuss that technological innovation can promote regional economic development. For example, Xiong and Wang used principal component analysis to measure the comprehensive index of high-quality economic development of 30 provinces in China from 2003 to 2016 and found that technological innovation has a significant positive role in promoting China's high-quality economic development [7]. Wang et al. studied the impact of technological innovation on regional economic development in Jiangsu province by constructing a CES function model considering the impact of cumulative patents [8]. Liu and Zhang found that regional economic growth is directly proportional to China's scientific and technological innovation and government investment in science and technology [9]. Zhang explored the mechanism of technological innovation on economic growth by constructing a spatial econometric model and found that innovation spillover would have a positive impact on the provincial economy through the spillover effect [10]. Ma et al. studied the effect of technological innovation in high-tech industries on high-quality economic development and found that in a low system, the effect of technological innovation efficiency in high-tech industries on the quality of economic development is promoting [11]. Liang and Yu, based on Chinese provincial panel data from 2009 to 2018, using the spatial econometric model, empirical analysis, and the different effect of technology innovation mode of regional economic development, found the technology innovation and regional economic development have significant spatial correlation and technology transfer, imitation innovation, and independent innovation have a positive role in promoting the regional economy development. Among them, independent innovation is the most significant [12]. On the other hand, as far as the interaction between technological innovation and regional economic development is concerned, most literature mainly focus on

empirical research. For example, Zong and Gao made an empirical analysis of the endogenous relationship between regional economic growth and technological innovation based on the panel data of 30 provinces in China from 2003 to 2014 and found that there was an inverted U-shaped relationship between the effect of technological innovation on economic growth and an inverted J-shaped relationship between the impact of regional economic growth on technological innovation level [13]. Du and Hu conducted a quantitative test on the interaction between scientific and technological innovation and regional economic growth and found that the positive interaction between them only appeared in the eastern region, while the benign interaction did not appear in the central and western regions and northeast regions [14].

By combing the literature on technological innovation and regional economic development of domestic and foreign scholars, it is found that the existing literature provides a large number of empirical analyses to investigate the impact of technological innovation on regional economic development or the interaction between technological innovation and regional economic development. These research results provide a useful reference for this paper. At the same time, it is not difficult to find that there are still some deficiencies in the existing research on technological innovation and regional economic development. On the one hand, most of the studies focused on the one-way impact and more on the promotion of technological innovation to regional economic development. There is a lack of literature on the coordination between technological innovation and regional economic development. Taking high-tech industry as the research object, there are few studies to analyze the space-time evolution characteristics of the coordination between technological innovation of the high-tech industry and regional economic development. For example, Wang took the central provinces as an example to calculate the coupling coordination degree between technological innovation in the high-tech industry and regional economic development [15]. Liang et al. analyzed the synergistic effect between technological innovation in the high-tech industry and regional economy in China and found that GDP and R&D expenditure are the main factors affecting the coupling level of technological innovation in the high-tech industry and regional economy [16]. On the other hand, most of the existing literature use econometric methods, and the research methods lack diversity.

Therefore, based on the analysis of the mechanism of technological innovation in the high-tech industry and regional economic development, this paper constructs the measurement index system of technological innovation in the high-tech industry and regional economic development. The chain network DEA model, entropy weight method, coupling coordination model, and exploratory spatial data analysis technology are comprehensively used to empirically analyze the technological innovation efficiency of high-tech industries, regional economic development level, and the coupling coordination relationship between them, and the spatiotemporal evolution trend in China's provinces (cities) from 2009 to 2018 is of great significance for implementing

the innovation-driven development strategy and promoting high-quality economic development in China.

## 2. Mechanism of Technological Innovation in High-Tech Industry and Regional Economic Development

Coupling coordination refers to the overall synergistic effect generated by the coordination and interaction between two or more systems or motion forms that is larger than the independent operation of each subsystem [17]. The coupling relationship between technological innovation in the high-tech industry and regional economic development not only includes the promotion effect of technological innovation in the high-tech industry on regional economic development but also includes the supporting effect of the corresponding latter on the former in different ways. The interaction mechanism between technological innovation in the high-tech industry and regional economic development is as follows.

*2.1. Technological Innovation in High-Tech Industry Is the Core Driving Force of Regional Economic Development.* The innovation drive is the first driving force to lead the high-quality development of the economy. The high-tech industry with the characteristics of knowledge, technology-intensive, and strong permeability is an important field driven by innovation. Technological innovation in the high-tech industry is the key to promoting the high-quality development of the regional economy. On the one hand, technological innovation can promote the efficient transformation of technological achievements by improving the innovation efficiency of high-tech enterprises, so as to create better commercial value for the technology or products of high-tech enterprises, gain a larger market and realize regional economic growth. On the other hand, technological innovation in the high-tech industry promotes regional industrial agglomeration and forms a regional innovation network through knowledge spillover and technology diffusion effect, thus driving the optimization and upgrading of industrial structure and forming a new economic growth pole.

*2.2. Regional Economic Development Provides Strong Support for Technological Innovation in High-Tech Industry.* On the one hand, financial resources and intelligence are considered to be the two most important conditions for technological innovation in high-tech industries [18]. Regional economic development can provide rich R&D funds as a financial guarantee for technological innovation in the high-tech industry. Technological innovation in the high-tech industry is characterized by great difficulty and high risk. A large amount of R&D investment is the key to ensuring the smooth development of innovation activities. High-quality talents play a significant role in the process of technological innovation in the high-tech industry. The higher the level of regional economic development is, the more it can attract a large number of high-quality talents to gather, thus providing intellectual support for technological innovation in

high-tech industries. On the other hand, regional economic development can provide new market demand for technological innovation in the high-tech industry [16]. Regional economic development is beneficial to optimize the technological innovation environment of the high-tech industry and increase its domestic and international market demand. Regional economic development requires the optimization and upgrading of traditional industries, and the industrial structure is more reasonable and advanced. However, the optimization and upgrading of traditional industries cannot be separated from the technology diffusion and penetration of high-tech industries. Therefore, the optimization and upgrading of traditional industries also indirectly create more market demands for technological innovation in high-tech industries.

## 3. Study Design and Data Source

### 3.1. Construction of Three-Stage Technology Innovation of High-Tech Industry Indicator System

*3.1.1. Connotation and Process of Three-Stage Technological Innovation of High-Tech Industry.* Technological innovation is a continuous and gradual process that begins with technological invention and ends with the commercialization and industrialization of innovative achievements [19]. When the concept of technological innovation is applied to high-tech industry, the technological innovation process of high-tech industry refers to a series of complex economic activities of high-tech from research to development, from technology to production, and from product to market [20]. Therefore, based on the research results of relevant scholars [21], this paper divides the technological innovation process of the high-tech industry into three stages: technology research and development, technology transformation, and industrialization. Among them, the technology research and development stage is mainly to conduct technology research and development through R&D input and then in the form of patent and nonpatent technology as scientific and technological achievements output. The technology transformation stage mainly reflects the ability to transform the scientific research results generated in the technology research and development stage into technology and products. The stage of technological industrialization is a process in which the achievements in the technological transformation stage are transformed into productive forces, new products are produced, and finally, the new products enter the market so that enterprises adopting new products can obtain economic benefits. The three-stage technological innovation process of the high-tech industry is shown in Figure 1.

