Pol. J. Environ. Stud. Vol. 32, No. 5 (2023), 4325-4339
DOI: *10.15244/pjoes/166359* ONLINE PUBLICATION DATE: 2023-06-29

Original Research

Exploring the Coupling and Forecasting of Industry Chain, Innovation Chain and Service Chain under the Background of Low Carbon Economy

Shouwen Wang[1], Xueqing Zhao[1, 2]*

[1]School of Economics and Management, China Three Gorges University, Yichang 443002, China
[2]School of Tourism and Education, Hubei Three Gorges Polytechnic, Yichang 443119, China

Received: 23 February 2023
Accepted: 20 May 2023

Abstract

Low carbon economy emphasizes innovative, green, and high-quality economic growth mode. The deep integration and coordinated development of the industry chain, innovation chain and service chain are an effective measure and inevitable requirement to transform the pattern of economic growth and boost the low-carbon economy. Taking the data of Wuhan, Nanchang and Changsha, the central cities of the middle reaches of the Yangtze River city cluster, from 2013 to 2020 as samples, this paper discusses the mechanism of the three-chain coordinated development to promote high-quality economic development, uses the coupling coordination model to measure the three-chain coordination degree, and the grey relational degree model to predict the future development of the three chains in this region. The research results show that: since the establishment of the case city cluster, the three chains of the central cities have experienced a change from disharmony to gradual coordinated development, and the trend is good. However, the coordination degree is still low at present, which is not conducive to the sustainable development of regional economy. According to the research results, policy suggestions are put forward to promote intra-city three-chain coordination and inter-city three-chain integration coordination.

Keywords: industry chain, innovation chain, service chain, collaborative innovation, low carbon economy

Introduction

Low carbon economy emphasizes innovative, green and high-quality economic growth mode. Scientific and technological innovation is the core element of low carbon economy, low carbon economy is also the inevitable result of scientific and technological innovation [1, 2]. Accelerating the optimization and upgrading of industrial structure through innovation drive, i.e., the synergy of innovation chain and industry chain, can effectively promote the sustainable development of regional economy with unified speed and quality. Similarly, innovation-driven, and industrial upgrading also require service factors such as proactive policies, relaxed cultural environment and good infrastructure, namely the support of service chain [3]. The organic connection,

*e-mail: zhaoxueqing@ctgu.edu.cn

high matching and deep integration of industry chain, innovation chain and service chain can solve the driving force of economic development (innovation), green and security issues (policy support and regulation). In recent years, China has been exploring the transformation of the dynamics of economic development to achieve low carbon development goals. In May 2016, President Xi Jinping [4] first proposed the proposition of "integration and development of innovation, industry, capital and policy chains"; In the report of the 20th National Congress, the Communist Party of China also emphasized the importance of "promoting the deep integration of innovation chains, industry chains, capital chains and talent chains" [5], reflecting China's commitment to promoting high-quality and sustainable economic development through the coordination of industry chains, innovation chains and service chains.

This paper takes the city cluster along the middle reaches of the Yangtze River (the following text is referred to as case city cluster) as a case to discuss and analyze the coordinated development degree of the three chains. The case city cluster is a mega national city cluster, with urban clusters around Wuhan in Hubei province (with Wuhan as the central city), the Changsha-Zhuzhou-Xiangtan city group in Hunan province (with Changsha as the central city) and clusters around Poyang Lake in Jiangxi province (with Nanchang as the central city) as the main body, covering 31 cities. The concept of this city cluster was proposed in 2012, and in 2015, the State Council of China recognized the construction of this city cluster at the national level. Since its establishment, the city cluster has developed rapidly and is gradually becoming the fourth largest economic growth pole in China. However, there are still gaps in the development of the region relative to other faster developing integration regions, and it still needs to improve regional competitiveness and maintain sustainable development. In the central city, the spillover effect is one of the important factors that determine the overall development level of the city cluster. The spillover effect is constrained by the strength of the cities themselves. Improving the competitiveness of central cities is beneficial to the overall economic development of the region. Therefore, this study focuses on the coordinated development of industry chain, innovation chain and service chain in Wuhan, Changsha and Nanchang, the three central cities in case city cluster.

In the context of low carbon economy, based on the idea of system theory, this study analyzes the data of case city cluster, deeply explores the coordination mechanism of the three chains, constructs the evaluation index system of the coordinated development level of the three chains, measures the coordination degree, and proposes countermeasures for the coordinated development of the three chains. The innovation of this study is mainly reflected in the following aspects: Firstly, this study creatively proposes that the coordinated development of three chains can build an industrial collaborative innovation system and promote high-quality and sustainable economic development. Secondly, this study thoroughly investigates the mechanism of coordinated development of three chains, and empirically analyzes and tests the degree of coordination of three chains in the case cities with the help of coupled coordination model. It provides realistic samples for assessing the current situation and trends of the coordinated development of the three chains, and proposes suggestions for improving the coordination degree of the three chains, extending the existing research findings. In this paper, the rest of the arrangement is as follows: the second part focuses on the literature review; the third part specifically outlines the research mechanism, data, and methodology; the fourth part shows the empirical results; and, the last part completes the conclusion and policy implications.

Literature Review

Industry Chain, Innovation Chain and Service Chain

(1) Industry chain. In 1958, Rasmussen and Hirschman [6] put forward the concept of industry chain for the first time in his book. Other scholars have conducted in-depth research on the concept of industry chain. At present, the industry chain has a relatively clear construct: a cooperative relationship is formed between enterprises as services and products are produced and delivered to consumers. The industry chain includes the upstream and downstream affiliated organizations connecting different enterprises with supply and demand, it is an industrial system composed of interconnected industries [7]. Several key nodes of the industry chain from top to bottom are composed of multiple factors such as raw material suppliers, producers, distributors, and end markets.

(2) Innovation chain. Marshell [8] introduced the concept of innovation chain in 1992, considering innovation as a process of interaction between different innovation agents and an interlocking chain. Hansen and Birkinshaw [9] proposed the concept of innovation value chain, which is a value-added process involving three consecutive stages, including idea generation, idea development and innovation diffusion. According to Timmers [10], the innovation chain refers to the chain from theoretical results to innovative products, which mainly consists of four stages: basic research, technology development, industrialization and marketization. Bamfield [11] divided the innovation chain into five links: R&D, process evolution, pilot testing, market launch, manufacturing and sales. It can be concluded that the essence of the innovation chain is the multifaceted cooperation among the innovation subjects oriented to the industry chain, which is a dynamic process to realize the whole chain value creation and obtain sustainable competitive advantage [12, 13]. The innovation chain consists of scientific research institutes, universities, enterprise R&D

institutions and other R&D institutions, and runs through the whole process of R&D, achievement transformation, marketization and other innovative achievements industrialization.

