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Research on the Coupling Development of Industry Chain and Innovation Chain in Xianyang City

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Abstract: *Promoting the integration of industry chain and innovation chain is an important implementation path to promote industrial transformation and upgrading, as well as high-quality economic development. Xianyang City has made significant progress in the integration of industry chain and innovation chain, but still faces challenges such as insufficient local transformation of scientific and technological achievements and limited technology transfer capacity. To further enhance the benefits of transformation of scientific and technological achievements, deepen the integration of innovation chain and industry chain, and realize the benign interaction between technology and industry, we use a coupling coordination degree model and a grey correlation degree model to quantitatively analyze the coupling development of the industry chain and innovation chain in Xianyang City. The results show that: With the overall development of Xianyang City, (1) the industry chain and innovation chain have gradually transitioned from low-level imbalanced development to high-level balanced development; (2) The coupling and coordination of the industry chain and innovation chain are showing a good upward trend; (3) Compared to the industry chain, the elements of the innovation chain contribute more to the overall level of coupling and coordination between the innovation chain and the industry chain, that is, the innovation chain has a higher degree of impact on coupled development.*

Keywords: *Xianyang City; Industry chain; Innovation chain; Coupling development*

1. The current situation of the integration and development of the industry chain and innovation chain in Xianyang City

The integration of industry chain and innovation chain has become an important measure for countries around the world to evaluate and improve their international competitiveness[1]. In the context of globalization, focusing on major industrial applications and key technological breakthroughs in the industry, effectively integrating and coordinating the innovation chain and industry chain has become the fundamental factor determining industrial innovation capability. The digitization of the industry chain is an important driving force for improving energy efficiency and achieving sustainable development[2]. The deep integration of innovation chain and industry chain is the core driving force of science and technology-driven economic growth, and is a necessary way to realize benign interaction between technology and industry, as well as high-quality economic and social development[3]. The construction of an innovative country and the implementation of the innovation-driven development strategy require the deployment of the innovation chain around the industry chain[4]. Academic research on the transformation of scientific and technological achievement under the integration of innovation chain and industry chain has made some progress. Gao Y & Li Y[5] analyzed the coupling between innovation chain and industry chain in Henan Province based on the onion model. Wang R[6] took the elements as the entry point and put forward the theoretical logic and operation mechanism of promoting the coupling between industry chain and innovation chain from the perspective of elements. Li Z[7] constructed a theoretical mechanism for the integration of innovation chain and industry chain ecology based on the theory of innovation ecology. Li H et al. [8] joined the talent chain and education chain on the basis of integrating the industry chain and innovation chain, and explored the construction path of municipal industry-education consortium. Huang X[9] analyzed the integration path between the industry chain and innovation chain of the equipment manufacturing industry cluster based on four elements: production input, market supply, subject cooperation, and results transformation. Scholars have also conducted research from the perspective of factors influencing the integration of industry chain and innovation chain.

For example, Jia W et al. [10] used a fixed effects model to empirically analyze the impact of digital basic technology and digital application technology on the integration of industry chain and innovation chain, and explored the moderation effect of industrial policy on their relationship.

As an important production and economic center city in central Shaanxi Province, Xianyang City is the core area for science and technology innovation and high-quality development in the Guanzhong region. With the unveiling of the Xianyang Branch Center of the Innovation Driven Science and Technology Achievement Transformation Service Center of the China Association for Science and Technology, Xianyang City actively promotes the cooperation between industries, universities and research institutes, and promotes the transformation of scientific and technological achievements to a new level. At present, Xianyang City has made significant progress in the integration of industry chain and innovation chain, but still faces challenges such as insufficient local transformation of scientific and technological achievements, limited capacity to undertake technology transfer, and fails to fully release the advantages of scientific and technological resources into industrial development momentum. To further enhance the benefits of the transformation of scientific and technological achievements, it is necessary to deepen the integration of innovation chain and industry chain, realize the benign interaction between technology and industry, and achieve high-quality economic and social development. Therefore, this paper focuses on Xianyang City, quantitatively analyzing the coupling development status of the industry chain and innovation chain in Xianyang City through the coupling coordination degree model and grey correlation degree model, and proposing relevant recommendations to promote the innovation ecology of high-tech industries in Xianyang City.

2. The coupling and coordination mechanism between the industry chain and innovation chain in Xianyang City

2.1 The connotation of coupling between industry chain and innovation chain

As early as 1950, the international academics began to study the industry chain. Hirschman[11] suggested that the economy is developed through industries that have a series of forward and backward connections in the input-output relationships. Since then, many scholars began to explore the connotation of the industry chain in depth and believed that the industry chain refers to the interdependence and connection and the formation of close connections through cooperation and coordination among different industrial links. Such linkages include vertical relationships between upstream and downstream enterprises, and horizontal relationships between different enterprises in the same industry. The understanding of the innovation chain began with the phased activities of innovation orientation between forward and backward linked enterprises of Marshall and Vredenburg's research[12]. It is now believed that the innovation chain refers to the process of introducing new scientific and technological knowledge to improve production efficiency and create new market opportunities and competitive advantages by changing or introducing new products, services, production processes, forms of organization and so on.