*3.1.2. Indicator System of Three-Stage Technological Innovation of High-Tech Industry.* Based on the analysis of input-output logic, this paper builds a three-stage indicator system of technological innovation in the high-tech industry by referring to scholars' evaluation research on technological innovation in the high-tech industry in recent years.

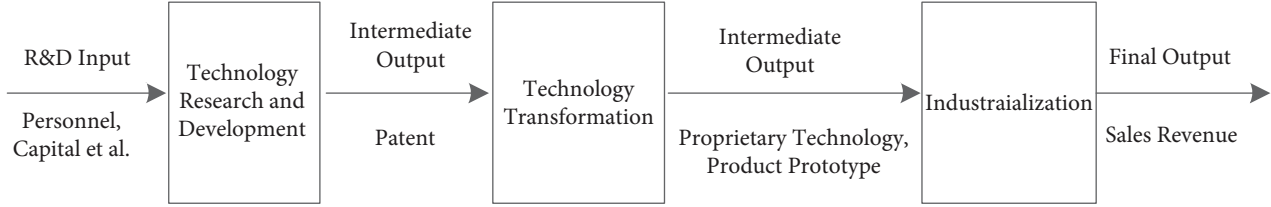


FIGURE 1: The three-stage technological innovation process of the high-tech industry.

TABLE 1: Indicator system of technology research and development stage.

Primary indicators	Secondary indicators	Tertiary indicators
The input in technology research and development	Personnel input	Number of R&D personnel for basic and applied research Full-time equivalent of R&D personnel for basic and applied research
	Capital input Technical input	Intramural expenditure on R&D for basic and applied research Number of inventions in force in the previous year
The output of technology research and development	R&D payoffs	Number of inventions in force for the year
		Number of new products

(1) *Indicator System of Technology Research and Development Stage.* R&D input consists of basic research input and applied research input in the technology research and development stage and experimental development research input in the technology transformation stage [22]. Therefore, the number of R&D personnel in basic research and applied research, the full-time equivalent of R&D personnel, and the intramural expenditure on R&D are taken as the personnel input and capital input in the technology research and development stage. Referring to the indicator system constructed by Liu et al. [21], the number of inventions in force in the previous year is taken as the technical input in the technology research and development stage. For the output indicator of this stage, the number of inventions in force and new products are selected as the patent indicator and the nonpatented technology indicator, respectively. The specific indicator system is shown in Table 1.

(2) *Indicator System of Technology Transformation Stage.* In this paper, the output of R&D payoffs, the number of R&D personnel, the full-time equivalent of R&D personnel, the intramural expenditure on R&D for experimental development, and the expenditure on new products development are selected as the technical input, personnel input, and capital input in the technology transformation stage. At the same time, the number of projects started for the year and the number of patents for utility models and designs are selected as the technical output indicator in the technology transformation stage. The specific indicator system is shown in Table 2.

(3) *Indicator System of Industrialization Stage.* In this paper, the technical output in the stage of technology transformation, the average number of net employed personnel, and the newly increased fixed assets are selected as the technical input, personnel input, and capital input in the stage of

industrialization, and the sales revenue of new products and delivery value of exports are selected as the profitability output indicators in the stage of industrialization. The specific indicator system is shown in Table 3.

3.2. *Indicator System of Regional Economic Development.* As for regional economic development, this paper refers to the research results of relevant scholars [16] and measures it from three aspects: basic economic level, economic construction input, and economic construction output, with a total of nine indicators. The indicator system is shown in Table 4, and related indicators are all positive indicators.

### 3.3. Research Methods

3.3.1. *Three-Stage Chain Network DEA Model with Additional Input.* The traditional DEA method regards the whole production system as a “black box” and only analyzes the input and output data, skipping the intermediate production link from input to output, so the impact of the efficiency of the middle part of the production process on the overall efficiency cannot be obtained. To solve this problem, Fare and Grosskopf put forward the concept of traditional network DEA in 1996. After that, relevant scholars at home and abroad have done a lot of research so that the theory and application of network DEA are constantly improved and developed.

Based on the research of relevant scholars [19], this paper builds a three-stage chain network DEA model with additional input and obtains the technological innovation efficiency of each decision-making unit, namely, the high-tech industry of each province (city). The chain network DEA model corresponding to the three-stage additional input in

TABLE 2: Indicator system of technology transformation stage.

Primary indicators	Secondary indicators	Tertiary indicators
The input in technology transformation	Technical input	Number of inventions in force for the year Number of new products
	Personnel input	Number of R&D personnel for experimental development Full-time equivalent of R&D personnel for experimental development
	Capital input	Intramural expenditure on R&D for experimental development Expenditure on new products development
The output of technological transformation	Technical output	Number of projects started for the year Number of patents for utility models and designs

TABLE 3: Indicator system of industrialization stage.

Primary indicators	Secondary indicators	Tertiary indicators
The input in industrialization	Technical input	Number of projects started for the year
	Personnel input	Number of patents for utility models and designs Average number of net employed personnel
	Capital input	Newly increased fixed assets
The output of industrialization	Profitable output	Sales revenue of new products Delivery value of exports

TABLE 4: Evaluation indicator system of regional economic development level.

Primary indicators	Secondary indicators	Tertiary indicators
Regional economic development level	Basic economic level	Household consumption expenditure Total retail sales of consumer goods Per capita disposable income of urban households
	Economic construction input	Total investment in fixed assets Foreign investment Governments expenditure
	Economic construction output	Per capita GDP Tax revenue Total value of exports

the three-stage technological innovation process of the high-tech industry is shown in Figure 2.

That is,

$$E_k = \max \frac{\sum_{r=1}^s u_r Y_{r,j}}{\sum_{i=1}^m v_i X_{i,j}}$$

$$E_k^{(1)} = \max \frac{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1}{\sum_{i=1}^{m_1} v_i X_{i,j}^1}$$

$$E_k^{(2)} = \max \frac{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2}{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1 + \sum_{i=1}^{m_2} v_i X_{i,j}^2}$$

$$E_k^{(3)} = \max \frac{\sum_{r=1}^s u_r Y_{r,j}}{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2 + \sum_{i=1}^{m_3} v_i X_{i,j}^3}$$

s.t.

$$\frac{\sum_{r=1}^s u_r Y_{r,j}}{\sum_{i=1}^m v_i X_{i,j}} \leq 1$$

$$\frac{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1}{\sum_{i=1}^{m_1} v_i X_{i,j}^1} \leq 1$$

$$\frac{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2}{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1 + \sum_{i=1}^{m_2} v_i X_{i,j}^2} \leq 1$$

$$\frac{\sum_{r=1}^s u_r Y_{r,j}}{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2 + \sum_{i=1}^{m_3} v_i X_{i,j}^3} \leq 1$$

$$v_i, w_{d1}^1, w_{d2}^2, u_r \geq 0 \forall i, d1, d2, r. \quad (1)$$

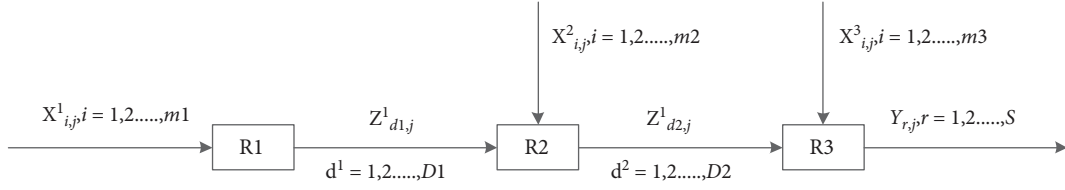


FIGURE 2: DEA model of three-stage chain network with additional input.

