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Research on Quality Evaluation of Innovation Chain and Industrial Chain Ecological Integration in Jilin Province —A Case Study of High-Tech Industry

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Abstract: Based on the theory of innovation ecology, this paper constructs a theoretical mechanism for the integration of innovation chain and industrial chain ecology. Based on the theory of ecological integration, ecological quality is introduced, the components of ecological integration quality are analyzed, and the evaluation index system of ecological integration quality of innovation chain and industrial chain is constructed. Through theoretical analysis, three ecological factors were extracted, including quality of structural elements, quality of dynamic optimization and quality of the relationship network. Based on the entropy weight method-mutation series method, the entropy value of ecological integration quality index of administrative units at the provincial (municipality and autonomous region) level in 2021 is calculated. Then it is carried out that the quality measurement and ranking by using the mutation system types of each level and the normalization formula to evaluate the quality of innovation chain and ecological integration of industrial chain of high-tech industry in Jilin Province. It will help to further promote the integrated development of high-tech industry innovation chain and industrial chain in Jilin Province.

1. Introduction

High-tech industry has the characteristics of high strategy, high profitability and high requirements, and can achieve high economic growth and low industrial energy consumption, and become a new element of high-quality economic development. The innovation level and industrialization level of high-tech industry are directly related to the scientific research and innovation ability of innovation chain group and the core competitiveness of industrial chain group. In the new development situation, the "chain" game between industry and innovation is replacing the product and innovation competition among individual enterprises [1], each chain group node must be closely integrated, and if any chain group node is broken, the whole chain cannot operate normally. Therefore, the integrated development of high-tech innovation chain and industrial chain affects the circular development of industrial economy and innovative economy.

Through the review of existing literature, it shows that the research on the integration of innovation chain and industrial chain focuses on the analysis of theoretical connotation and integration path, and lacks the dynamic development trend and ecological characteristics of integration development,and neglects the factors analysis and quality evaluation of integrated development.Therefore, this paper introduces the theory of "ecological quality" into the innovation chain and industrial chain ecological integration mechanism, constructs a model and evaluation system of innovation chain and industrial chain ecological integration quality elements, and emphasizes the sustainable development and high-quality development of the chain and group ecological integration system.[2]

2. Theoretical analysis

2.1 Analysis of constituent elements

This paper considers that ecological quality is the degree of meeting the requirements of ecological system, and describes the sum of innovative activities' ability to meet the ecological development.Innovation chain and industrial chain ecological integration Ecological quality should emphasize not only the integration of elements structure among the main body of the chain group, but also the ecological and adaptive development of the relationship between the chain group organizations.The quality of chain network includes not only the quality of inter-subject elements and the quality of structure, but also the effectiveness, stability and sustainability of ecological network relationship and dynamic adaptation ability of chain group organization.Therefore, this paper will build the quality component system of innovation chain and industrial chain ecological integration, which is the following model.[3]

2.1.1 Quality of structural elements

On the one hand, the accumulating factor resources gradually form the basis of the main body's R & D capability, and the composition of the quantity and quality of the factors is the material condition for the ecological integration of the industrial chain and the innovation chain.On the other hand, ecological integration is also reflected in the continuous optimization of the quality of the network structure. The network structure between different chain groups is the core and premise of the chain group innovation ecosystem, and is also an important part of the chain group ecological quality.

2.1.2 Quality of the relationship network

Ecological integration depends on the coordination and mutual support of the chain group relationship network, each chain group subject through industrial activities and technology docking, break through the chain group gap and subject restrictions to integrate the development of industry-university-research relationship, the multi-agent cooperation between the chain group is the basis of ecological integration, and the degree of cooperation also affects the stability of ecological integration development.At the same time, the degree of openness of the innovation industry environment among various subjects also affects the dynamic and diversified quality of ecological integration, and promotes the open exchange and cooperation of domestic and foreign chain groups, which helps to improve the endogenous impetus of innovation.[4]

2.1.3 Quality of dynamic optimization

In the process of dynamic evolution, ecological quality should reflect the self-organizing ability

of the main body of the chain group to organize innovation, competition and technological improvement;The ability of continuous optimization should reflect the continuous research and development of science and technology and patent application, and improve the ability to respond to technological changes and market changes;In the process of continuous adaptation between the internal system and the external environment, the biological quality should reflect the internal ecological capacity and dynamic adaptability to cope with the changes and impacts brought by the external environment.