(3) Service chain. Li et al. [14] put forward the idea of science and technology service chain, believing that the chain is a structure based on innovation and synthesized by related service groups, which is a bridge connecting innovation and market demand and aims to provide services for the transformation of innovation achievements. Some scholars analyzed from the perspective of productive service industry, considering that the service chain is a collection of service industries developed around a certain industry, such as various intermediaries, financial institutions, business service institutions, etc. [15]. Wang et al. [16] put forward a broader concept of service chain. They believe that service chain is a kind of supply chain formed by various service units through close or loose connections, supplying various service elements required by industrial development. Some concepts related to or overlapping with the service chain, including policy chain, capital chain or financial chain, have also received extensive attention [17, 18], these chains can be classified as service chain in a broad sense. To sum up, the service chain, i.e., the chain composed of the suppliers of service elements needed by the industry, includes all possible subjects such as intermediaries, financial institutions, other productive service industries and the government providing policy support.

Multi- Chain Collaboration and Collaborative Innovation System

(1) Multi-chain collaboration. Haken [19] proposed and established Synergetics, he believes that the world is a complex open system, and the coordinated division of labor and collaboration among internal subsystems can lead to good performance of the whole system. Scholars have conducted in-depth research on various synergistic phenomena related to industry chains. Take two-chain collaboration as an example. Mondejar [20] argued that technological innovation is an approach to optimize industrial output and organizational decisions. Pietrobeilli and Staritz [21] suggested that innovation is often driven by both technological innovation and business models. Capello et al. [22] believed that a cooperative innovation network could be formed between the industry chain and the innovation chain to carry out technological innovation, enterprise innovation and even regional innovation, improve innovation performance, and develop into a kind of relational capital. Take three-chain collaboration as an example. Etzkowitz [23] believed that universities, government and industry cooperate closely in innovation, interact with each other under the principle of reciprocity and mutual benefit, overlap, strengthen and supplement each other in functions, and create value for the society. Frolund et al. [24] proposed that universities, enterprises and government are the main bodies in an innovation system, among which the cooperation between enterprises and universities is the key driving force of innovation economy and the mainstay of enterprise R&D. Although the starting points of the study of multi-chain collaboration are different, scholars agree on the significance of the development of multi-chain collaboration. They believe that the coordinated development of the industry chain, innovation chain and other service support chains can integrate production factors and jointly create value.

(2) Collaborative innovation system. Baba and Imai [25] first proposed the definition of industrial collaborative innovation system. They believed that the system was a basic institutional arrangement to deal with systematic innovation, and the main linkage mechanism of the system framework was the innovation cooperation relationship between enterprises. Cooke and Morgan [26] proposed a related concept of regional innovation system, which is composed of a number of well-defined and interrelated enterprises, higher education institutions, research institutes, etc. Based on the above ideas, it can be argued that the industry chain, innovation chain, service chain and their synergistic development are precisely the basic elements and operational mechanisms of the industrial collaborative innovation system or regional innovation system [27]. Fan and He [28] believed that modern industrial system pursues coordinated development of real economy, scientific and technological innovation, modern finance, human resources and other aspects. This kind of synergistic development was not only reflected in various industries, but also in many aspects such as talent education, financial support and environmental constraints required by industrial development, which precisely met the multi-dimensional requirements of sustainable economic development. Caliari et al. [29] further proposed that varied and pervasive (quality) rather than more intensive (quantity) innovation systems enhance a country's participation in higher value-added stages of the value chain.

Through the review of the above literature, it can be found that the previous literature discussed the issues related to the coordinated development of the three chains from the aspects of the concept of industry chain, innovation chain, service chain, the mutual relationship between some chains, and the significance of the coordinated development of different chains. However, there are relatively few researches on the mechanism of the coordinated development of the three chains and the measurement of the coordinated development degree of the three chains, which is exactly the focus of this study.

Material and Methodology

Principles of Research

In the complex system composed of industry chain, innovation chain and service chain, i.e., the

industrial collaborative innovation system based on the coordination of the three chains, the industry chain is the core, the innovation chain provides the power for industrial development, and the service chain is the support and guarantee for industrial development (see Fig. 1). An idealized industrial collaborative innovation system should meet the following conditions: (1) The three chains are strongly developed, with no broken or weak chains. The industry chain should be supported by modern industrial infrastructure and have advanced industrial structure; the innovation chain has strong innovation input and output capacity; and the service chain is complete in all links, which can provide support and guarantee for industrial development and regulate the direction of industrial and innovation chain development. (2) The three chains should coordinate with each other and gradually realize close integration through the evolution process of "industry chain" –"innovation industry chain" – "coordinated development of the three chains of production, innovation and service". First of all, innovation chain and industry chain are integrated to form a chain that jointly creates value, namely innovation-industry chain. The nodes between the innovation chain and the industry chain as well as the whole industry chain itself realize two-way information exchange, forming a synergistic relationship of mutual integration and mutual power: the innovation chain is laid out around the industry chain, and the output of the innovation chain precisely matches the needs of the industry chain, providing intellectual support for the upgrading of the industry chain [30]. At the same time, the practices and demands of the industry chain can be fed back to the innovation chain in time, providing the source and impetus for the development of the innovation chain, and prompting the relatively free nodes in the innovation chain to play a greater innovative kinetic energy. Secondly, the service chain and the innovation-industry chain interact with each other and develop together. Each node in the service chain provides support respectively or jointly for a certain link or whole process of the innovation-industry chain, including policy support, financial support, scientific and technological achievements transformation support, talent support, infrastructure support, supporting construction services, etc. Service chain not only interacts with innovation-industry chain as a whole, but also integrates with innovation chain and industry chain respectively. In this process, the service chain provides security for and acts as the link between the innovation chain and the industry chain. The government is in a central position in all links of the service chain. It plays a leading and coordinating role through policy coordination mechanism, risk control mechanism, innovation incentive mechanism, etc. [31], while other service links are directly or indirectly influenced by the government. As a complex system formed with the industry chain as its core, the goal of the industrial collaborative innovation system is to achieve high-quality development of regional industries, which has the general characteristics of a conventional system, such as dynamism, openness, wholeness, etc. The large and small systems within the system interact actively and closely with each other and make the overall function greater than the sum of the elements. This overall effect is exactly the basic mechanism and internal driving force of industrial collaborative innovation system.

Methodology

Methodology Selection

Based on analyzing the existing research, the improved coupling coordination model is used to evaluate the development degree of three-chain collaboration. Firstly, the data are standardized, and secondly, the entropy value method is applied to determine the weights of each evaluation index, and the respective development level functions of the industry chain, innovation chain and service chain are determined