After Charnes–Cooper transformation, the linear programming model is

$$\begin{aligned}
 E_k &= \max \sum_{r=1}^s u_r Y_{r,j} \\
 E_k^{(1)} &= \max \frac{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1}{\sum_{i=1}^{m_1} v_i X_{i,j}^1} \\
 E_k^{(2)} &= \max \frac{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2}{\sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1 + \sum_{i=1}^{m_2} v_i X_{i,j}^2} \\
 E_k^{(3)} &= \max \frac{\sum_{r=1}^s u_r Y_{r,j}}{\sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2 + \sum_{i=1}^{m_3} v_i X_{i,j}^3} \\
 \text{s.t.} \\
 \sum_{i=1}^m v_i X_{i,j} &= 1 \\
 \sum_{r=1}^s u_r Y_{r,j} - \sum_{i=1}^m v_i X_{i,j} &\leq 0 \\
 \sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1 - \sum_{i=1}^{m_1} v_i X_{i,j}^1 &\leq 0 \\
 \sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2 - \sum_{d1=1}^{D1} w_{d1}^1 Z_{d1,j}^1 - \sum_{i=1}^{m_2} v_i X_{i,j}^2 &\leq 0 \\
 \sum_{r=1}^s u_r Y_{r,j} - \sum_{d2=1}^{D2} w_{d2}^2 Z_{d2,j}^2 - \sum_{i=1}^{m_3} v_i X_{i,j}^3 &\leq 0 \\
 v_i, w_{d1}^1, w_{d2}^2, u_r &\geq 0 \forall i, d1, d2, r.
 \end{aligned} \tag{2}$$

The model assumptions are as follows:

- (1) The number of DMUs is  $n$ , and each DMU has  $m$  types of inputs;  $d$  types of intermediate outputs; and  $s$  types of outputs.
- (2) Each DMU has the above three stages of R1, R2, and R3 and does not contain the ring structure
- (3) The  $i$ -th input of the  $j$ -th decision unit  $DMU_j$  in the R1 stage is  $X_{i,j}^1$ ; the  $i$ -th input in the R2 stage is  $X_{i,j}^2$ ; the  $i$ -th input in the R3 stage is  $X_{i,j}^3$ ; and the  $r$ -th output is  $Y_{r,j}$ .
- (4)  $Z_{d1,j}^1$  represents the  $d1$ -th intermediate output of  $DMU_j$  in the R1 stage, which is also part of the input in the R2 stage.  $Z_{d2,j}^2$  represents the  $d2$ -th

intermediate output of  $DMU_j$  in the  $R2$  stage, which is also part of the input in the  $R3$  stage.

- (5)  $v_i$  is the weight of the  $i$ -th input;  $w_{d1}^1$  and  $w_{d2}^2$  are, respectively, the weight of intermediate output of  $R1$  and  $R2$  stages; and  $u_r$  is the weight of the  $r$ -th output.  $E_k$ ,  $E_k^{(1)}$ ,  $E_k^{(2)}$ , and  $E_k^{(3)}$  are the comprehensive efficiency value and the efficiency value of  $R1$ ,  $R2$ , and  $R3$ , respectively.

**3.3.2. Entropy Weight Method.** In this paper, the entropy weight method considering the time variable is adopted to sum up the time (year) based on the traditional method, determine the weight of each evaluation index, and calculate the regional economic development level of each year. The specific steps are as follows:

*Step 1.* Considering the inconsistency of the nature and dimension of each indicator, standardize the indicators to eliminate the influence of different dimensions as follows:

$$x'_{\theta ij} = \frac{x_{\theta ij} - x_{\min}}{x_{\max} - x_{\min}}, \quad (3)$$

where  $x_{\theta ij}$  and  $x'_{\theta ij}$ , respectively, represent the original data and standardized value of the  $j$ -th regional economic development index of the  $i$ -th province (city) in the  $\theta$ -th year.

*Step 2.* In order to meet the requirements of the base in logarithmic operation, the index data is translated as follows:

$$x''_{\theta ij} = x'_{\theta ij} + A, \quad (4)$$

where  $x''_{\theta ij}$  represents the value after translation and  $A$  represents the magnitude of translation.

*Step 3.* Determine the weight of indicators as follows:

$$y_{\theta ij} = \frac{x''_{\theta ij}}{\sum_{\theta} \sum_i x''_{\theta ij}} \quad (\theta = 1, 2, \dots, r; i = 1, 2, \dots, n), \quad (5)$$

where  $r$  and  $n$  represent the number of years and provinces (cities) in the sample, respectively.

*Step 4.* Calculate the entropy value of the  $j$ -th regional economic development index as follows:

$$e_j = -k * \sum_{\theta} \sum_i y_{\theta ij} \ln(y_{\theta ij}), \quad (6)$$

where  $k > 0$ ,  $k = \ln(r * n)$ ,  $e_j \geq 0$ .

*Step 5.* Calculate the weight of each indicator as follows:

$$w_j = \frac{1 - e_j}{\sum_j (1 - e_j)} \quad (j = 1, 2, \dots, m). \quad (7)$$

*Step 6.* Calculate the regional economic development level of each province (city) as follows:

$$H_{\theta i} = \sum_j (w_j * x'_{\theta ij}). \quad (8)$$

**3.3.3. Coupling Coordination Degree Model.** In order to analyze the interaction between technological innovation in the high-tech industry and regional economic development, this paper adopts the coupling coordination degree model to evaluate the degree and stage of coupling coordination between the two. The specific steps are as follows:

- (1) Calculation of coupling degree

Based on the measurement of technological innovation efficiency in the high-tech industry and regional economic development level in the above provinces (cities), the following formula is used to calculate the coupling degree between them:

$$C = \left\{ \frac{H_{\theta i} \times E_{\theta i}}{[H_{\theta i}/2 + E_{\theta i}/2]^2} \right\}^{\alpha}. \quad (9)$$

In the formula,  $H_{\theta i}$  is the comprehensive level of regional economic development,  $E_{\theta i}$  is the comprehensive efficiency of technological innovation in the high-tech industry, and  $C$  is the coupling degree. The value range is  $[0, 1]$ . The greater the value, the better the coupling relationship between technological innovation of the high-tech industry and regional economic development, and the more orderly the operation state is.  $\alpha$  is the adjustment coefficient. According to the characteristics of the relationship between the research topics, this paper takes  $\alpha = 2$ .