The integrated development of industry chain and innovation chain is not a simple superposition of the two concepts, but based on the core position of enterprises as the main body, closely focusing on the urgent needs of national development and strategic planning, comprehensive integration of policy guidance, capital investment, talent pooling, market expansion and other key elements of resources. The demand of the upstream of the industry chain will directly affect the development direction of the innovation chain, while the technological innovation of the innovation chain provides support for the industry chain in terms of new production processes, product design, etc., thus driving the development of the industry chain. The industry chain and innovation chain together build a complete industrial ecosystem, with interdependence and mutual promotion among the links. In this ecosystem, the innovation chain provides new technologies and products for the industry chain, while the industry chain provides market demand and application scenarios for the innovation chain.

2.2 The Mechanism of Coupling and Coordination between Industry Chain and Innovation Chain

The coordinated development of the coupling between the industry chain and the innovation chain is a continuous and dynamic process, and its core lies in building a long-term mechanism to ensure the organic integration of the elements of the innovation chain and the industry chain. Based on the perspective of elements, the operational mechanism of dual chain coupling involves multiple elements such as government guidance, market demand driven, and interest driven. Firstly, government policies play a crucial role in the dual chain coupling, guiding and coordinating resource integration in various

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links through policy tools such as talent, industrial technology, and innovative technology development, finance, providing solid support for the operation of the dual chain coupling mechanism. At the same time, as the decisive force in resource allocation, the market guides the flow of talent, technology, and capital through changes in demand, promoting the optimization of element resource allocation. Secondly, the balance of interests is the key driving force for dual chain coupling. The reasonable distribution of interests among innovation entities, technology entities, and funding entities can motivate all parties to actively participate and promote the smooth progress of innovation and industrial activities. Only when the interests of all parties are balanced and satisfied can innovative achievements be transformed, the industry chain can receive sustained innovation support, and thus achieve transformation and upgrading.

In the process of dual chain coupling, the chain of elements such as the talent chain, technology chain, and capital chain do not operate in isolation, but are intertwined and interact with each other. Talents are the carriers of technology, and the realization of the value of technology depends on financial support, while the return of capital depends on the industrialization and marketization of technology. This interdependence and mutual influence relationship promotes the factor chains to play a synergistic role in the dual chain coupling and jointly promote the coordinated development of the industry chain and innovation chain. Therefore, to realize the coordinated development between the industry chain and the innovation chain, it is necessary to build a long-term mechanism, fully leverage the roles of the government, market, and interest mechanisms, and promote the deep integration and effective allocation of elements between the innovation chain and the industry chain[4].

3. Research Design

3.1 Data sources

Considering the completeness and availability of comprehensive data, this paper selects relevant data at the municipal level in Xianyang City, Shaanxi Province from 2012 to 2022. The data of the industry chain subsystem is from the Xianyang Statistical Yearbook and the Statistical Bulletin of National Economic and Social Development of Xianyang City, while the data of the innovation chain subsystem is from the Shaanxi Science and Technology Yearbook and the China Torch Statistical Yearbook, with comprehensive reference to official websites such as the National and Shaanxi Provincial Bureau of Statistics and the Xianyang Municipal Bureau of Statistics. Partial missing data will be supplemented by nearest interpolation and mean interpolation methods in this paper.

3.2 Research Methods

3.2.1 Entropy method

The entropy method, as a relatively objective and widely used multi-attribute decision analysis method, plays an important role in the comprehensive evaluation of multiple indicators. Its main idea is to determine the weight of each attribute by calculating the entropy value of each attribute's contribution to the comprehensive decision, thereby effectively weighing the degree of difference between various indicators in the system. Compared with traditional subjective assignment methods such as Delphi method and multi-level analysis method, entropy method can calculate multiple indicator weights without subjective assignment, and the calculation results are scientifically reliable. Therefore, it is widely used in multi-attribute decision analysis. This paper uses the entropy method to assign values to the constructed indicator system for the industry chain and innovation chain in Xianyang City, converting the relative importance of each indicator into numerical values, providing scientific and quantifiable basis for subsequent measurement and comprehensive evaluation.

3.2.2 Weighted average method

The weighted average method, as a multi-attribute decision analysis method with basic comprehensive indicators, considers the evaluation indicators of each system as independent of each other and assigns weights to each indicator. After weighted scoring, decision-makers analyze the system according to the high and low scores. Due to its simple calculation, easy understanding, and easy allocation of weights to different attributes, it is most widely used in multi-attribute decision-making methods. The main idea is to use the observations of the same variable arranged in chronological order in the past, and use the chronological order number as the weight to calculate the weighted arithmetic mean of the observations, finally, it uses this number as the comprehensive evaluation indicator. Therefore, this paper adopts the weighted average method to calculate the comprehensive evaluation values of the industry chain and innovation chain subsystems in Xianyang City.