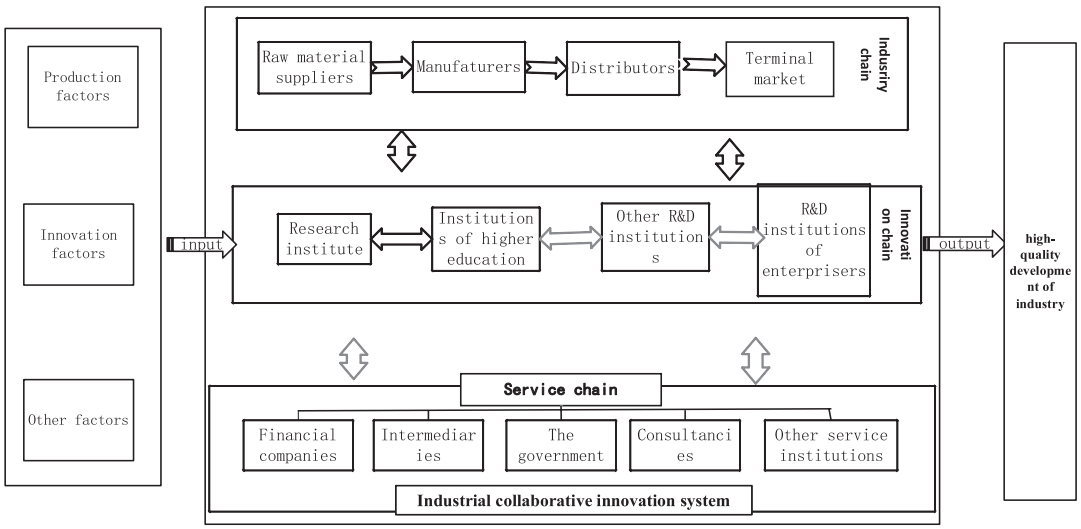

Fig. 1. Schematic diagram of industrial collaborative innovation system with coordinated development of three chains.

accordingly. Then a coupling coordination degree model is established to measure the coordination degree of the three chains. Finally, according to the current situation of the coordination degree of the three chains, the gray forecasting model GM (1.1) is used to predict the development level and coordination degree of the three chains in the next five years.

(i) Standardized processing of initial data

Firstly, range standardization is carried out on the original data of each index according to the following formula, so as to realize the comparability of different indexes across regions and years and eliminate the differences of magnitude and direction between the original data.

$$v_{ij} = \frac{v_{ij} - minv_{ij}}{maxv_{ij} - minv_{ij}},\ v_{ij} \text{ represents positive index} \quad (1)$$

$$v_{ij} = \frac{maxv_{ij} - v_{ij}}{maxv_{ij} - minv_{ij}},\ v_{ij} \text{ represents reverse index} \quad (2)$$

In the above formula, v_{ij} represents the standardized value of the jth index of system i; v_{ij} represents the original value of the jth index of system i; $maxv_{ij}$ and $minv_{ij}$ represent the maximum and minimum values of the jth index of system i respectively. In order to avoid that, logarithms cannot be obtained when partial index values are 0, the indexes are non-zeroized.

(ii) Process of index weights

The entropy weight method is used to determine the weight of each index. The formula is as follows:

$$w_j = \frac{1 - H_j}{m - \sum_{j=1}^{m} H_j} \quad (3)$$

H_j represents the entropy value E corresponding to the jth index. The formula is as follows:

$$H_j = -k \sum_{i=1}^{n} (f_{ij} \times Inf_{ij}) \quad (4)$$

and $k = \frac{1}{Inm}$, $f_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}$

(iii) Determination of the development level function of the industry chain, innovation chain and service chain

Calculate the standardized values of the three subsystems of industry chain, innovation chain and service chain. The formula is as follows:

$$U_1(x) = \sum_{i=1}^{m_1} a_i x_i \quad (5)$$

$$U_2(y) = \sum_{i=1}^{m_2} b_i y_i \quad (6)$$

$$U_3(z) = \sum_{i=1}^{m_3} c_i z_i \quad (7)$$

In the formula, m_1, m_2 represent the number of indexes of the first, second and third subsystems respectively; while a_i, b_i, c_i represent the weights of each index.

Using the entropy weighting method, i.e., formulas (1) and (2) to determine the weights of the standardized values of each subsystem. Subsequently, the integrated development level function of each subsystem is further calculated based on the standardized values and weights. The formulas are as follows:

$$T = \sum_{i=1}^{n} a_i \times U_i,\ \sum_{i=1}^{n} a_i = 1 \quad (8)$$

In the formula, U_i represents the normalized value of the ith subsystem; while a_i represents the weight of the ith subsystem.

(iv) Build the coupling degree model to develop the calculation

The coupling degree model can reveal the degree of interaction and mutual influence among the industry chain, innovation chain and service chain within a city cluster. When n = 3, the formula of coupling degree model is shown as follows:

$$C = \sqrt{\left[1 - \frac{\sqrt{(U_3 - U_1)^2} + \sqrt{(U_2 - U_1)^2} + \sqrt{(U_3 - U_2)^2}}{3}\right] \times \sqrt{\frac{U_1}{U_3} \times \frac{U_2}{U_3}}} \quad (9)$$

In the formula, C represents the coupling degree of the three chains and takes the values of [0,1]. The larger the value of C, the less discrete the subsystem and the higher the coupling degree; conversely, the lower the coupling degree between subsystems. By drawing on the modified version of Wang [32], the advantage of this model is to distribute C as much as possible in [0,1] and increase the differentiation of C values. Based on this modified coupling degree model, the further calculated coordination development degree can measure the coupling coordination relationship and development level more reasonably.

(v) Build a coordinated development degree model and calculate the coordinated development degree of the three chains

The coupling degree model can only describe the degree of mutual influence between systems and cannot determine whether the relationship between systems is mutually synergistic or antagonistic. It is necessary to accurately measure the coupling coordination between systems with the help of the coordination development degree model, so as to judge the level of system coordination. The calculation formula for the degree of coordination development D is as follows:

$$D = \sqrt{C \times T} = \sqrt{\left[\frac{\prod_{i=1}^{n} U_i}{\frac{1}{n}\sum_{i=1}^{n} U_i}\right]^{\frac{1}{n}} \times \frac{1}{n}\sum_{i=1}^{n} U_i}$$

$$= \sqrt{\frac{(\prod_{i=1}^{n} U_i)^{\frac{1}{n}}}{\frac{1}{n}\sum_{i=1}^{n} U_i} \times \frac{1}{n}\sum_{i=1}^{n} U_i} = \sqrt[2n]{\prod_{i=1}^{n} U_i} \quad (10)$$

Table 1. Classification criteria of coordination level and coordination development degree.

Interval	C value	D value	Categories
[0,0.1]	Extreme incoordination	Extreme incoordination	Dissonant recession
[0.1,0.2]	Severe incoordination	Severe incoordination	
[0.2,0.3]	Moderate incoordination	Moderate incoordination	
[0.3,0.4]	Mild incoordination	Mild incoordination	
[0.4,0.5]	Near incoordination	near incoordination	Transitional development
[0.5,0.6]	Barely coordination	Barely coordination	
[0.6,0.7]	Primary coordination	Primary coordination	Coordinated development
[0.7,0.8]	Intermediate coordination	Intermediate coordination	
[0.8,0.9]	Well-coordinated	Well-coordinated	
[0.9, 1]	Quality coordination	Quality coordination	

Note: In the table, C value is the degree of coupling coordination, D value is the degree of coordination development.

With reference to the existing research results [33], the degree of coordinated development can be classified according to the following criteria (see Table 1). The larger the D value, the higher the coordination degree between the three chains.

(vi) Further research: Grey forecasting model GM (1,1) is used to predict the coordinated development trend of the three chains in the next five years.