- (2) Calculation of coupling coordination degree

By introducing the coupling coordination degree evaluation model, as shown in the following equation, the coupling coordination development level between technological innovation in the high-tech industry and regional economic development of provinces (cities) is further calculated:

$$D = \sqrt{C \times T}, \quad (10)$$

$$T = \eta H_{\theta i} + \mu E_{\theta i},$$

where  $C$  is the coupling degree;  $T$  is the comprehensive evaluation index, which is used to reflect the overall development level of technological innovation in the high-tech industry and regional economic development;  $\eta$  and  $\mu$  are the undetermined weight coefficient, which is taken as 0.5 in this paper; and  $D$  is the coupling coordination degree, and the value is within the interval  $[0, 1]$ . Referring to the existing relevant research [23], with 0.2, 0.4, 0.6, 0.8, and 1 as the separation points, it is divided into five states: "maladjustment," "antagonism," "adaptation," "coupling," and "coordination."

**3.3.4. Exploratory Spatial Data Analysis Method.** In this paper, two types of spatial autocorrelation methods are used to analyze the spatiotemporal evolution characteristics of the coupling coordination degree between high-tech industry technological innovation and regional economic development

in provinces (cities) from 2009 to 2018. Firstly, the global spatial autocorrelation index is used to identify the existence of a spatial correlation between selected research regions from 2009 to 2018. Secondly, the local spatial autocorrelation index is used to identify the hot spots and cold spots of the coupling coordination degree of high-tech industries technological innovation and regional economic development in Chinese provincial (municipal) from 2009 to 2018.

(1) *Global Spatial Autocorrelation Analysis*. Global Moran index  $I$  was an exploratory spatial analysis index proposed by Moran in 1950, which is used to test spatial correlation and agglomeration and reflect the similarity of each unit and its neighboring units in the whole research area. The specific calculation formula is as follows:

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n w_{ij} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (11)$$

$$= \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j=1}^n w_{ij}},$$

where  $I$  is the global Moran index, and its value range is  $(-1, 1)$ .  $I > 0$  means positive correlation, indicating that similar attributes gather together.  $I < 0$  means negative correlation, indicating that dissimilar attributes gather together.  $I = 0$  means that all attributes are randomly distributed and there is no spatial autocorrelation.  $n$  represents the total number of research units in the research area.  $w_{ij}$  represents the spatial weight matrix, and this paper uses the  $K$ -nearest neighbor rule to determine the spatial weight matrix.

(2) *Local Spatial Autocorrelation Analysis*. Local Moran index  $I_i$  was proposed by Anselin in 1995, which can more accurately reflect the aggregation phenomenon of observed values in local space. The calculation formula is as follows:

$$I_i = \frac{(x_i - \bar{x}) \sum_{j=1}^n w_{ij} (x_j - \bar{x})}{S^2} \quad (12)$$

where  $I_i > 0$  means that a high attribute value is surrounded by a high attribute value (“high-high” cluster) or a low attribute value is surrounded by a low attribute value (“low-low” cluster).  $I_i < 0$  indicates that a high attribute value is surrounded by low attribute values (“high-low” cluster), or a low attribute value is surrounded by high attribute values (“low-high” cluster).

*3.4. Data Sources and Processing*. This paper used all the raw data from the 2010–2019 “China Statistical Yearbook on High Technology Industry,” “China Statistical Yearbook on Science and Technology,” “China Statistical Yearbook,” “China Social Statistical Yearbook,” and “Statistical Yearbook of the Chinese Investment in Fixed Assets” such as statistics. For some missing data, this paper uses interpolation or extrapolation to completion. As for the selection of research objects, some data on high-tech industries in Inner Mongolia, Tibet, Qinghai, Xinjiang, Hainan, Ningxia,

Gansu, Hong Kong, Macao, and Taiwan are seriously missing and difficult to be completed. Therefore, this paper does not consider these regions and only analyzes the following 24 provinces (cities), include that Beijing, Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Chongqing, Sichuan, Shaanxi, Guizhou, Yunnan, Guangxi, and Shanxi.

## 4. Empirical Analysis

### 4.1. Measurement of Technological Innovation Efficiency of High-Tech Industry and Regional Economic Development Level

*4.1.1. Measure of Technological Innovation Efficiency of High-Tech Industry*. According to the aforementioned three-stage chain network DEA model of additional input, the three-stage technological innovation efficiency and total efficiency of Chinese provincial (municipal) high-tech industries from 2009 to 2018 are calculated. The overall performance of the decade is shown in Table 5, where “\*” and “#” represent the driving factors and weak links of technological innovation efficiency of Chinese provincial (municipal) high-tech industries, respectively.

As shown in Table 5, there are significant differences in the total efficiency of technological innovation of high-tech industries among provinces (cities) from 2009 to 2018. Chongqing, which ranks first, has an innovation efficiency of 0.5432 in the technology R&D stage of the high-tech industry, which is 2.36 times that of Heilongjiang province. Among the 24 provinces (cities), “Chongqing, Tianjin, Fujian, Zhejiang, and Jiangsu” and “Yunnan, Shaanxi, Hebei, Jilin, and Heilongjiang” rank the top five and the bottom five, respectively, in the total efficiency of technological innovation in high-tech industries. Its specific performance in each stage is as follows:

- (1) The average level of technological innovation efficiency of the 24 provinces (cities) is significantly different in different stages, which is most prominent in the stage of technological research and development, followed by the stage of industrialization, and finally in the stage of technological transformation. This is because China, as a large developing country, has actively implemented the innovation-driven development strategy. The high-tech industry is an important innovation-driven field, and provinces and cities have long attached great importance to giving full play to the role of technological innovation in the high-tech industry in promoting economic growth. However, how to promote regional industry-university-research collaborative innovation development and realize the improvement of regional high-tech industry technology transformation efficiency is still in the exploratory stage.
- (2) The top five provinces (cities) are mainly distributed in economically developed regions, but there are



TABLE 5: Average value and ranking of three-stage technological innovation efficiency and total efficiency of Chinese provincial (municipal) high-tech industry from 2009 to 2018.