3.2.3 Coupling Coordination Model

The coupling coordination model is an improvement of the commonly used decision analysis method. It is mainly used to evaluate the relationship and degree of influence between various indicators in the decision-making scheme of two or more systems or elements, and to provide guidance for adjusting the uncoordinated relationship to achieve the goal of comprehensive coordination. It is an important indicator scale for evaluating the coupling state. The basic idea of the coupling coordination model is to quantify the interrelationships between various indicators as coupling, in order to obtain comprehensive evaluation results. This paper uses the coupling coordination model to analyze the development of the industry chain and innovation chain in Xianyang City, and adopts the research results of scholar Liao Z[13] to divide the coupling coordination degree levels (as shown in Table 1).

Table 1: Coupling Coordination Degree Classification

Coupling level	Degree of coupling coordination D (Num)	Degree of coupling coordination	Coupling level	Degree of coupling coordination D (Num)	Degree of coupling coordination
1	0.00 ~ 0.09	Extreme disorder	6	0.50 ~ 0.59	Reluctant coordination
2	0.10 ~ 0.19	Severe disorder	7	0.60 ~ 0.69	Primary coordination
3	0.20 ~ 0.29	Moderate disorder	8	0.70 ~ 0.79	Intermediate coordination
4	0.30 ~ 0.39	Mild disorder	9	0.80 ~ 0.89	Good coordination
5	0.40 ~ 0.49	Border on disorder	10	0.90 ~ 1.00	High quality coordination

3.2.4 Grey correlation model

The grey correlation model is based on the grey correlation degree theory, which points out that there are differences in the reference value of each indicator due to different weights. It is used to study the correlation degree between different indicators involving multiple subjects, systems, or elements. The main idea of the grey correlation model is to calculate the correlation degree between multiple dimensional indicators in the research objective and weight them to obtain the grey correlation coefficients of different indicators. By comparing the correlation degree between each indicator, the main factors affecting the correlation degree can be identified. This paper mainly uses the grey correlation model to separately measure the coupling relationship and degree of the industry chain and innovation chain in Xianyang City, and ranks the contribution of the integration of the industry chain and innovation chain based on different indicators in the indicator system. The correlation level is divided into four levels according to the research results of Wu Y[14], as shown in Table 2.

Table 2: Grey Correlation Level Classification

Correlation Level	Interval	Degree of correlation
1	0.00 ~ 0.35	Low correlation
2	0.35 ~ 0.65	Medium correlation
3	0.65 ~ 0.85	Higher correlation
4	0.85~ 1	High correlation

3.3 Construction of indicator system

3.3.1 Construction of Industry Chain Evaluation Indicators

The industry chain is a dynamic network organization formed around the production or horizontal exchange, vertical cooperation, and alliance of different intermediate products, based on value appreciation, division of labor and cooperation, and industry self-selection, with the goal of pursuing the maximization of long-term interests[10]. In order to comprehensively understand the main factors affecting the high-quality development of the industry chain in Xianyang City, this paper combines the selection of relevant statistical indicators in previous literature, and characterizes the industry chain evaluation indicator system based on the principles of scientific nature, systematicity, and data accessibility. The final evaluation indicator system of the industry chain in Xianyang City is shown in

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Table 3.

Table 3: Industry Chain Evaluation Indicator System of Xianyang City

Subsystem	Level indicators	Secondary indicators	Factor	Unit of measurement	Indicator direction
Industry Chain	Development capability	Number of industrial enterprises above designated size	X_1	PCS	Positive
		Operating income of industrial enterprises above designated size	X_2	Ten Thousand Yuan	
		The average number of employees of industrial enterprises above designated size	X_3	Person	
	Industrial structure	Advanced: output value of the tertiary industry/output value of the secondary industry	X_4	%	
		Coordinated: output value of the tertiary industry/output value of the primary industry	X_5	%	
		Service-oriented: output value of the tertiary industry/total output value	X_6	%	

One is to measure the development capacity of the industry chain in Xianyang City using three indicators: "Number of industrial enterprises above designated size", "Operating income of industrial enterprises above designated size", and "Average number of employees of industrial enterprises above designated size". The indicator of "Number of industrial enterprises above designated size" represents the scale of the entire industry. The expansion of its scale is conducive to the vigorous development of the entire industry, promotes industrial division of labor, and thus achieves the extension, strengthening, and supplementation of the industry chain. The indicator of "Operating income of industrial enterprises above designated size" is the driving goal and source of industrial development, and is the foundation for forming industrial value. In addition, talent quality is an important support for the standardization and specialization of industrial development. The "Average number of employees of industrial enterprises above designated size" indicator can measure the economies of scale and innovation technology diffusion ability based on personnel, in order to improve the efficiency of the industry chain and promote the optimization and upgrading of the industry.