According to the existing calculation results, the first order linear differential model GM (1,1) in grey system theory was selected by SPSS 20.0 software for modeling. GM (1,1) forecasting model is based on a set of random time series and analyzes the new series formed by time accumulation. This model is mainly used for data with few samples and weak regularity, which is just suitable for this study. The model is used to forecast and analyze the development level of the industry chain, innovation chain and service chain of the three central cities of city cluster along the Yangtze River from 2021 to 2025, as well as the three-chain coordination degree of the three cities.

The concrete modeling is as follows: Suppose the original non-negative sequence is $x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), ...x^{(0)}n\}$, n represents the number of data, and its one-time accumulation generates the sequence $= x^{(1)} = \{x^{(1)}(1), x^{(1)}(2), ...x^{(1)}n\}$, with $x^{(1)}$ (k) $= \Sigma_{i=1}^{k} x^{(0)}(i)$, k = 1, 2, ..., n;. Generate an equal-weighted series $z^{(1)} = \{z^{(1)}(2), z^{(1)}(3), ..., z^{(1)}(n)\}$ based on the mean of the immediate neighbors of $x^{(1)}$, with $z^{(1)}$ (k) = 0.5 $x^{(1)}$(k-1) + 0.5 $x^{(1)}$(k), k = 2, 3, …, n.

The following formula is the basic form of GM (1,1) model:

$$x^{(0)}(k) + \alpha\, x^{(1)}(k) = b \tag{11}$$

Estimate the parameter vector $\hat{\alpha} = [\alpha, b]^T$ in formula (11) using the least squares method:

$$\hat{\alpha} = (B^T B)^{-1} B^T Y \tag{12}$$

and,

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, B = \begin{bmatrix} -x^{(1)}(2) & 1 \\ -x^{(1)}(3) & 1 \\ \vdots & \vdots \\ -x^{(1)}(n) & 1 \end{bmatrix} \tag{13}$$

Establish a first-order linear differential equation model for $x^{(1)}$, that is, the whitening form of the GM (1,1) model is:

$$\frac{d\, x^{(1)}}{dt} + \alpha\, x^{(1)} = b \tag{14}$$

α represents the development coefficient, and the effective effect is (-2,2). b represents the gray action quantity, and formula (14) is discretized to obtain grey differential equation, that is, the mean value form of GM (1,1) model is as follows:

$$x^{(0)}(k) + \alpha\, z^{(1)}(k) = b \tag{15}$$

The least square method can also be used to estimate the parameter vector $\hat{\alpha} = [\alpha, b]^T$. The elements in the matrix B are as follows:

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \tag{16}$$

By solving the differential equation, the grey forecasting model ofthe original sequence $x^{(0)}$ is obtained as follows:

$$x^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-\alpha k} + \frac{b}{a}, k = 0,1\ldots, n \tag{17}$$

Table 2. Prediction accuracy levels of P and C values.

Prediction accuracy/Name	Excellent	Qualified	Barely	Unqualified
P value	>0.95	>0.8	>0.7	≦0.7
C value	≦0.35	≦0.5	≦0.65	≦0.65

Table 3. indexes of coordinated development degree of three chains.

First level index	Second level index	Third level index	Unit	Index Attributes
Industry chain	Advanced industrial structure	Ratio of tertiary industry to secondary industry	%	+
	Service-oriented industrial structure	Ratio of output value of tertiary industry to total output value	%	+
Innovation chain	Science and Technology Inputs	Ratio of R&D personnel to secondary industry employees in enterprises above the scale	%	+
		Ratio of R&D expenditure to GDP	%	+
	Science and Technology Output	Number of patent applications	Piece	+
		Number of specialties authorized	Piece	+
Service chain	Financial Support	Number of loans from financial institutions	Ten thousand	+
		Ratio of scientific research expenditure to government general public budget expenditure	%	+
	Infrastructure	Total amount of freight transported by railroad, highway and waterway	Ten thousand tons	+
		Information facilities: Internet penetration rate	%	+

After modeling, the accuracy of the model was tested by variance Cand small error probability P respectively. Subsequently, the prediction accuracy was determined by referring to the criteria in Table 2.

Design of Index System

In this study, the keywords „industry chain" or „innovation chain" or „service chain" and „coupling" or „integration" were searched on WOS and CNKI, and 114 related literatures in the past five years were obtained, among which the index design was selected. Based on the principles of systematic, scientific, objective and operable index selection, with reference to the index settings in the existing literature and the opinions of experts, this paper establishes an evaluation index system for the coordinated development degree of case city cluster industry chain – innovation chain – service chain (see Table 3).

Advanced industrial structure and service-oriented industrial structure are two important aspects of high-quality industrial development, symbolizing the development of industry chain. Advanced industrial structure emphasizes that the industrial structure should constantly break the lock of economic structure at the low end based on industrial innovation and complete the evolution iteration from low to high level. The ratio of tertiary industry to secondary industry is used to indicate the level of advanced industrial structure. The service-oriented industrial structure is the trend of rationalized development of industrial structure, in which the proportion of the tertiary industry increases relative to the second primary industry, and the resource allocation is efficient and the market mechanism is perfect. The proportion of the output value of the tertiary industry to the regional GDP is selected to represent the level of industrial structure service. In terms of innovation chain, innovation input and innovation output are mainly examined. The ratio of the number of R&D personnel in enterprises above the scale to the number of employees in the secondary industry and the ratio of R&D expenditure in enterprises above the scale to GDP are selected to represent the degree of science and technology input; and, the number of patent applications and patent licenses are selected to represent the science and technology output. The service chain involves a relatively large number of links. Financial support and infrastructure development, etc. are important components of the service chain, which have an important impact on the development of the industry chain and the innovation chain, and are also relatively easy to quantify. Therefore, these two aspects are used to represent the development status of the service chain. Finally, the number of loans from financial institutions and the ratio of government research expenditure to government general public budget expenditure are selected to characterize the intensity of financial support, and the total amount of freight transported by railroads, roads and waterways

Table 4. index weights and subsystem weights of the coordinated development degree of the three chains.

First level index	Second level index	Third level index	Index weights	Subsystem weights
Industry chain	Advanced industrial structure	Ratio of tertiary industry to secondary industry	0.07504084	0.1642
	Service-oriented industrial structure	Ratio of output value of tertiary industry to total output value	0.089232132	
Innovation chain	Science and Technology Inputs	Ratio of R&D personnel to secondary industry employees in enterprises above the scale	0.210813791	0.5039
		Ratio of R&D expenditure to GDP	0.045819715	
	Science and Technology Output	Number of patent applications	0.144162863	
		Number of specialties authorized	0.103227258	
Service chain	Financial Support	Number of loans from financial institutions	0.109074593	0.3319
		Ratio of scientific research expenditure to government general public budget expenditure	0.061812527	
	Infrastructure	Total amount of freight transported by railroad, highway and waterway	0.101850547	
		Information facilities: Internet penetration rate	0.058965735	

and the penetration rate of Internet access are used to represent the improvement of infrastructure.

According to Equations (3) and (4), the weights of each index and each subsystem are determined, as shown in Table 4.