Province (city)	Technology R&D efficiency	Ranking	Technology transformation efficiency	Ranking	Industrial efficiency	Ranking	Overall efficiency	Ranking
Beijing	0.3618 <sup>#</sup>	24	0.3046	17	0.9016*	1	0.4632	7
Tianjin	0.4015 <sup>#</sup>	20	0.3827	13	0.8659*	2	0.5105	2
Hebei	0.4895*	5	0.2253 <sup>#</sup>	24	0.1622	20	0.2615	22
Shanxi	0.4343	13	0.2784 <sup>#</sup>	19	0.2460	18	0.3099	19
Liaoning	0.4127 <sup>#</sup>	17	0.3355	15	0.2905	16	0.3426	14
Jilin	0.4403	12	0.3853	12	0.0945 <sup>#</sup>	24	0.2521	23
Heilongjiang	0.4234	15	0.2917	18	0.0983 <sup>#</sup>	23	0.2299	24
Shanghai	0.4113	18	0.2447 <sup>#</sup>	23	0.6581*	3	0.4046	12
Jiangsu	0.4640	8	0.4434	9	0.5359*	7	0.4795	5
Zhejiang	0.4700	7	0.5076*	5	0.4735	9	0.4834	4
Anhui	0.5182*	2	0.5722*	2	0.3511	12	0.4704	6
Fujian	0.4452	10	0.4060	10	0.6495*	4	0.4897	3
Jiangxi	0.5111*	3	0.4748	7	0.1449 <sup>#</sup>	22	0.3276	16
Shandong	0.4576	9	0.3895	11	0.4763*	8	0.4395	9
Henan	0.4901*	4	0.5126*	4	0.3684	10	0.4523	8
Hubei	0.4272	14	0.2460 <sup>#</sup>	22	0.3291	13	0.3258	17
Hunan	0.4169 <sup>#</sup>	16	0.5903*	1	0.3052	14	0.4219	11
Guangdong	0.3952 <sup>#</sup>	22	0.2600	20	0.6247*	5	0.4004	13
Guangxi	0.4424	11	0.5027*	6	0.1528 <sup>#</sup>	21	0.3239	18
Chongqing	0.5336*	1	0.5329	3	0.5636	6	0.5432	1
Sichuan	0.4787*	6	0.4692	8	0.3622	11	0.4333	10
Guizhou	0.4095 <sup>#</sup>	19	0.3261	16	0.2907	15	0.3386	15
Yunnan	0.3963 <sup>#</sup>	21	0.3424	14	0.2187	19	0.3096	20
Shaanxi	0.3776 <sup>#</sup>	23	0.2529	21	0.2597	17	0.2916	21
Mean value	0.4420		0.3865		0.3926			

significant differences in their driving factors and weak links. In terms of driving factors, Chongqing is mainly in the stage of technology R&D. Tianjin, Fujian, and Jiangsu are mainly in the stage of industrialization, and Zhejiang is mainly in the stage of technology transformation. In terms of weak links, Chongqing and Zhejiang are mainly in the industrialization stage. Tianjin is mainly in the technology research and development stage, and Fujian and Jiangsu are mainly in the technology transformation stage.

- (3) The performance of the last five provinces (cities) in the three stages is lower than the average level in each stage except for Hebei province, which has higher innovation efficiency in the technological R&D stage. There is no obvious driving factor, and there is a big gap with other provinces (cities).

#### 4.1.2. Measure of Regional Economic Development Level.

According to the entropy weight method considering the time variable mentioned above, the economic development level of the 24 provinces (cities) from 2009 to 2018 is evaluated. The scores and comprehensive scores of provinces (cities) under the three secondary indicators are calculated and sorted. The overall performance of the decade is shown in Table 6.

Table 6 shows the ranking of the comprehensive level of regional economic development of provinces (cities) from 2009 to 2018. The comprehensive score of regional economic development of Guangdong province, which ranks first, is

0.5431, which is 5.88 times that of Guizhou province (0.0923), with a significant difference. Among the 24 provinces (cities), “Guangdong, Jiangsu, Shanghai, Shandong, and Zhejiang” and “Jilin, Heilongjiang, Yunnan, Shanxi, and Guizhou” rank the top five and the bottom five, respectively, in regional economic development level. The driving factors and weak links of regional economic development in 24 provinces (municipalities) are represented by “\*” and “#,” respectively, in Table 6. For example, as a representative of economically developed provinces (cities), Guangdong province, which ranks first place, has outstanding performance in various regional economic development indicators. The performance of the last five provinces (Jilin, Heilongjiang, Yunnan, Shanxi, and Guizhou) in all indicators is lower than the average level of 24 provinces (cities). Although the comprehensive level of Shanghai’s regional economic development ranks first, its investment in economic construction is relatively weak.

#### 4.2. Analysis of Coupling Coordination between Technological Innovation in High-Tech Industry and Regional Economic Development

4.2.1. Coupling Coordination Degree Measure. Based on the analysis of technological innovation and regional economic development level of high-tech industries in 24 provinces (cities), the coupling coordination degree is calculated based on formulas (9) and (10) to analyze the coupling coordination relationship between them. The specific results are shown in Table 7.

TABLE 6: Average value and ranking of regional economic development level of Chinese provincial (municipal) from 2009 to 2018.

Province (city)	Basic economic level	Ranking	Economic construction input	Ranking	Economic construction output	Ranking	Comprehensive	Ranking
Beijing	0.1576*	2	0.0573 <sup>#</sup>	16	0.1249	5	0.3398	6
Tianjin	0.0977*	7	0.0496 <sup>#</sup>	20	0.0938*	7	0.2411	7
Hebei	0.0651 <sup>#</sup>	14	0.0935*	7	0.0444	12	0.2030	13
Shanxi	0.0475	22	0.0376 <sup>#</sup>	24	0.0298	20	0.1149	23
Liaoning	0.0878	9	0.0886*	8	0.0640	9	0.2403	8
Jilin	0.0493	19	0.0430 <sup>#</sup>	22	0.0352	18	0.1275	20
Heilongjiang	0.0511	18	0.0443 <sup>#</sup>	21	0.0291 <sup>#</sup>	21	0.1245	21
Shanghai	0.1733*	1	0.0699 <sup>#</sup>	13	0.1543	3	0.3974	3
Jiangsu	0.1466	4	0.2218*	1	0.1725	2	0.5410	2
Zhejiang	0.1441	5	0.1056*	4	0.1336*	4	0.3833	5
Anhui	0.0541	16	0.0801*	10	0.0365 <sup>#</sup>	17	0.1707	15
Fujian	0.0882*	8	0.0734	12	0.0751*	8	0.2368	9
Jiangxi	0.0477 <sup>#</sup>	21	0.0599	15	0.0328	19	0.1405	18
Shandong	0.1253	6	0.1650*	3	0.0996	6	0.3899	4
Henan	0.0715	11	0.1043*	5	0.0435 <sup>#</sup>	14	0.2193	10
Hubei	0.0752	10	0.0882*	9	0.0481	10	0.2115	12
Hunan	0.0699	12	0.0788*	11	0.0370 <sup>#</sup>	16	0.1857	14
Guangdong	0.1564	3	0.1744	2	0.2123*	1	0.5431	1
Guangxi	0.0491	20	0.0562	17	0.0264 <sup>#</sup>	22	0.1317	19
Chongqing	0.0606 <sup>#</sup>	15	0.0555	18	0.0454*	11	0.1615	16
Sichuan	0.0686 <sup>#</sup>	13	0.1022*	6	0.0443 <sup>#</sup>	13	0.2152	11
Guizhou	0.0334 <sup>#</sup>	24	0.0396	23	0.0192 <sup>#</sup>	24	0.0923	24
Yunnan	0.0437 <sup>#</sup>	23	0.0522	19	0.0232 <sup>#</sup>	23	0.1192	22
Shaanxi	0.0519 <sup>#</sup>	17	0.0650	14	0.0398	15	0.1567	17

TABLE 7: Coupling coordination degree of 24 provinces (cities).