The second is to measure the industrial structure of the industry chain in Xianyang City using the proportional relationship between the output value of the primary industry, the output value of the secondary industry, and the output value of the tertiary industry, based on the three indicators of "advanced", "coordinated", and "service-oriented". Among them, "Advanced" adopts the ratio of the output value of the tertiary industry to the secondary industry. The secondary industry dominates among the three major industries, while the tertiary industry plays an important role in the industry chain. Therefore, the ratio of the two can better reflect the degree of industry chain upgrading in a certain region. "Coordinated" adopts the output value of the tertiary industry and the primary industry. Among the three major industries, the output value of the primary industry is at the bottom. With the continuous upgrading of the industry chain, the gap between the output value of the tertiary industry and the primary industry continues to widen. Therefore, the larger the ratio of the output value of the tertiary industry to the output value of the primary industry, the less coordinated the industry chain is. "Service-oriented" emphasizes that the industrial structure should be based on industrial innovation, continuously break the lock of the economic structure at the low-end, and complete the evolutionary iteration from the low-end to the high-end. Compared with the primary industry and secondary industry, the proportion of the tertiary industry has increased, thereby improving the efficiency of resource allocation; At the same time, it also makes the market system sounder, so this paper chose to represent the proportion of the output value of the tertiary industry in the total output value.

3.3.2 Construction of evaluation indicators for innovation chain

The innovation chain is a creative system composed of innovative elements, guided by meeting market demand, connecting relevant innovation participants through knowledge innovation activities to achieve the economic process of knowledge and the optimization goals of the innovation system. Drawing on existing research results, this paper evaluates the innovation chain from three dimensions: innovation input, innovation output, and innovation environment. It constructs an innovation chain evaluation indicator system that includes six secondary indicators, as shown in Table 4.

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Table 4: Evaluation Indicator System for Innovation Chain in Xianyang City

Subsystem	Level indicators	Secondary indicators	Factor	Unit of measurement	Indicator direction
Innovation chain	Innovation investment	R&D personnel equivalent to full-time equivalent	X_7	Person	Positive
		Internal expenditure of R&D funds	X_8	Thousand Yuan	
	Innovation output	Number of valid patent inventions	X_9	PCS	
	Innovation environment	Number of higher education institutions	X_{10}	PCS	
		Number of high-tech enterprises in the high-tech zone	X_{11}	PCS	
		Financial technology funding	X_{12}	Ten Thousand Yuan	

One is to use two indicators, "R&D personnel equivalent to full-time equivalent" and "Internal expenditure of R&D funds", to measure the investment of the innovation chain in Xianyang City. Among them, "R&D" refers to the systematic and creative activities carried out in the field of science and technology to increase the total amount of knowledge and apply this knowledge to create new applications. Internationally, the scale and intensity indicators of R&D activities are commonly used to reflect a country's technological strength and core competitiveness. "R&D personnel equivalent to full-time equivalent" refers to the total number of full-time personnel plus non full-time personnel converted to full-time personnel based on workload, which can directly reflect the investment of technology personnel in the innovation chain. "Internal expenditure of R&D funds" refers to the actual expenditure of research units used for internal R&D activities (such as basic research, applied research, and experimental development), which can reflect the level of technological investment in the innovation chain.

The second is to use the indicator of "Number of valid patent inventions" to measure the innovation output of the innovation chain. "Number of valid patent inventions" is intended to measure the output of projects initiated and research conducted in the current year, which can represent the effective output of the innovation chain in that year.

The third is to use three indicators: "Number of higher education institutions", "Number of high-tech enterprises in the high-tech zone", and "Financial technology funding" to measure the innovation environment of the innovation chain in Xianyang City. In the actual innovation chain, national high-tech zones serve as the cradle of innovation, and high-tech enterprises play a supporting and leading role in the entire innovation chain. At the same time, enterprises collaborate with higher education institutions, coupled with the government's financial support, to ultimately form a good innovation environment and stimulate the vitality of the innovation chain.