Data Sources

This paper adopts the relevant data of the three cities since the establishment of case city cluster, that is, from 2013 to now, to conduct the study. The data are mainly derived from the statistical yearbooks of the three cities in the above years, and refer to the statistical communiques of national economic and social development of the cities.

Results

Based on the calculation results of the above model, the integrated level and coordinated development of the three chains of central cities among the case city cluster in the period of 2013-2020 can be analyzed.

Integrated Development Level of Three Chains of Central Cities

From the overall perspective, the development level of the three cities in the three chains can be divided into two stages by 2016 (see Table 5). The first stage (2013-2015): the development level of the three chains is generally low, and the development of the industry chain significantly lags behind that of the innovation and service chains. The second stage (2016-present): the industry chain develops rapidly, and the development level of each chain is improved. Although the development level of the service chain is still higher than the other two chains, the gap between the three chains is narrowing and tends to be balanced. The characteristics of this stage may be related to the Development Plan of Yangtze River Midstream City Cluster approved by the State Council of China in 2015. The recognition of this city cluster from the national level has promoted the development of node cities and led to the development of the three chains to a certain extent. In the current year, not only did Wuhan and Changsha's industrial structure service index improve significantly, the number of patent applications in the three cities also increased by about 35% compared to the previous year.

From the perspective of different cities individually, the development level of the three chains in the three cities varies widely. As the core city in the city cluster along the middle reaches of the Yangtze River, Wuhan is ahead of the other two cities in the development level of industry chain, innovation chain and service chain, among which the development level of innovation chain in particular is significantly ahead. During the study period, the city's innovation input and output are both higher than those of the other two places. For example, since 2014, the city's government research expenditure accounted for more than 4% of the general government public budget expenditure. Nanchang did not reach that ratio until 2019, while Changsha has never reached it. Since 2015, Wuhan's annual patent grant reached 21,740 pieces and has been rising year by year since then, reaching 58,923 pieces in 2020; Changsha's annual patent grant party reached 21,188 pieces in 2018 and 33,012 pieces in 2020; while Nanchang's annual patent grant did not reach 20,000 pieces by 2020. In addition, the development pattern of the three chains in the three

Table 5. Development levels of the three chains in the three cities by year.

City	Category	Year							
		2013	2014	2015	2016	2017	2018	2019	2020
Total	Industry chain	0.0190	0.0246	0.0385	0.0900	0.1012	0.1140	0.1181	0.1214
	Innovation chain	0.0646	0.0733	0.0764	0.0848	0.1051	0.1177	0.1220	0.2090
	Service chain	0.0653	0.0800	0.0837	0.1019	0.1301	0.1542	0.1752	0.1727
Wuhan	Industry chain	0.0488	0.0576	0.0724	0.1238	0.1352	0.1488	0.1539	0.1659
	Innovation chain	0.0879	0.0874	0.0764	0.0738	0.0858	0.1113	0.1296	0.2828
	Service chain	0.0901	0.1151	0.1082	0.1352	0.1596	0.1814	0.1920	0.1836
Changsha	Industry chain	0.0022	0.0091	0.0307	0.1096	0.1229	0.1269	0.1309	0.1269
	Innovation chain	0.0573	0.0681	0.0783	0.0693	0.0738	0.0792	0.0841	0.1020
	Service chain	0.0385	0.0432	0.0528	0.0653	0.0846	0.1019	0.1275	0.1461
Nanchang	Industry chain	0.0018	0.0018	0.0057	0.0263	0.0345	0.0563	0.0587	0.0612
	Innovation chain	0.0077	0.0213	0.0236	0.0523	0.0928	0.0821	0.0565	0.0636
	Service chain	0.0073	0.0139	0.0174	0.0248	0.0560	0.0797	0.0955	0.1047

cities all show different characteristics. Before 2016, Wuhan's industry chain lagged behind the innovation chain and service chain, after which, the industry chain developed rapidly, the three chains tended to be balanced, and the service chain was slightly ahead. In 2020, the innovation chain overtook the service chain, showing a pattern of the innovation chain leading the development of the service and industry chains. In that year, the city's science and technology input and science and technology output are both significantly higher than the previous year. Relatively speaking, Changsha ranks in the middle of the three cities in terms of the development level of the three chains; before 2016, the city's innovation chain led the development of the other two chains, and since then, the development level of the industrial and service chains has improved. As of 2020, the development of the service chain tops the list, followed by the industry chain and the innovation chain at the bottom. Compared with the other two places, the comprehensive level of the three chains in Nanchang is low, the development is relatively slow, and the development of the industry chain is significantly backward. This shows that Nanchang still needs to be strengthened in terms of rationalization and upgrading of industrial structure.

Coordinated Development Degree of Three Chains of Central Cities

According to the calculated results of the coupling degrees of industry chain, innovation chain and service chain in central cities among the case city cluster in 2013-2020 (Table 6), it can be seen that, except for some years, the coupling degrees among the three chains in each city are in the range of [0.60, 1], which indicates that the three chains have a strong mutual influence on each other and are basically in a medium-level coupling state. In summary, Wuhan has the highest coupling degree among the three chains, with C-values fluctuating between [0.79,1] on average. Followed by Changsha, and finally Nanchang.

The three-chain coordination of the three cities has gone through a process of gradual development from dysfunctional to coordinated since the establishment of the case city cluster (see Fig 2). The overall situation is still not well coordinated, some cities are even on the verge of imbalance. However, it is encouraging that the level of three-chain coordination in this region is constantly improving, and the trend is good. 2016 was an important landmark in the development of three-chain coordination in central cities among the case city

Table 6. Measurement results of three-chain coupling degree (C value) in three cities.

City/Year	2013	2014	2015	2016	2017	2018	2019	2020
Wu Han	0.8410	0.7698	0.8193	0.8234	0.8011	0.8225	0.8396	0.6245
Changsha	0.3944	0.5295	0.7057	0.7720	0.7883	0.8281	0.8754	0.8695
Nanchang	0.6831	0.4824	0.6459	0.6922	0.6748	0.8956	0.7665	0.7607
Total	0.6052	0.6060	0.6690	0.7898	0.7609	0.7513	0.7250	0.7564

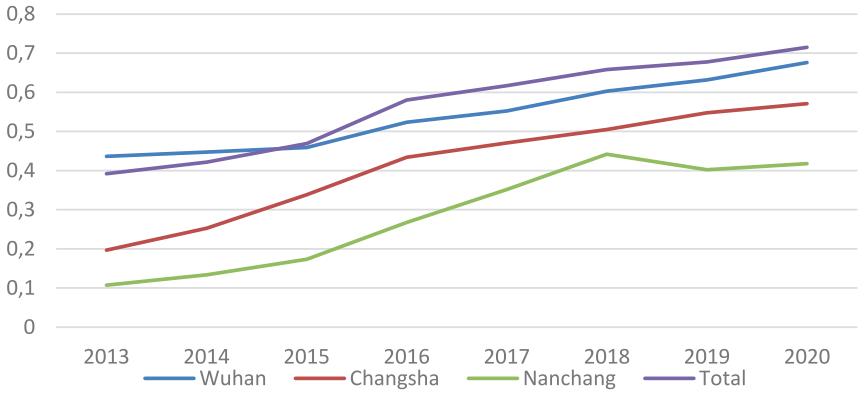

Fig. 2 Trend chart of coordination degree of three chains in three cities.

cluster. In the same year, with the realization of barely coordinated three-chain in Wuhan, the overall three-chain coordination level of the three cities also changed from disordered to barely coordinated. With the passage of time, the overall coordination degree of the three chains of the three cities has reached the intermediate level.