3. Construction of index system

3.1 Evaluation system design

Table 1: Quality evaluation index system of innovation chain and industrial chain ecological integration

Overall index	Primary index	Secondary index	Three-level index
Ecological quality	Quality of structural elements(A1)	Main R&D capability(B1)	Number of enterprises(C1)
			Number of enterprises with R&D institutions(C2)
			Number of enterprises with R&D activities(C3)
			Number of new product items(C4)
		Structure optimization ability(B2)	The proportion of enterprises with R$D institutions(C5)
			The proportion of enterprises with R&D activities(C6)
			Proportion of R&D researchers(C7)
	Quality of the relationship network(A2)	Agent cooperation degree(B3)	External R&D expenditure(C8)
			Enterprise funds for internal expenditure of R&D funds(C9)
			Government funds for internal expenditure of R&D funds(C10)
		Environmental openness(B4)	Expenditure on technology introduction(C11)
			Expenditures for the purchase of domestic technology(C12)
	Quality of dynamic optimization(A3)	Self-organizing ability(B5)	R&D expenditure as a proportion of sales revenue(C13)
			R&D personnel accounted for the proportion of employees(C14)
			New product development funds(C15)
			The proportion of valid patents(C16)
		Continuous optimization capability(B6)	Profit growth rate(C17)
			Income rate(C18)
		Dynamic adaptability(B7)	Expenditures for technological transformation(C19)
			New product development and export level(C20)

Based on the above analysis of the quality factors of innovation chain and industrial chain ecological integration, this paper constructs an index system from three dimensions: factor structure quality, relationship network quality and dynamic optimization quality, and from seven aspects:

subject R&D ability, structure optimization ability, subject cooperation degree, environmental openness, self-organization ability, sustainable optimization ability and dynamic adaptation ability. Considering the availability and feasibility of economic data, 20 indicators were initially selected to measure the ecological quality of water level.[5] In order to prevent subjective assumptions, the principles of scientificity, feasibility and systematicness were followed in the selection of indicators, and the ecological quality evaluation index system was finally established, as shown in Table 1.

3.2 Description of data collection and research methods

The index data selected in this paper are from China High-tech Industry Statistical Yearbook. The lack of data in the district was serious, so it was not included in the study. According to the "China High-tech Industry Statistical Yearbook", this paper takes four high-tech industries of Jilin Province as the object of empirical research, and evaluates the ecological quality of high-tech industries in Jilin Province horizontally and vertically. Based on entropy weight method and mutation series method, this paper scores and ranks the ecological integration quality of provincial (municipality, autonomous region) level administrative units in 2021, and further evaluates the ecological integration quality of high-tech industry innovation chain and industrial chain in Jilin Province.[6]

4. Process of quality evaluation

Firstly, the mutation system types at each level of the evaluation index system can be determined according to the mutation series theory.[7] According to the normalization formula and mutation series model types, the ecological integration quality evaluation models of innovation chain and industrial chain are shown as follows:

$$A=\frac{\sqrt{A_1}+\sqrt[3]{A_2}+\sqrt[4]{A_3}}{3} \tag{1}$$

$$A_1=\frac{\sqrt{B_1}+\sqrt[3]{B_2}}{2} \tag{2}$$

$$A_2=\frac{\sqrt{B_3}+\sqrt[3]{B_4}}{2} \tag{3}$$

$$A_3=\frac{\sqrt{B_5}+\sqrt[3]{B_6}+\sqrt[4]{B_7}}{3} \tag{4}$$

4.1 The index weight based on entropy method

In order to ensure the fairness and objectivity of the weight coefficient, the index weight can be obtained by calculating the information entropy value of the index and then weighting the index. The specific steps are as follows:

4.1.1 Standardization of raw data

Considering that there are inconsistent units in the economic data indicators obtained, data are first processed without lines and standardized formulas are adopted as follows:

Positive indicators:

$$x_{ij}^{+}=\frac{x_{ij}-\min(x_{ij})}{\max(x_{ij})-\min(x_{ij})} \tag{5}$$

Negative indicator:

$$x_{ij}^{-} = \frac{\max\left(x_{ij}\right) - x_{ij}}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)} \tag{6}$$

4.1.2 Quantification of the index in the same degree

Equations (5) and (6) are used to carry out coordinate translation of the standardized data. Where A is the translation amplitude, and the closer the value of A is to $\min X_{ij}''$, the more significant the evaluation result will be. In this study, $A = 0.00001$, the proportion of each indicator in each sample is calculated by the operational formula (8).

$$X_{ij}'' = X_{ij}' + A \tag{7}$$

$$Y_{ij} = X_{ij}'' / \sum_{i=1}^{m} X_{ij}''(i = 1,2,\cdots\cdots,m; j = 1,2,\cdots\cdots,n) \tag{8}$$

4.1.3 Calculation of the index information entropy

Formula (9) is used to calculate the information entropy of each indicator, and according to the information entropy, formula (10) is used to obtain the utility value of the indicator.