4. Empirical analysis

4.1 Coupling coordination analysis

4.1.1 Analysis of comprehensive development level

This paper takes the panel data of Xianyang City from 2012 to 2022 as the sample, and based on the evaluation system of industry chain and innovation chain constructed in Section 3.3, uses the entropy method to calculate the development level of the industry chain and innovation chain in Xianyang City. We measure the industry chain and innovation chain indicator system constructed earlier in Xianyang City by using this systematic evaluation method, which can provide scientific support for the next step of measuring the comprehensive development level, in order to have a more comprehensive understanding of the development of the industry chain and innovation chain in Xianyang City. Due to the different dimensions of each variable, it will affect the quantitative relationship between the variable data. Firstly, it is necessary to use the range method to perform dimensionless processing on the data sample[15] to avoid errors caused by inconsistent statistical units of indicators. Then, the weight W_j of each indicator is calculated. The specific calculation results are shown in Table 5:

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Table 5: The weight of the evaluation indicator system for the industry chain in Xianyang City

Level indicators	Secondary indicators	Information entropy value	Weight coefficient(%)
Development capability	Number of industrial enterprises above designated size	0.9920	11.8640
	Operating income of industrial enterprises above designated size	0.9926	10.9470
	The average number of employees of industrial enterprises above designated size	0.9890	16.2443
Industrial structure	Advanced: output value of the tertiary industry/output value of the secondary industry	0.9830	25.1632
	Coordinated: output value of the tertiary industry/output value of the primary industry	0.9917	12.3047
	Service-oriented: output value of the tertiary industry/total output value	0.9842	23.4767

From the weight of the indicators obtained in Table 5, it can be seen that the first level indicator that affects the development of the industry chain in Xianyang City is “Industrial structure”, accounting for 60.94% of the weight; The second most influential factor is “Development capability”, accounting for a weight of 39.06%. From Table 5, it can be seen that the secondary indicators that have a relatively significant impact on the development of the industry chain in Xianyang City are “Advanced”, “Service-oriented”, and “Coordinated”, with weights of 25.16%, 23.48%, 12.30%, respectively.

Table 6: The weight of the evaluation indicator system for the innovation chain

Level indicators	Secondary indicators	Information entropy value	Weight coefficient(%)
Innovation investment	R&D personnel equivalent to full-time equivalent	0.9895	13.4626
	Internal expenditure of R&D funds	0.9904	12.3165
Innovation output	Number of valid patent inventions	0.9904	12.3353
Innovation environment	Number of higher education institutions	0.9774	28.9680
	Number of high-tech enterprises in the high-tech zone	0.9908	11.8146
	Financial technology funding	0.9836	21.1029

From the weight of the indicators obtained in Table 6, it can be seen that the first level indicator that affects the development of the innovation chain in Xianyang City is “Innovation environment”, accounting for 61.88% of the weight; The second most influential factor is “Innovation investment”, accounting for a weight of 25.78%; The third most influential factor is “Innovation output”, accounting for a weight of 12.34%. From Table 6, it can be seen that the secondary indicators that have a relatively significant impact on the development of the innovation chain in Xianyang City are “Financial technology funding”, “Number of higher education institutions” and “Number of high-tech enterprises in the high-tech zone”, with weights of 28.97%, 21.10%, and 11.81%, respectively.

4.1.2 Coupling coordination analysis

Based on the development indicators of the industry chain and innovation chain mentioned earlier, the weighted average method is used to calculate the comprehensive evaluation values of the two subsystems (industry chain and innovation chain) in Xianyang City. Then, a coupling coordination model is used to calculate the coupling coordination of the development of the industry chain and innovation chain in Xianyang City from 2013 to 2023, in order to determine the degree of coordination between the development of the industry chain and the innovation chain. The formulas for calculating the comprehensive evaluation value and coupling coordination degree of subsystems are as follows:

(1) Calculation of comprehensive evaluation values for subsystems

$$U_{1i} = \sum_{j=1}^{m} X_{ij} W_{ij} \tag{1}$$

$$U_{2i} = \sum_{j=1}^{m} X_{ij} W_{ij} \tag{2}$$

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Among them, U_1 is the comprehensive evaluation value of the industry chain in Xianyang City, and U_2 is the comprehensive evaluation model of the innovation chain in Xianyang City; X_{ij} is the result of data standardization; W_{ij} is the weight of the relevant indicator.

(2) Coupling coordination calculation

$$C = \sqrt{(U_1 \cdot U_2)/(U_1 + U_2)^2} \tag{3}$$

$$T = \alpha \cdot U_1 + \beta \cdot U_2 \tag{4}$$

$$D = \sqrt{C \cdot T} \tag{5}$$

In the formula, C represents the coupling degree between the industry chain and the innovation chain, with a value range of [0, 1]. The closer the value of C is to 1, the higher the coupling degree between the two; T is the coordination indicator, reflecting the comprehensive development level of the industry chain and innovation chain. α and β are undetermined coefficients, this paper refers to relevant research and assumes that the role of the industry chain and the innovation chain in coupled and coordinated development is equally important. Therefore, the two subsystems are given the same weight, that is $\alpha = \beta = 0.5$; D is the degree of coupling coordination between the industry chain and the innovation chain, with a value range of [0,1]. The closer the value of D is to 1, the higher the degree of coupling coordination between the two before. D is used to evaluate the coordinated development between the industry chain and innovation chain, the specific calculation results are shown in Table 7.