There are great regional differences in the coordinated development level of the three chains in the three cities, and the overall development is unbalanced (see Table 7). At present, Wuhan's three chains have achieved primary coordination, Changsha has entered the stage of barely coordinated, and Nanchang is still on the verge of imbalance. The development foundation of Wuhan's three chains is relatively good, and from 2013 to 2016, although the city's three chains did not achieve coordinated development, the degree of dissonance was low, and it was in the transition stage from dissonance to coordination. Since 2016, the three chains in Wuhan have achieved a reluctant coordination. From 2018 to now, the development of the three chains in Wuhan has maintained a primary coordination state. Before 2018, the coordination degree of the three chains in Changsha has been steadily improving, gradually developing from serious imbalance to being on the verge of imbalance, and achieved reluctant coordination in 2018. By 2020, the three chains in Changsha have maintained reluctant coordination. The coordination degree of the three chains

Table 7. Measurement results of three-chain coordination degree in three cities (D value).

Year /City	Category	Wuhan	Changsha	Nanchang	Total
2013	Value	0.4368	0.1966	0.107	0.3921
	Level	Near incoordination	Severe incoordination	Severe incoordination	Mild incoordination
2014	Value	0.4475	0.2525	0.1337	0.4219
	Level	Near incoordination	Moderate incoordination	Severe incoordination	Near incoordination
2015	Value	0.4589	0.338	0.1737	0.4688
	Level	Near incoordination	Mild incoordination	Severe incoordination	Near incoordination
2016	Value	0.5235	0.4342	0.2676	0.5802
	Level	Barely coordination	Near incoordination	Moderate incoordination	Barely coordination
2017	Value	0.5522	0.4709	0.3518	0.6171
	Level	Barely coordination	Near incoordination	Mild incoordination	Primary coordination
2018	Value	0.6026	0.5051	0.4419	0.658
	Level	Primary coordination	Barely coordination	Near incoordination	Primary coordination
2019	Value	0.6318	0.5475	0.4018	0.6774
	Level	Primary coordination	Barely coordination	Near incoordination	Primary coordination
2020	Value	0.6763	0.571	0.4178	0.715
	Level	Primary coordination	Barely coordination	Near incoordination	Intermediate coordination

in Nanchang is poor: before 2016, the city's three chains were in a serious imbalance, and then began to improve, entering a moderate imbalance period. However, the coordinated development has not been realized so far, and the three chains are on the verge of imbalance.

Development Trend of Three Chains of Central Cities

Based on the calculation results in Table 5, the gray forecasting model GM (1,1) was used to predict the development level of the three chains in the three cities during the period from 2021 to 2025. As shown in Table 8, except for the innovation chain predicted values of Wuhan and Nanchang, other predicted values passed the C value and P value test, and the accuracy was qualified. From a general view, the development level of innovation chain will gradually lead and widen the gap with service chain and industry chain, and show a good pattern of leading development. Among them, Wuhan's innovation chain is expected to develop at the fastest pace. The development level may fluctuate downward in 2021 and 2022, but after that, it will develop rapidly and far exceed the development speed of industry and service chains. The industrial and service chains do not differ much from each other in terms of development level. From the predicted values, the development level of innovation chains in Changsha and Nanchang is not satisfactory and basically lags behind the development level of industrial and service chains. Changsha's industry chain and service chain have little gap between each other, and Nanchang's service chain development level is predicted to be the most developed among the three chains, which is much higher than the industry chain and innovation chain development level. Comparatively speaking, in the future, the average development level of the three chains in Wuhan will still be higher than that of the other two places, especially the innovation chain, which has maintained a large competitive advantage. But starting in 2023, the service chain will lag behind the others. The industry chain gap between the three places will also be gradually narrowed, and the industry chain development level of Nanchang is expected to catch up with the other two places around 2024.

Development Trend of Coordination Degree of Three Chains of Central Cities

According to the calculation results shown in Table 7, the grey forecasting model GM (1,1) is used to predict the development trend of the three-chain coordination degree of the three central cities in the future (see Table 9). After the C-value and P-value tests, the prediction accuracy of the numerical values of the three-chain coordination degree in all the cities reached the excellent grade, except for Nanchang, where the prediction accuracy of the numerical values of the three-chain coordination degree was qualified. As can be seen from the predicted results, the three-chain coordination degree of the three central cities as a whole will reach the high

Table 8. Forecast of the development level of the three chains in the three cities during 2021-2025.

City/Year		2021	2022	2023	2024	2025	C value	Prediction accuracy	P value	Prediction accuracy
Total	Industry chain	0.1668	0.1976	0.2339	0.277	0.328	0.4152	Qualified	1	Excellent
	Innovation chain	0.2164	0.2611	0.315	0.38	0.4584	0.3484	Excellent	0.875	Qualified
	Service chain	0.216	0.2483	0.2854	0.3281	0.3771	0.2271	Excellent	1	Excellent
Wuhan	Industry chain	0.2066	0.2369	0.2718	0.3118	0.3577	0.3421	Excellent	1	Excellent
	Innovation chain	0.138	0.2043	0.3025	0.4479	0.5631	0.8274	Unqualified	0.75	Barely
	Service chain	0.2203	0.2422	0.2662	0.2925	0.3215	0.3037	Excellent	1	Excellent
Changsha	Industry chain	0.1879	0.2236	0.266	0.3166	0.3767	0.5186	Barely	0.875	Qualified
	Innovation chain	0.0993	0.1052	0.1115	0.1182	0.1253	0.4304	Qualified	1	Excellent
	Service chain	0.1833	0.2242	0.2741	0.3352	0.4099	0.0722	Excellent	1	Excellent
Nanchang	Industry chain	0.1077	0.1417	0.1865	0.2455	0.3231	0.3788	Qualified	1	Excellent
	Innovation chain	0.0871	0.0975	0.109	0.1219	0.1363	0.6762	Unqualified	0.625	Unqualified
	Service chain	0.1697	0.2273	0.3045	0.4078	0.5463	0.2664	Excellent	1	Excellent

Table 9. Forecast of the coordination degree of the three chains in the three cities during 2021-2025.