$$e_j = -k\sum_{i=1}^{m}\left(Y_{ij}\ln Y_{ij}\right), k = 1/\ln(m) \tag{9}$$

$$d_j = 1 - e_j \tag{10}$$

4.1.4 Calculation of index weight

Formula (11) is used to determine the weight of the secondary index.According to the additivity of entropy, the weights of first-level indexes are determined by the formulas (12), (13) and (14).The results are shown in Table 2.

$$w_j = d_j / \sum_{j=1}^{n} d_j \tag{11}$$

Calculated the sum of utility values D_k for each category of indicators in the lower layer:

$$D_k = d_1 + d_2 + \cdots\cdots + d_k\left(k = 1,2,\cdots\cdots,k\right) \tag{12}$$

Calculate the sum of all indicator utility values D:

$$D = D_1 + D_2 + \cdots\cdots + D_k \tag{13}$$

The corresponding upper index weights are:

$$W_k = D_k / D \tag{14}$$

Table 2: Comprehensive weights of the evaluation index system of ecological integration quality of the innovation chain of high-tech industries

Overall index	Primary index	Secondary index	Three-level index
Ecological quality	A1:Quality of structural elements(0.283136175)	B1:0.247657748	C1:0.054160885
			C2:0.082932845
			C3:0.056522759
			C4:0.054041258
		B2:0.035478428	C5:0.022754774
			C6:0.006064514
			C7:0.006659139
	A2:Quality of the relationship network(0.449918786)	B30.191169411	C80.087138222
			C9:0.060092394
			C10:0.043938796
		B4:0.258749375	C11:0.157334855
			C12:0.10141452
	A3:Quality of dynamic optimization(0.266945038)	B5:0.096160672	C13:0.012377608
			C14:0.009800881
			C15:0.065131255
			C16:0.008850927
		B6:0.022264894	C17:0.01239667
			C18:0.009868224
		B7:0.148519473	C19:0.073361709
			C20:0.075157764

4.2 Evaluation of integration quality ecological

4.2.l Empirical analysis

After the ranking results of each index are obtained, the relevant calculation of the mutation system model is carried out according to the ranking results. The embodied calculation process is as follows:

First, secondary index system.The R&D capability of the main body includes four tertiary indicators, which belong to butterfly mutation. The aggregate weight is ranked as C2>C3>C1>C4, and the average value is selected according to the principle of system complementarity,then: $x_{B1}=\frac{\sqrt{C2}+\sqrt[3]{C3}+\sqrt[4]{C1}+\sqrt[5]{C4}}{4}=0.438759$.The structural optimization ability includes three three-level indicators, which belong to dovetail mutation. The comprehensive weight is ranked as C5>C7>C6, and the average value is selected according to the principle of system complementarity,then: $x_{B2}=\frac{\sqrt{C5}+\sqrt[3]{C7}+\sqrt[4]{C6}}{3}=0.773512$.The degree of agent cooperation includes three three-level indicators, which belong to the swallow tail mutation. The comprehensive weight order is C8>C9>C10, and the minimum value is selected according to the principle of system non-complementarity,then: $x_{B3}=MIN\left(\sqrt{C8},\sqrt[3]{C9},\sqrt[4]{C10}\right)=0.350782$.Environmental openness includes two three-level indicators, which belong to cusp mutation. The comprehensive weight order is C11>C12, and the average value is selected according to the principle of system complementarity, then: $x_{B4}=\frac{\sqrt{C11}+\sqrt[3]{C12}}{2}=0.320391$.Self-organizing ability includes four tertiary indicators, which belong to butterfly mutation. The comprehensive weight order is C15>C13>C14>C16, and the average value is selected according to the principle of system complementarity,then: $x_{B5}=\frac{\sqrt{C15}+\sqrt[3]{C13}+\sqrt[4]{C14}+\sqrt[5]{C16}}{4}=0.764686$.The continuous optimization ability

includes two three-level indicators, which belong to cusp mutation. The comprehensive weight ranking is C17>C18, then: $x_{B6}=\frac{\sqrt{C17}+\sqrt[3]{C18}}{2}=0.994030$.Dynamic adaptability includes two three-level indicators, which belong to cusp mutation. The comprehensive weight ranking is C19>C20, $x_{B7}=\frac{\sqrt{C20}+\sqrt[3]{C19}}{2}=0.318299$.