Table 7: The degree of coupling coordination between industry chain and innovation chain in Xianyang City (2012-2022)

Year	U_1	U_2	C	T	D	Coordination level	Coupling coordination degree	Coordination status
2012	0.1800	0.3180	0.9608	0.2490	0.4891	5	Border on disorder	Imbalanced development
2013	0.1998	0.3560	0.9597	0.2779	0.5164	6	Reluctant coordination	Coordinated development
2014	0.2729	0.4238	0.9762	0.3483	0.5832	6	Reluctant coordination	
2015	0.3318	0.4385	0.9903	0.3852	0.6176	7	Primary coordination	
2016	0.4180	0.4480	0.9994	0.4330	0.6578	7	Primary coordination	
2017	0.2321	0.1480	0.9752	0.1900	0.4305	5	Border on disorder	Imbalanced development
2018	0.2735	0.3296	0.9957	0.3016	0.5480	6	Reluctant coordination	Coordinated development
2019	0.5759	0.4279	0.9891	0.5019	0.7046	8	Intermediate coordination	
2020	0.5811	0.3576	0.9713	0.4693	0.6752	7	Primary coordination	
2021	0.6787	0.5872	0.9974	0.6329	0.7945	8	Intermediate coordination	
2022	0.6437	0.9534	0.9810	0.7985	0.8851	9	Good coordination	

According to the evaluation results in Table 7 and the classification criteria for coupling coordination, it can be seen that the overall coordination of the development of the industry chain and innovation chain in Xianyang City tends to be coordinated, with a range of coupling coordination changes between 0.4305 and 0.8851. Among them, in 2012, it was on the edge of disorder. From 2013 to 2016, the level of coordination increased, and the coordination situation improved from “Reluctant coordination” to “Primary coordination”; In 2017, the level of coordination plummeted to “Border on disorder”. From 2018 to 2022, the level of coordination continued to rise, optimizing from “Reluctant coordination” to “Good coordination”. The coordinated development of the industry chain and innovation chain in Xianyang City continued to improve. Except for a slight decrease in the coordination status of the industry chain and innovation chain in Xianyang City in 2017, the overall coordination status of the industry chain and innovation chain in Xianyang City has experienced steady improvement process, that

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is Reluctant-Primary-intermediate-good, indicating that the industry chain in Xianyang City has synchronized with the development of the innovation chain and has become an important driving force for sustained economic development.

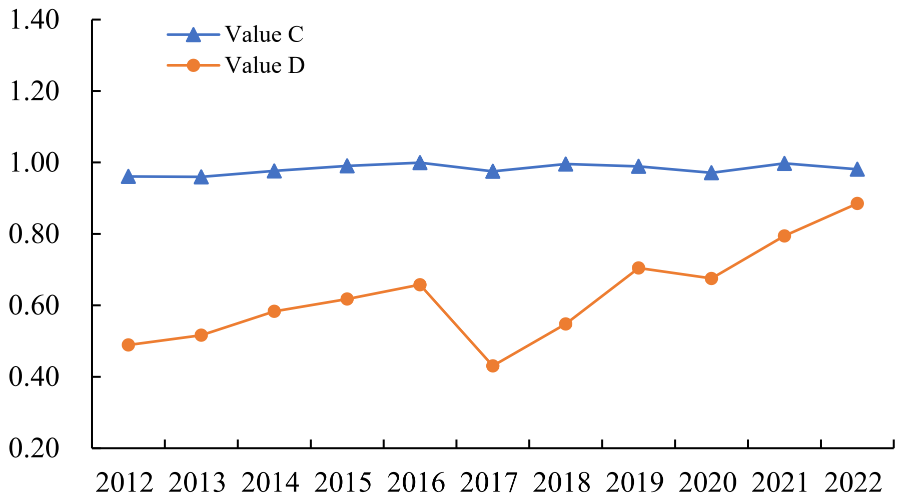

Figure 1: Changes of Value C and Value D in Xianyang City (2012-2022)

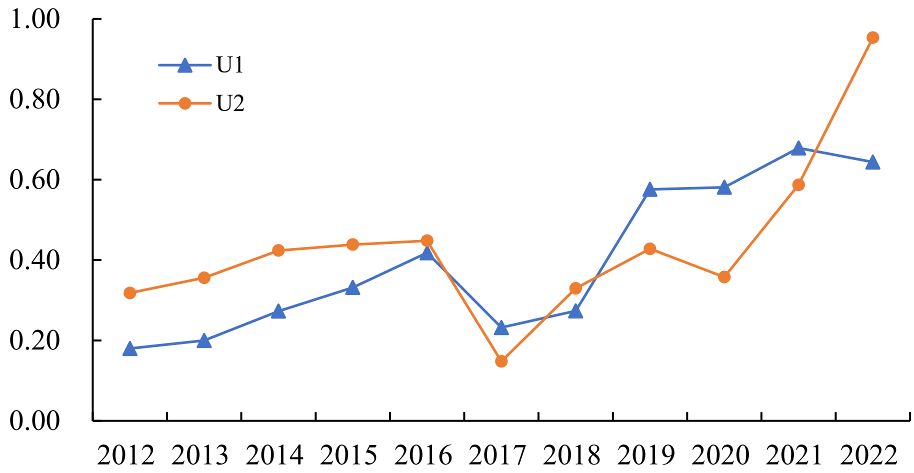

Figure 2: Changes in the Integration and Development of Industry chain and Innovation Chain in Xianyang City (2012-2022)

