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Research on Health Evaluation of Sustainable Regional Innovation Ecosystems Based on Improved Niche Suitability Model

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Abstract

While researchers have used the traditional index system – part of the niche-fitness model – to evaluate the innovation ecosystem, this index system can be seen as not being sufficiently objective, with the consequent problem that it gives equal weight to the indicators and so does not specify the important factors. To remedy this problem of insufficient objectivity, this paper seeks to improve the traditional niche-fitness model in two ways, which are based on the theory of the innovation ecosystem. First, by introducing the principal components analytic method to solve multiple mutual linear problems. Second, by constructing a new evaluation index system from the four aspects of openness, synergy, sustainability, and growth. This new evaluation index system is closer to the characteristics of the organic and evolutionary nature of the sustainable innovation ecosystem compared with the traditional index system. By using the evaluation index system, the research carries out a health assessment for the sustainable innovation ecosystems in different regions of provincial and municipal China from the two perspectives of descriptive and quantitative analyses. Through these analyses, our findings suggest that the sustainable regional innovation ecosystems in China are, on the whole, in an imbalance: there is a gradual decreasing trend from the eastern coastal areas to the central and western regions, and then the northeast regions.

Keywords

sustainable regional innovation ecosystem; ecological health; niche-fitness; PCA; evaluation; sustainable development

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1. Introduction

Innovation is the source of enterprise value creation, an important driving force for regional economic development, and the core competitiveness of a country. Academia has never stopped exploring the factors that induce innovation, ways to make innovation sustainable, and evaluation of innovation capabilities. So far, researches on the innovation system have been conducted and improved by scholars at home and abroad, starting a new round of upgrading from an emphasis on speed and engineering technology to an organic innovation ecosystem of artificial intelligence and ecological transition to achieve balanced and sustainable development of economy and nature. The fundamental idea behind the organic innovation ecosystem is to extend the capacity of an actor beyond its boundary and to cooperate with others to transform knowledge into innovation (Adner, 2006). Only by forming a stable ecosystem, can we provide continuous impetus for innovation and promote the transformation of innovation ideas to products and then achieve regional sustainable development. Yawson (2009) noted that one of the reasons for the emergence of a sustainable innovation ecosystem was the failure of traditional innovation models to provide successful policy strategies to promote innovation at the national level. He argued that evidence-based platforms for innovation policies needed to be extended beyond input-output relevance, such as research and development (R&D) and patent counts. Kaisa (2016) pointed out that sustainable innovation is a competitive advantage for innovation ecosystems, and the success of sustainable innovation constitutes its impact on the well-being of people. Later, scholars and practitioners have increasingly recognized the effectiveness of the dynamic innovation ecosystem in explaining innovation activities, compared with the previous focus on static innovation elements and innovation systems. A consensus was reached at the 2018 International Science, Technology, and Innovation Think Tank Forum, that a sustainable innovation occurs and develops in an ecosystem, especially in a relatively small geographic space. Sustainable technological innovation being an economic concept, is essential to promote local economic development, create job opportunities, and improve the quality of life.

However, previous researchers mainly focus on the qualitative analysis of the sustainable regional innovation ecosystem structure and the path of building a sustainable regional innovation ecosystem. Few quantitative analyses, especially on the evaluation of the health status of the sustainable regional innovation ecosystem, were implemented; and the few existing quantitative evaluation studies still use the previous evaluation index system designed for the static and isolated innovation systems. Such an evaluation index system ignores the ecological characteristics of the sustainable regional innovation ecosystem in terms of openness, diversity, synergy, and dynamic evolution, which fails to conform to the characteristics of the innovation ecosystem. As verified in this study, the characteristic of dynamic evolution is of particular importance in the evaluation of the health status of the sustainable regional innovation ecosystems. Diversity and synergy are also important considerations for evaluating the health status of the urban innovation ecosystem. Therefore, no matter how deep the understanding we have of the structure and functioning mechanism of the regional innovation ecosystem, copying the previous index system to carry out empirical research will cause the deviation in empirical results and will not contribute to the theory development of the sustainable regional innovation ecosystem. Therefore, this study conducts an in-depth investigation of the unique attributes of the sustainable regional innovation ecosystem from the perspectives of system theory and ecology and formulates a more scientific and reasonable evaluation index system based on the characteristics of subject interaction, factor flow, and dynamic development of the regional innovation ecosystem. It is expected to obtain a more accurate evaluation of the health status of the sustainable regional innovation ecosystem and put forward more targeted guidance and suggestions.