Table 3: The ecological quality evaluation of national high-tech industry in 2021

Province	Quality of innovation relationship	Quality of innovation relationship	Quality of dynamic optimization	Ecological quality	Sort
Beijing	0.819685	0.579150	0.825712	0.883380	5
Tianjin	0.787080	0.368410	0.759454	0.821262	16
Hebei	0.803458	0.443493	0.727403	0.839707	12
Shanxi	0.713084	0.281547	0.676881	0.777018	23
Inner Mongolia	0.728176	0.216421	0.664284	0.755888	27
Liaoning	0.772013	0.371157	0.749979	0.819063	18
Jilin	0.720090	0.354115	0.688278	0.800744	19
Heilongjiang	0.759537	0.316860	0.716605	0.798455	20
Shanghai	0.778581	0.460005	0.772122	0.845196	11
Jiangsu	0.913356	0.627664	0.890645	0.911319	2
Zhejiang	0.921073	0.539291	0.849031	0.889081	4
Anhui	0.859185	0.470633	0.805735	0.861376	7
Fujian	0.823376	0.491780	0.824386	0.863804	6
Jiangxi	0.834391	0.345194	0.773043	0.822213	15
Shandong	0.862807	0.582675	0.825184	0.889477	3
Henan	0.799001	0.361096	0.775726	0.822443	14
Hubei	0.845743	0.425394	0.785213	0.846416	10
Hunan	0.832384	0.460241	0.784479	0.853403	8
Guangdong	0.968667	1.000000	0.962837	0.993340	1
Guangxi	0.709060	0.240440	0.660757	0.761219	25
Hainan	0.768893	0.318723	0.639433	0.791637	21
Chongqing	0.817330	0.381256	0.765409	0.829260	13
Sichuan	0.832557	0.447888	0.778103	0.849730	9
Guizhou	0.773945	0.213872	0.706583	0.765808	24
Yunnan	0.750567	0.284470	0.660281	0.781192	22
Shaanxi	0.780207	0.376673	0.741841	0.820799	17
Gansu	0.713364	0.227482	0.683335	0.759889	26
Qinghai	0.382569	0.155722	0.580264	0.664448	29
Ningxia	0.737408	0.073543	0.698438	0.696271	28
Xinjiang	0.562928	0.000000	0.266245	0.514672	30

Second, the first level index system.he factor structure quality includes two secondary indexes, which belong to cusp mutation system, and the index importance is B2>B1. The average value is selected according to the principle of system complementarity,then: $x_{A1}=\frac{\sqrt{B2}+\sqrt[3]{B1}}{2}=0.819685$.The quality of the relationship network includes two secondary indexes, which belong to the cusp sudden change system, and the importance degree of the indexes is B4>B3. The average value is selected according to the principle of system complementarity,then: $x_{A2}=\frac{\sqrt{B4}+\sqrt[3]{B3}}{2}=0.579151$.The quality of dynamic optimization includes three secondary indexes, which belong to the dovetail mutation. The comprehensive weight ranking is B7 > B5 > B6, and the average value is selected according to the principle of system complementarity,then: $x_{A3}=\frac{\sqrt{B7}+\sqrt[3]{B5}+\sqrt[4]{B6}}{3}=0.825712$.

Third, the total index system.The overall index ecological integration quality includes 3 first-level indicators, which belong to dovetail mutation. The aggregate weight is ranked as A2 > A1 > A3, and the average value is selected according to the principle of systematic complementarity, then: $x_A = \frac{\sqrt{A2} + \sqrt[3]{A1} + \sqrt[4]{A3}}{3} = 0.883380$.

According to the above calculation methods and steps, the evaluation results of the ecological integration quality of the remaining 29 provincial administrative units can be obtained, and the evaluation results are sorted and summarized, as shown in Table 3.

5. Conclusion

Based on the evaluation results obtained in Table 3, on the whole, the overall level of ecological integration quality of high-tech industry innovation chain and industrial chain in 30 provinces (autonomous regions and municipalities) is not high, and there is a large difference in quality between provinces, showing an unbalanced development trend. Among them, Guangdong is far ahead in the quality level of ecological integration in the country, and the ecological integration quality in East China is the first in the country. More provinces in high-quality integrated development are distributed in Beijing-Tianjin-Hebei Region, Yangtze River Delta, Pearl River Delta region. With a strong industrial base and significant innovation advantages, high-tech industries have matured and continue to provide capital and talent support for innovation and development, forming a trend of ecological integration of high-quality innovation chains and industrial chains.

Locally, the overall ecological quality of Northeast China is low, and the internal differentiation is serious, and the ecological quality of Jilin Province in Northeast China is at the middle level.J ilin Province is relatively low in the comprehensive score ranking, indicating that its ecological quality is low; The scores of various quality indicators are also not high, reflecting that the integration relationship between production, university and research is not close, the efficiency level of factors is not high, the innovation ecological structure is not perfect, and the dynamic optimization quality is not high. The phenomenon of overall function decline is caused by the low level of factor construction, indicating that the internal structure of ecological quality in Jilin Province needs to be improved, and the indicators of ecological integration quality also need to be improved. This also reflects that the evolution process of the innovation chain and the ecological development of the industrial chain of high-tech industry in Jilin Province is relatively slow, at the primary level and needs to be improved and upgraded, and has not yet realized the sustainable development of self-organization, continuous optimization and dynamic adaptation.

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