From Fig.1, it can be seen that the overall trend of the integrated development of the industry chain and innovation chain in Xianyang City from 2012 to 2022 is good. The results in Fig.2 show that the overall trend of the industry chain and innovation chain in Xianyang City from 2012 to 2022 is good and on the rise. From 2012 to 2016, the overall level of innovation chain development in Xianyang City was higher than that of the industry chain; From 2016 to 2018, the development of the innovation chain was slightly lower than that of the industry chain; In 2018, the innovation chain briefly surpassed the industry chain; Since 2018, the development of the industry chain in Xianyang City has been leading the innovation chain, which may be caused by the COVID-19; Since 2021, the gap between the two has widened, with a decline in industry chain and an increase in innovation chain. It can be seen that the industry chain in Xianyang City is a major driving force behind innovation chain, and the development of the innovation chain has also driven the development of the industry chain.

4.2 Grey correlation analysis

The previous comprehensively described the overall picture of the integration of industry chain and innovation chain through the coupling coordination model. The coupling interaction between industry chain and innovation chain forms a dynamic system, and its overall coupling level is inevitably influenced by each sub chain. Therefore, exploring the mechanism of the interaction between the industry chain and the innovation chain in the global coupling is an important way to clarify their internal

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operating mechanisms. To further analyze the specific factors of the interaction between the industry chain and innovation chain in Xianyang City on the system, this paper introduces the grey correlation analysis method based on the entropy method for calculation, and conducts further empirical research on the industry chain and innovation chain in Xianyang City.

Firstly, select the raw data related to the industry chain and innovation chain in Xianyang City from 2012 to 2022 (Table 8), including X_1 (Number of industrial enterprises above designated size), X_2 (Operating income of industrial enterprises above designated size), X_3 (Average number of employees in industrial enterprises above designated size), Advanced: X_4 (Output value of tertiary industry /Output value of secondary industry), Coordinated: X_5 (Output value of tertiary industry /output value of primary industry), Service-oriented: X_6 (Output value of tertiary industry/total output value), X_7 (R&D personnel equivalent to full-time equivalent), X_8 (Internal expenditure of R&D funds), X_9 (Number of valid patent inventions), X_{10} (Number of higher education institutions), X_{11} (Number of high-tech enterprises in the high-tech zone), and X_{12} (Financial technology funding).

Table 8: Related data on the industry chain and innovation chain in Xianyang City (2013-2023)

Year	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
2012	641	21256200	285096	45	146	26	1528	389477	565	13	0	3617
2013	708	24540800	253998	44	149	25	2150	583680	1529	13	0	2927
2014	776	26885300	249046	47	250	26	3180	638167	2049	13	15	3446
2015	874	29601000	247159	47	178	27	2995	761726	1764	13	20	4162
2016	956	34479924	251675	47	190	28	2862	843610	2305	13	19	4000
2017	727	29092417	192315	48	211	28	3004	814302	1788	11	18	4000
2018	720	25897000	164657	55	259	31	3212	340717	2079	11	24	16066
2019	698	25436203	165000	87	289	40	6485	122590	2656	11	36	16095
2020	725	23353871	153295	92	263	41	4541	484321	4385	11	46	10368
2021	781	29201297	141892	87	586	39	6096	1846786	6406	11	65	12575
2022	859	32781521	183122	80	263	38	6705	2031464	5915	13	97	13832

Secondly, the grey correlation system comprehensive evaluation method is adopted to calculate the specific factors of the interaction between the industry chain and innovation chain in Xianyang City on the system.