City/Year	2021	2022	2023	2024	2025	C	P	Prediction accuracy
D Value of Wuhan	0.7317	0.7857	0.8438	0.906	0.9729	0.106	1	Excellent
	Intermediate coordination	Intermediate coordination	Well-coordination	Quality coordination	Quality coordination	/	/	/
D Value of Changsha	0.6767	0.7551	0.8426	0.9402	1	0.2535	1	Excellent
	Primary coordination	Intermediate coordination	Well-coordination	Quality coordination	Quality coordination	/	/	/
D Value of Nanchang	0.5578	0.649	0.7551	0.8786	1.	0.3943	0.875	Qualified
	Barely coordination	Primary coordination	Intermediate coordination	Well-coordination	Quality coordination	/	/	/
D Value of total	0.8049	0.8721	0.9449	1	1	0.2471	1	Excellent
	Well-coordination	Well-coordination	Quality coordination	Quality coordination	Quality coordination	/	/	/

quality coordination in 2023, among which Wuhan and Changsha will achieve the high quality coordination in 2024 respectively. Relatively late, Nanchang will also achieve three chain quality coordination in 2025.

Discussion

In this study, the coupling coordination model is used to analyze the coordination degree of industry chain, innovation chain and service chain in central cities among the case city cluster, and the gray forecasting model is used to predict the future development trend. The results are consistent with previous studies. For example, Liang et al. [34] found that the three-chain coordination degree is in line with the regional economic development condition, the degree in a developed district is higher than a developing area. The degree increased with the increase of their respective development level enhancement, and the three chains seem to promote each other: service chain significantly promote the development of the industry chain and innovation chain, innovation chain significantly promote the development of the industry chain, industry chain significantly promoted the development of innovation chain [35]. Liang and Huang [36] have confirmed that the intensity of R&D investment is the main reason for the low coordination degree of the "three chains". Therefore, improving the respective development levels of the three chains is an effective way to improve their coordination degree [37]. This study found that there are regional differences in the coordination degree of the three chains, and it is low in the case cluster. The results are also consistent with previous studies. Except for a few regions, the coordination degree of three chains is low in most regions of China, and there have not yet formed an efficient collaborative innovation system to promote the industrial development in those districts. However, in recent years, this situation is continuously improving and is expected to get better.

Conclusions and Suggestions

Conclusions

Four basic conclusions are drawn as follows: (1) In terms of time-series characteristics, the construction of the case city cluster has promoted the coordinated development of the three chains in the central cities, and the coordination degree of the three chains in the three cities has shown a gradually increasing trend, experiencing a transformation from dysfunctional to coordinated development. However, the degree of coordination of the three chains is still relatively low, and Wuhan, which is in the best condition, is only in the primary coordination stage. (2) In terms of spatial characteristics, the development of the three chains in the three central cities is uneven, with large regional differences: Wuhan and Changsha have achieved primary coordination and barely coordinated respectively, while Nanchang is still on the verge of imbalance. (3) Each of the three chains in the three central cities has different characteristics. Relatively speaking, Wuhan has a more reasonable three-chain pattern. The innovation chain leads the development of the other two chains, and the innovation-oriented stage of economic development has begun to emerge, and the industrial development momentum is expected to be stronger. Changsha and Nanchang are ahead of the other two chains in terms of service chain development, and the trend of exogenous factors such as policy and environment driving development is more obvious, and they are still in the investment-oriented stage of economic development [38], and may not be able to support long-term sustained economic growth. To a certain extent, the conclusion of (2) and (3) above reflects the current situation of unbalanced regional development in the case city cluster. The policy dividend for the construction of city cluster is more applicable to core cities and cities with a better economic base, while the ability of cities

with a relatively poor economic base to undertake the policy has yet to be strengthened, and there is still a gap with the requirement of unified efficiency and equity for sustainable development. (4) From the perspective of forecasting, the three chains of the three central cities show a positive development trend. It is expected that in the next 3-4 years, the three chains of all cities will achieve quality coordination. However, the imbalance of regional development may continue to exist, and the innovation chain development level of Nanchang and Changsha may still lag the development level of their respective industrial and service chains for some time in the future, and have a large gap with Wuhan's innovation chain development level.

Policy Suggestions

In view of the current situation of the coordination degree of the three chains, the case city cluster and the same type of regions can start from the following aspects to improve the level of coordinated development of three chains, to realize the coordinated development and sustainable development. (1) Promote the coordinated development of three chains within each city. Targeted measures should be taken to address existing weaknesses and deficiencies in three chains. It is necessary to promote industry chain-led, strengthen goal-oriented, deploy innovation and service chains around industry chains, and combine science and technology innovation, policy support with the needs of industrial development. In terms of innovation chain, it is necessary to enhance scientific and technological innovation capacity through various ways such as external attraction and internal strengthening, improve the intermediate link of innovation results transformation, make each innovation body work closely with enterprises, align with industrial and regional development needs, and provide differentiated and precise services for industry chain development. In terms of service chain, it is necessary to improve infrastructure construction, strengthen the service capacity of each link, and create a good ecology for innovation-industry chain development through policy guidance. (2) Promote the coordinated development of three chains among cities. City cluster should improve the coordination of region-wide industrial, innovation and service chains based on the idea of integration, to promote the overall development. For example, in terms of service chain, cities should break the boundaries between administrative divisions, establish a virtual joint government of city cluster, guide the region to achieve a high degree of integration such as the same planning, the same chain of division of labor, the same transportation network, and the same sharing of public services. In the innovation chain, it is necessary to actively carry out policy innovation to promote the free flow of scientific researchers between research institutions and enterprises in urban clusters and to facilitate the timely sharing of knowledge and information among cities. In terms of industry chain, it is necessary to carry out inter-city gradient transfer of some industries or parts of the industry chain to realize the complementary synergy of industries in the city cluster and promote the optimization of industrial structure. It is necessary to play the role of industry chain of leading enterprises to reduce vicious competition, co-brand regional brands and strengthen regional advantageous industries. (3) Promote the overall sustainable development of economy, society and resources. First, pursue a rational and high-quality economic growth mode. Promote industrial upgrading and transform the high-consumption, high-pollution economic growth mode into an intelligent, flexible, sustainable and inclusive growth mode. Second, regulate the balance of environment and development. Through policy regulation, make good spatial planning, promote resource recycling, form an industrial structure that conserves resources and protects the environment, and reduce ecological disturbance and damage. Third, improve the quality of the population. Leading the adjustment of industry chain with the goal of sustainable development, leading the training of talents with the demand of industry chain, matching skilled and knowledge-based talents around the industry chain, and promoting employment.

Acknowledgments

The paper is supported by the Soft Science Major Project of Department of Science and Technology of Hubei Province (No.2021EDA014), and by Hubei Institute of Vocational and Technical Education Project (No. ZJGB2022113). The authors gratefully acknowledge the reviewers and editors for their fruitful comments.

Conflict of Interest

The authors declare no conflict of interest.