Province (city)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean value
Beijing	0.4743	0.5078	0.5487	0.5749	0.5723	0.5492	0.6102	0.6432	0.6215	0.7057	0.5808
Tianjin	0.3477	0.4061	0.4685	0.4890	0.5363	0.5314	0.5706	0.6073	0.5818	0.5977	0.5136
Hebei	0.3265	0.3680	0.3909	0.4527	0.4305	0.4555	0.4939	0.5460	0.5034	0.5735	0.4541
Shanxi	0.2137	0.2616	0.3206	0.3473	0.3776	0.3754	0.4162	0.4237	0.4080	0.4197	0.3564
Liaoning	0.4081	0.4541	0.5039	0.5516	0.5043	0.4787	0.5389	0.5211	0.5129	0.5534	0.5027
Jilin	0.2457	0.2945	0.3335	0.3638	0.3917	0.4016	0.4180	0.4424	0.4173	0.4572	0.3766
Heilongjiang	0.2283	0.2828	0.3270	0.3572	0.3817	0.3953	0.4169	0.4343	0.4083	0.4282	0.3660
Shanghai	0.5354	0.5499	0.5519	0.5935	0.5809	0.4828	0.6152	0.6845	0.6201	0.7182	0.5932
Jiangsu	0.5715	0.6073	0.6390	0.7144	0.6589	0.6010	0.7166	0.8009	0.6903	0.8072	0.6807
Zhejiang	0.4819	0.5250	0.5748	0.6216	0.6422	0.5974	0.6774	0.7186	0.6650	0.7531	0.6257
Anhui	0.2417	0.3023	0.3436	0.3653	0.4473	0.4650	0.4986	0.4814	0.5288	0.5799	0.4254
Fujian	0.3114	0.3816	0.4558	0.4728	0.5211	0.5135	0.5694	0.5955	0.5850	0.6484	0.5054
Jiangxi	0.2223	0.2730	0.3291	0.3536	0.3959	0.4166	0.4535	0.4799	0.4826	0.5201	0.3927
Shandong	0.4787	0.5328	0.5717	0.6214	0.5897	0.5673	0.6563	0.7141	0.6409	0.6994	0.6072
Henan	0.3155	0.3640	0.4064	0.4537	0.4947	0.5161	0.5567	0.5940	0.5801	0.6434	0.4925
Hubei	0.2688	0.3429	0.4012	0.4400	0.4655	0.4702	0.5355	0.5717	0.5246	0.6179	0.4638
Hunan	0.2497	0.2976	0.3627	0.3946	0.4547	0.4879	0.5210	0.5511	0.5281	0.5959	0.4443
Guangdong	0.5605	0.5911	0.5608	0.6614	0.6386	0.5133	0.6167	0.6861	0.6705	0.7891	0.6288
Guangxi	0.2142	0.2775	0.3200	0.3537	0.3860	0.4087	0.4407	0.4528	0.4594	0.5050	0.3818
Chongqing	0.1984	0.2640	0.3302	0.3714	0.4342	0.4583	0.4732	0.4867	0.5176	0.5306	0.4065
Sichuan	0.3127	0.3726	0.4019	0.4619	0.4949	0.4991	0.5357	0.5741	0.5713	0.6256	0.4850
Guizhou	0.0583	0.1212	0.2017	0.2228	0.3020	0.3523	0.3819	0.4112	0.4047	0.4545	0.2911
Yunnan	0.1708	0.2135	0.2797	0.3125	0.3768	0.3877	0.4047	0.4387	0.4372	0.4905	0.3512
Shaanxi	0.1910	0.2804	0.3404	0.3882	0.4281	0.4188	0.4655	0.4980	0.4630	0.5243	0.3998
Mean value	0.3178	0.3697	0.4152	0.4558	0.4794	0.4726	0.5243	0.5566	0.5343	0.5933	0.4719

(1) On the whole, the coupling coordination degree between technological innovation in the high-tech industry and regional economic development in 24

provinces (cities) increased year by year from 2009 to 2018 and reached the highest level in 2018. According to the above judgment criteria, it is in the adaptation

TABLE 8: Global Moran's I index of coupling coordination degree in 24 provinces (cities) from 2009 to 2018.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Global Moran's I index	0.317	0.312	0.325	0.261	0.234	0.154	0.278	0.254	0.205	0.209

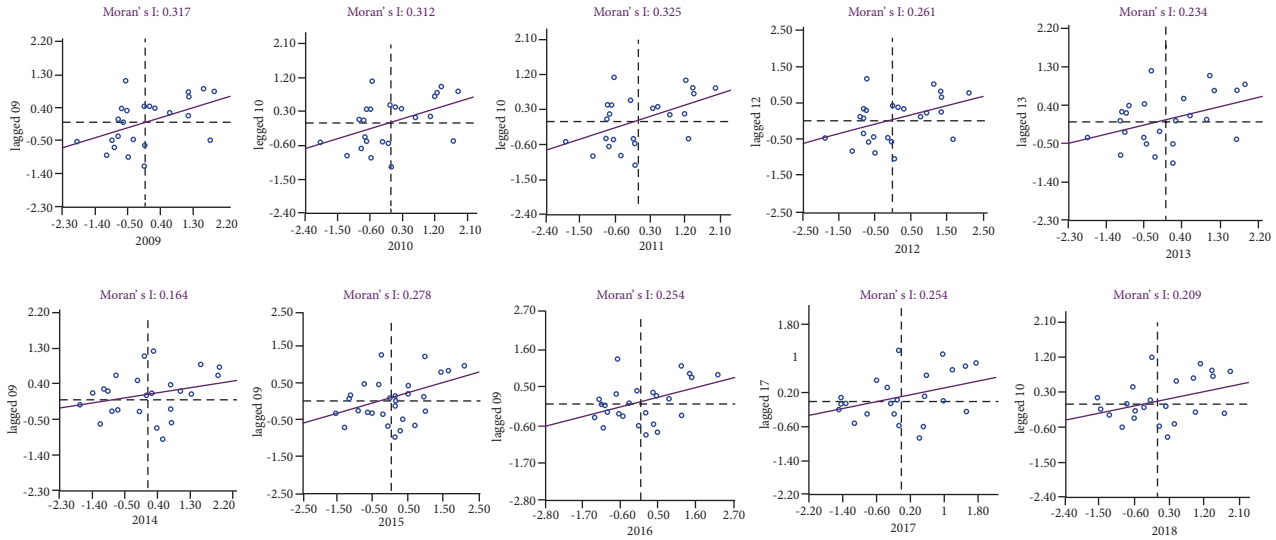


FIGURE 3: Moran's I scatter diagram of the coupling coordination degree between technological innovation in the high-tech industry and regional economic development.

stage of technological innovation in the high-tech industry and regional economic development. There is still a gap between coupling coordination level and benign coordinated development.