The specific steps of grey relational analysis method are as follows:

(1) Determine the reference sequence and comparison sequence, and note that the reference sequence in this paper represents the maximum value of each standardized set of indicators.

$$X_0\left\{X_0(1), X_0(2), \cdots, X_0(\mathrm{n})\right\} \tag{6}$$

$$X_1\left\{X_1(1), X_1(2), \cdots, X_1(\mathrm{n})\right\} \tag{7}$$

(2) Calculate correlation degree

$$\xi i(k)=\frac{\min_i \min_k \left|X_0(k)-X_i(k)\right|+\delta \max_i \max_k \left|X_0(k)-X_i(k)\right|}{\left|X_0(k)-X_i(k)\right|+\delta \max_i \max_k \left|X_0(k)-X_i(k)\right|} \tag{8}$$

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\xi_{\mathrm{i}}(k) \tag{9}$$

Among them, ξ_i is the grey correlation coefficient; δ is the resolution coefficient, and the range of values is [0, 1], usually taken as $\delta = 0.5$; γ_i is the degree of correlation, and the range of values is [0, 1]. The closer the value of γ_i is to 1, the stronger the correlation between system indicators. According to the above formulas, the grey correlation coefficients of 12 indicators in the industry chain and innovation chain systems were calculated. The calculation results and rankings are shown in Table 9:

The grey correlation calculation results (Table 9) show that the highest correlation between the industry chain and innovation chain in Xianyang City is "Number of higher education institutions" (X_{10}), followed by "Service-oriented": Output value of tertiary industry /total output value (X_6) and "R&D personnel equivalent to full-time equivalent" (X_7), with the three being the main factors. The least correlated are "Number of high-tech enterprises in the high-tech zone" (X_{11}) and "Coordinated": Output

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value of the tertiary industry/output value of the primary industry (X_5), with a relatively small impact.

Table 9: Grey correlation ranking

Correlation ranking	Indicators	Grey correlation degree
1	X_{10}	0.6970
2	X_6	0.5569
3	X_7	0.5496
4	X_{12}	0.5462
5	X_3	0.5434
6	X_2	0.5430
7	X_4	0.5257
8	X_9	0.5079
9	X_1	0.5028
10	X_8	0.4908
11	X_{11}	0.4655
12	X_5	0.4345

5. Conclusion and policy recommendations

This paper uses the coupling coordination model and grey correlation model to empirically analyze the degree of coupling between the industry chain and innovation chain in Xianyang City from 2012 to 2022. The following conclusions are drawn: (1) With the overall development of Xianyang City, the industry chain and innovation chain are transitioning from a state of “Border on disorder” to “Good coordination”, gradually transitioning from a low-level imbalance to a high-level balanced development; (2) The coupling and coordinated development trend of the industry chain and innovation chain is consistent, that is, "up-down-up". Overall, the coupling and coordination of the two show a good upward trend; (3) The innovation chain has a higher degree of impact on coupled development. Specifically, the elements of the innovation chain, such as the number of higher education institutions and R&D personnel, rank among the top contributors to the overall level of coupling and coordination between the innovation chain and the industrial chain. In order to promote the coupling development of the industry chain and innovation chain in Xianyang City, this paper proposes the following recommendations:

Shaping a new ecosystem of science and technology innovation, leading the development of industrial clusters. On the one hand, focusing on the development foundation of high-tech industries, laying out innovation chains around key industry chains such as new-energy and intelligent-connected vehicles, and biopharmaceuticals, construct a high-tech industry cooperation network through regional cooperation, promote the transformation and upgrading of high-tech industries in Xianyang through scientific and technological innovation, and consolidate the modernization level of Xianyang's high-tech industry chain; On the other hand, focusing on innovative resources and aiming at cutting-edge fields such as artificial intelligence and integrated circuits in the process of jointly building the National Science and Technology Center, focus on tackling a number of common and key core technologies in the industry chain, in order to form a new competitive advantage in the high-tech industry of Xianyang City.

Enhance the integration of industry chain and innovation chain by linkage and collaboration. Starting from the organic connection between production factors and innovation factors, cultivate a symbiotic and interactive relationship between high-tech industries in Xianyang, and improve the spatial synergy between the high-tech industry chain and innovation chain in Xianyang City. Continuously promote institutional and mechanism reforms, optimize the business environment, promote efficient flow of technology, funds, knowledge, talents, and information between regions, and promote more efficient transformation of innovative achievements into real productivity, as well as supporting and improving the industry chain; Construct and optimize the spatial layout of high-tech core enterprises and related enterprises in Xianyang City, promote the construction of the regional high-tech industry ecosystem in Xianyang City by creating and developing characteristic high-tech industry clusters with high spatial synergy.

Seize digital opportunities and develop high-tech industries. Enhance the collaborative agglomeration level of high-tech manufacturing and high-tech service industries in Xianyang City, and promote the integrated development of digital economy empowering industry chain and innovation chain. On the one hand, in the context of rapid development of the digital economy, high-end technological innovation services have become different from the past, and the high-tech manufacturing industry is increasingly

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dependent on them. Therefore, Xianyang City should seize the opportunity, promote the integration of services into the industry chain, and promote the transformation and upgrading of traditional manufacturing industries; On the other hand, the characteristics of the generation and diffusion of tacit knowledge make face-to-face communication essential for high-tech service enterprises. Xianyang City should emphasize that high-tech enterprises focus on their main business, improve division of labor, and promote the agglomeration of high-tech service industries, in order to promote the emergence of new industries, models, and formats.

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