References

1. RANTA V., AARIKKA-STENROOS L., VAISANEN J.M. Digital technologies catalyzing business model innovation for circular economy – Multiple case study. Resources, Conservation and Recycling, **164**, 105155, **2021**.
2. HOSAN S., KARMAKER S. C., RAHMAN M. M., CHAPMAN A. J., SAHA B. B. Dynamic links among the demographic dividend, digitalization, energy intensity and sustainable economic growth: Empirical evidence from emerging economies. Journal of Cleaner Production, **330**, 129858, **2022**.
3. MICHAELIS T.L., ALADIN R., POLLACK J.M. Innovation culture and the performance of new product launches: A global study. Journal of Business Venturing Insights, **9**, 116, **2018**.
4. XI J.P. Struggle to build a world power in science and technology – Speeches at the National Conference on

Science and Technology Innovation, the Conference of Academicians of the Two Academies and the Ninth National Congress of the Chinese Association for Science and Technology. Beijing: People's Publishing House, **2016**.
5. XI J.P. Hold High the Great Banner of Socialism with Chinese Characteristics and Strive in Unity to Build a Modern Socialist Country in All Respects – Report at the 20th National Congress of the Communist Party of China. Beijing: People's Publishing House. **2022**.
6. RASMUSSEN P.N., HIRSCHMAN A.O. The strategy of economic development. Yale University Press, New Haven, **1958**.
7. YANG M., LIN Z.J. Research on global science and technology innovation center in the Guangdong-Hong Kong-Macao Greater Bay Area based on innovation ecosystem theory and the "four chain" integration. Science and Technology Management Research, **13**, 87, **2021**.
8. MARSHALL J., VREDENBURG H. An empirical study of factors influencing innovation implementation in industrial sales organizations. Journal of the academy of marketing science, **20** (3), 205, **1992**.
9. HANSEN M.T., BIRKINSHAW J. The innovation value chain. Harvard business review, **85** (6), 121, **2007**.
10. TIMMERS P. Building effective public R&D programs. PICMET Book of Summaries, **1**, 591, **1999**.
11. BAMFIELD P. Research and development management in the chemical and pharmaceutical industry. John Wiley & Sons, **2006**.
12. GAO H.W. Promoting the integration of industrial chain and innovation chain: Theory, reality and policy advice. Contemporary Economic Management, **44** (5), 73, **2022**.
13. QU G.N., CHEN K.H., CHEN J. Meaningful "innovation chain" management for the new development pattern. Studies in Science of Science, **41** (01), 134-142+180, **2023**.
14. LI Y., ZHOU Y., WANG H.Q., YU L.Q. Review and prospect on the integration of industrial innovation chain and service chain Scientific management research, **36** (04), 25-27+50, **2018**.
15. CHEN G.L., YUAN K., XU W.X. Research on the formation mechanism and spatial spillover effect of industrial conglomeration. Zhejiang: Zhejiang University Press, **2020**.
16. WANG H.Q., WANG M., LI Y. Research on the structure and sustainable development of regional science and technology service industry from the perspective of ecological relations. Forum on Science and Technology in China, **1**, 117, **2021**.
17. WANG W., LI M.Y., WEI Y.Z., XU S.C. Design and Innovation of Supporting Policies for the Implementation of Territorial Spatial Planning from the perspective of Policy Chain: Based on the analysis of existing main functional zone policy Texts. Urban development research, **27** (07), 40, **2020**.
18. CHIAPPINI R., MONTMARTIN B. Sophie Pommet, Samira Demaria,Can direct innovation subsidies relax SMEs' financial constraints?Research Policy, **51** (5), 104493, **2022**.
19. HAKEN H. Synergetics: An Introduction. Non-equilibrium phase transitions and self-organization in physics, chemistry and biology. Springer-Verlag, **2013**.
20. MONDEJAR M.E., AVTAR R., DIAZ H.L.B., DUBEY R.K., ESTEBAN J., GOMEZ-MORALES A., GARCIA-SEGURA S. Digitalization to achieve sustainable development goals: Steps towards a smart green planet. Science of the Total Environment,**794**, 148539, **2021**.
21. PIETROBElLLI C., STARITZ C. Upgrading, interactive learning, and innovation systems in value chain interventions. The European Journal of Development Research, **30**, 557, **2018**.
22. CAPELLO R., NIJKAMP P. eds. Handbook of regional growth and development theories: revised and extended second edition. Edward Elgar Publishing, **2019**.
23. ETZKOWITZ H. Incubation of incubators: innovation as a triple helix of university-industry-government networks. Science & Public Policy, **29** (2), 115, **2012**.
24. FROLUND L., MURRAY F., RIEDEL M. Developing successful strategic partnerships with universities. MIT Sloan Management Review, **59** (2), 71, **2018**.
25. BABA Y., IMAI K. Systemic innovation and cross-border networks: the case of the evolution of the VCR systems. Schumpeter Society Conference on Entrepreneurship, Technological Innovation and Economic Growth. held at Airlie House, VA, USA., 3-5, **1990**.
26. COOKE P., KEVIN M. The creative milieu: A regional perspective on innovation – the handbook of industrial innovation. Vermont: E. Elgar Pub. Co. **1994**.
27. LUNDVALL B.A. The origins of the national innovation system concept and its usefulness in the era of the globalizing economy. 13th Globelics Conference. Havana, Cuba. **2015**.
28. FAN H.J., HE S.J. Modern industrial system and Sustainable Economic Development: The moderating effect of economic policy uncertainty and the number of government talents. China Business and Market, **35** (12), 16, **2021**.
29. CALIARI T., RIBEIRO L. C., PIETROBELLI C., VEZZANI A. Global value chains and sectoral innovation systems: An analysis of the aerospace industry. Structural Change and Economic Dynamics, **65**, 36, **2023**.
30. DROSTE N., HANSJURGENS B., KUIKMAN P., OTTER N., ANTIKAINEN R., LESKINEN P., THOMSEN M. Steering innovations towards a green economy: Understanding government intervention. Journal of Cleaner Production, **135**, 426, **2016**.
31. PARKS D. Directionality in transformative innovation policy: who is giving directions? Environmental Innovation and Societal Transitions, **43**, 1, **2022**.
32. WANG S.J. Misunderstanding and correction of coupling coordination degree model in China. Journal of Natural Resources, **36** (3), 793, **2021**.
33. YUAN Y., LI L.H. Study on the coupling coordination effect of digital economy, technological innovation and high-quality economic development. Journal of Industrial Technological Economics, **351** (1), 45, **2023**.
34. LIANG S.G., ZHANG P.P., ZANG W.J. Research on Coupling Coordination Degree and Coupling Path of Manufacturing Innovation Chain, Industrial Chain and Capital Chain. The world of study and research. **352** (1), 52, **2023**.
35. SMALLBONE D., SARIDAKIS G., ABUBAKAR Y.A. Internationalization as a stimulus for SME innovation in developing economies: Comparing SMEs in factor-driven and efficiency-driven economies. Journal of Business Research, **144**, 1305, **2022**.
36. LIANG W.L., HUANG R.L. Measurement and evaluation of the integration degree of "three chains" in Jiangsu High-tech Industry: An empirical study based on the synergy degree model of composite system. Modern Management Science, **332** (1), 51, **2022**.
37. LIU J.S., SHI H.B., QI X. Research on the integration Path of innovation Chain and capital Chain: Configuration

analysis based on the theoretical framework of symbiosis of regional innovation Ecosystem. Scientific management research, **40** (01), 153, **2022**.
38. FU B.Z., SHENG C.X., XU J.W., ZHOU J., REN J.Q. Accelerating the development of a modern industrial system featuring coordinated development of the real economy, scientific and technological innovation, modern finance, and human resources. Macroeconomic Research, **4**, 41, **2019**.