- (2) From the perspective of provinces, Jiangsu, Guangdong, Zhejiang, and Shandong have a high degree of coupling coordination between technological innovation in the high-tech industry and regional economic development from 2009 to 2018, which is in the coupling stage. Shanghai, Beijing, Tianjin, Fujian, Liaoning, Henan, Sichuan, Hubei, Hebei, Hunan, Anhui, and Chongqing are in the adaptation stage. Finally, Shaanxi, Jiangxi, Guangxi, Jilin, Heilongjiang, Shanxi, Yunnan, and Guizhou are in the antagonism stage between technological innovation in the high-tech industry and regional economic development.

#### 4.2.2. Spatiotemporal Evolution Analysis of Coupling Coordination Degree

(1) *Global Spatiotemporal Analysis.* Based on the exploratory spatial data analysis method, the global Moran's I index of the coupling coordination degree between technological innovation of high-tech industries and regional economic development in the 24 provinces (cities) from 2009 to 2018 is calculated by using *GeoDa* software. The results are shown in Table 8. The global Moran's I indexes are all positive, indicating that there is a positive spatial autocorrelation between the coupling coordination degree of high-tech industry innovation and regional

economic development in the 24 provinces (cities). The spatial aggregation characteristics are as follows. Provinces (cities) with a high degree of coupling and coordination between technological innovation of high-tech industries and regional economic development are adjacent to provinces (cities) with a high degree of coupling and coordination between technological innovation of high-tech industries and regional economic development. Provinces (cities) with a low degree of coupling and coordination between technological innovation of high-tech industries and regional economic development are adjacent to provinces (cities) with a low degree of coupling and coordination between technological innovation of high-tech industries and regional economic development.

According to Figure 3, scatters are mainly distributed in the first, second, and third quadrants. Meanwhile, the number of low-high clustering in the second quadrant and the number of low-low clustering in the third quadrant are significantly higher than the number of high-high clustering in the first quadrant. It shows that there are obvious provinces (cities) with a high coupling coordination degree between technological innovation in the high-tech industry and regional economic development and provinces (cities) with a low coupling coordination degree between technological innovation in the high-tech industry and regional economic development. In addition, the number of agglomerations in provinces (cities) with low coupling coordination degree between high-tech industry technological innovation and regional economic development is much larger than that in provinces (cities) with high coupling coordination degree between high-tech industry technological innovation and regional economic development,

showing a serious imbalance of regional heterogeneity phenomenon. Provinces (cities) with high coupling coordination degree of technological innovation in the high-tech industry and regional economic development have weak radiation driving effect on surrounding provinces (cities), and provinces (cities) located in the third quadrant may fall into a cycle of constant weakness. In addition, Moran's  $I$  in 2018 is smaller than Moran's  $I$  in 2009, indicating that the difference in coupling coordination degree between technological innovation in the high-tech industry and regional economic development in the 24 provinces (cities) is weakened, which may lead to the implementation of innovation-driven development strategy and high-quality development. Make provinces (cities) pay more attention to the collaborative development between technological innovation in the high-tech industry and regional economic development.

(2) *Local Spatiotemporal Analysis*. In order to distinguish the local spatial aggregation degree of the 24 provinces (municipalities), this paper analyzes the similarity degree and spatial differentiation characteristics of coupling coordination degree between technological innovation in the high-tech industry and regional economic development of one province (city) and its neighboring provinces (city). This paper classifies the agglomeration characteristics of the coupling coordination degree between technological innovation of high-tech industries and regional economic development in provinces (cities) into the following four categories:

- (a) *Diffusion effect type*. The coupling coordination degree between technological innovation in the high-tech industry and regional economic development is high in both the province (city) and neighboring provinces (cities), presenting the characteristics of "high-high" spatial agglomeration. From 2009 to 2018, Jiangsu, Shanghai, Shandong, Zhejiang, and Tianjin were the provinces (cities) of the diffusion effect. Hebei province only appeared in this category in 2009, while Fujian and Beijing did not appear in this category in 2009 and 2018, respectively.
- (b) *Polarization effect type*. The coupling coordination degree of high-tech industry innovation and regional economic development is higher in the province (city), while the coupling coordination degree of high-tech industry innovation and regional economic development is lower in the neighboring province (city), presenting the characteristics of "high-low" spatial differentiation. From 2009 to 2018, Guangdong province was the only province (city) that always belonged to the polarization effect type. The number of provinces (cities) in this category showed an increasing trend from 2009 to 2018, from one in 2009 to six in 2018, namely Henan, Guangdong, Beijing, Sichuan, Hunan, and Hubei.
- (c) *Transitional type*. The coupling coordination degree between high-tech industry innovation and regional economic development is low in the province (city), while the coupling coordination degree between high-tech industry innovation and regional economic development is high in the neighboring province (city), presenting the characteristics of "low-high" spatial differentiation. From 2009 to 2018, the transitional provinces (cities) included Anhui province and Jiangxi province, and the number of these provinces (cities) remained stable at five or six.
- (d) *Low-speed growth type*. The coupling coordination degree between technological innovation in the high-tech industry and regional economic development is low in both the province (city) and neighboring provinces (cities), presenting the characteristics of "low-low" spatial agglomeration. From 2009 to 2018, Guizhou, Guangxi, Shaanxi, Chongqing, and Yunnan have always been low-speed growth provinces (cities).

In conclusion, the coupling coordination degree of high-tech industry innovation and regional economic development in the 24 provinces (cities) has obvious spatial dependence. That is, the coupling coordination degree of high-tech industry innovation and regional economic development in most provinces (cities) shows clustering characteristics with neighboring provinces (cities). Furthermore, by analyzing the spatial clustering status of coupling coordination degree between high-tech industry technological innovation and regional economic development in the 24 provinces (cities) in 2009, 2015, and 2018, it is found that the coupling coordination degree between high-tech industry technological innovation and regional economic development in the 24 provinces (cities) form two different spatial clustering zones. The first is the "low-low" low-speed growth area with the coupling coordination degree between technological innovation in the high-tech industry and regional economic development, which consists of Guizhou, Guangxi, Chongqing, and Yunnan. These areas are located in the remote central and western regions, and the collaborative development process of technological innovation in the high-tech industry and regional economy is relatively slow. The other is the "high-high" diffusion effect zone of coupling coordination degree between technological innovation in the high-tech industry and regional economic development, which is composed of Shandong, Jiangsu, Shanghai, Zhejiang, and Fujian, all of which are located in the eastern coastal region.

## 5. Conclusion

Based on the chain network DEA model, entropy weight method, coupling coordination model, and exploratory spatial data analysis technology, this paper constructed the measurement indicator system of technological innovation in the high-tech industry and regional economic development. The empirical analysis is made on technological innovation efficiency, regional economic development level,

coupling coordination relationship, and temporal and spatial evolution trend of high-tech industries in the 24 provinces (cities) in China. Specific conclusions are as follows:

- (1) The average level of technological innovation efficiency of high-tech industries in the 24 provinces (cities) from 2009 to 2018 is significantly different in different stages, with the most outstanding performance in the technology research and development stage, followed by the industrialization stage, and finally in the technology transformation stage.
- (2) From 2009 to 2018, the coupling coordination degree between technological innovation in the high-tech industry and regional economic development in the 24 provinces (cities) shows an increasing trend year by year and is in the adaptation stage of technological innovation in the high-tech industry and regional economic development. There is still a certain gap between the coupling coordination level and benign coordinated development.
- (3) There is a positive spatial autocorrelation between the coupling coordination degree of high-tech industry innovation and regional economic development in the 24 provinces (cities). The number of agglomeration in provinces (cities) with a lower coupling coordination degree is much larger than that in provinces (cities) with a higher coupling coordination degree, showing a serious imbalance of regional heterogeneity. And the provinces (cities) with higher coupling coordination degrees have a weak radiation driving effect on the surrounding provinces (cities).
- (4) The coupling coordination degree between technological innovation in the high-tech industry and regional economic development in the 24 provinces (cities) formed two different spatial agglomeration zones from 2009 to 2018. The high-tech industrial technological innovation and regional economic development coupling and coordination of “high-high” diffusion effect area composed of Shandong, Jiangsu, Shanghai, Zhejiang, and Fujian, and the “low-low” low-speed growth area composed of Guizhou, Guangxi, Chongqing, and Yunnan.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

### Acknowledgments

This work was supported by the Key Program of Hebei Province Social Science Foundation (HB19GL001).

### References

- [1] A. S. P. Joseph, *The Theory of Economic Progress*, pp. 73-74, Commercial Press, 2000.
- [2] P. M. Romer, “Increasing returns and long-run growth,” *Journal of Political Economy*, vol. 94, pp. 1002-1037, 1986.
- [3] V. H. Torres-Preciado, M. Polanco-Gaytán, and M. Tinoco-Zermeo, “Technological innovation and regional economic growth in Mexico: a spatial perspective,” *Annals of Regional ence*, vol. 52, no. 1, pp. 183-200, 2014.
- [4] M. Adak, “Technological progress, innovation and economic growth: the case of Turkey,” *Procedia-Social and Behavioral Sciences*, vol. 42, pp. 776-782, 2015.
- [5] O. B. Koshovets and N. A. Ganichev, “Ambiguous effect of arms export on the development of the Russian high technology industry,” *Studies on Russian Economic Development*, vol. 26, pp. 188-197, 2015.
- [6] Y. Chen, X. Su, and Q. Zhou, “Spatial differentiation and influencing factors of the green development of cities along the Yellow River basin,” *Discrete Dynamics in Nature and Society*, vol. 2022, pp. 1-20, 2022.
- [7] S. Y. Xiong and X. Y. Wang, “Overcapacity, technological innovation and high-quality development of China’s economy,” *Statistics & Decisions*, vol. 36, no. 16, pp. 86-90, 2020.
- [8] H. M. Wang, K. Wang, and G. Liu, “The relationship between technological innovation and regional economic development—a case of Jiangsu province,” *Science and Technology Management Research*, vol. 37, no. 08, pp. 98-105, 2017.
- [9] L. Liu and Y. Zhang, “An analysis on the spillover effect of science and technology innovation input on regional economic growth,” *East China Economic Management*, vol. 33, no. 01, pp. 62-66, 2019.
- [10] Q. Z. Zhang, “Research on technological innovation, knowledge spillover and regional economic growth,” *Statistics & Decisions*, vol. 14, pp. 122-124, 2015.
- [11] Y. Ma, W. H. Qiu, and X. Y. Wang, “Research on the effect of high-tech industry agglomeration and innovation on high-quality economic development—regression model based on panel smoothing transformation,” *Journal of Industrial Technological Economics*, vol. 39, no. 02, pp. 13-20, 2020.
- [12] L. N. Liang and B. Yu, “Economic growth—the synergistic effect of technological innovation and industrial structure upgrade,” *Studies in Science of Science*, vol. 39, no. 09, pp. 1574-1583, 2021.
- [13] G. Zong and Y. Gao, “Research on the endogenous growth of regional economy and technological innovation—based on the analysis of Chinese provincial panel data from 2003 to 2014,” *Journal of Hebei University of Economics and Business*, vol. 38, no. 02, pp. 101-105, 2017.
- [14] L. S. Du and H. Y. Hu, “Research on the interactive relationship between scientific and technological innovation and regional economic growth under the new normal—analysis of simultaneous equations based on provincial panel data,” *Inquiry into Economic Issues*, vol. 08, pp. 1-8, 2019.
- [15] J. Y. Wang, *Research on the Coordinated Development of Technical Innovation in High-Tech Industry and Regional Economy in the Central Region*, Nanchang University, China, 2018.
- [16] L. Liang, Z. B. Wang, and D. Luo, “Synergy effects and its influencing factors of China’s high technological innovation and regional economy,” *PLoS One*, vol. 15, 2020.
- [17] J. E. Bardram, “Temporal coordination: on time and coordination of collaborative activities at a surgical department,”

- Computer Supported Cooperative Work*, vol. 9, no. 2, pp. 157–187, 2000.
- [18] C. Liu and G. Xia, “Research on the dynamic interrelationship among R&D investment, technological innovation, and economic growth in China,” *Sustainability*, vol. 10, no. 11, p. 4260, 2018.
- [19] Y. L. Zhao, *The Enocomiccs of Innovation*, , pp. 24–28, Tsinghua University, 2017.
- [20] J. Zheng, *Research on Improved DEA Method for Evaluating Technological Innovation Efficiency of High-Tech Industry*, Harbin Institute of Technology, Harbin, 2008.
- [21] S. L. Liu, X. P. Jiang, and Q. Yu, “Characteristics and evolution of three stages of technological innovation in China’s high-tech industry,” *The Journal of Quantitative & Technical Economics*, vol. 32, no. 07, pp. 104–116, 2015.
- [22] F. C. Liu, N. Zhang, and L. S. Zhao, “Research on innovation efficiency evaluation of three provinces in northeast China in high-tech manufacturing industry based on two-stage network DEA model,” *Management Review*, vol. 32, no. 04, pp. 90–103, 2020.
- [23] Y. Z. Lu and N. Wang, “Study on coupling and coordination between tourism industry and social development,” *Resource Development & Market*, vol. 35, no. 06, pp. 855–860, 2019.