This study synthesizes the description of the characteristics of the innovation ecosystem in previous studies, holding that a sustainable innovation ecosystem is an interdisciplinary system of symbiotic competition and dynamic evolution between the innovation community and the innovation environment, as well as within the innovation community, through the connection and transmission of material flow, energy flow, and information flow within a certain region. Compared with the innovation system, the sustainable innovation ecosystem enjoys a richer concept and connotation, highlighting the structure of an organic dynamic system paradigm. In terms of basic connotation, the sustainable innovation ecosystem provides a new perspective and research method to study the innovation system: (1) To reveal the system paradigm of innovation with more vivid biological metaphors. According to evolutionary economics, the process of innovation manifested as the response process of species/populations and even communities to the formation of environmental change disturbances; (2) To promote the value realization of innovation with a smoother flow of knowledge. Sustainable innovation ecosystems realize the exchange of material, energy, and information within species, populations, communities, and the environment through the material flow, energy flow, and information flow to maintain the stability and efficiency of the system. (3) To distinguish the levels of innovation ecosystem by the more sustainable innovation emergence. The evolutionary development of the innovation ecosystem aims fundamentally to realize continuous innovation. Sustainability depends on the healthy balance between research, development, and application communities. The goal of sustainable innovation ecosystem evolution is to promote the continuous emergence of innovation and achieve sustainable and high-quality economic development by organically integrating innovation input, innovation demand, innovation infrastructure, and innovation management in the innovation process. A well-functioning and continuously evolving regional innovation ecosystem is the key to a country or region's sustainable competitive advantage.

With the development of innovation ecosystem theory, many countries and regions in the world are exploring and applying the concept to examine innovation state and innovation behavior, actively cultivating, and optimizing the innovation ecosystem to enhance regional innovation capabilities. As the U.S. President's Council of Advisors on Science and Technology (PCAST) noted in two reports, building a National Innovation Ecosystem and sustaining a National Innovation Ecosystem, the economic prosperity and leadership of the United States in the global economy have benefited from a strong sustainable innovation ecosystem. It depends on the vitality and dynamic evolution of the innovation ecosystem to maintain its leading position in technology and economy, to improve people's living standards, and to continue to be an innovative and technological leading country. The key to Israel's emergence as an innovation-driven country is the construction of an ecosystem suitable for innovation and entrepreneurship. Many other related plans, such as the Japan Innovation 25 Strategy, India Innovation Ecology Cultivation Program, Netherlands Innovation Ecosystem Evaluation, have been implemented successively, and have achieved good results in practice.

As the foundation of innovation-driven development, the sustainable innovation ecosystem emphasizes the interaction, interdependence, and mutual promotion between innovation subjects as well as between innovation subjects and the environment, and forms a networked system with ecosystem characteristics through symbiosis. Its theoretical connotation accords with the requirements in the new era that innovation guides development. Therefore, by evaluating the health status of regional innovation ecosystems, it is possible to effectively identify the current level, sustainability, and development potential of innovation ecosystems in various regions. Through an in-depth analysis of regions in the excellent health condition of the innovation ecosystem, we can summarize the commonness of these outstanding regions, draw useful experience for the construction of regional innovation ecosystems, thereby promoting the regional innovation capabilities and the healthy and sustainable development of a regional economy. The Davos World Forum in 2017 noted that China's innovation ecosystem possesses six advantages: a strong government pushing for innovation, strong state-owned enterprises, a relatively large investment in research and development, a large and systematic financial system, relatively complete infrastructure, and Sci-Tech Parks. Therefore, the study redesigns a more scientific and reasonable evaluation index system, constructs a new evaluation model, and conducts a health evaluation of the innovation ecosystems by introducing ecological and system theory principles with representative regions of China as samples. Then we can obtain the status quo of innovation ecosystem construction in different regions of China, differences between regions, and important factors that affect the health status of sustainable innovation ecosystems. It is hoped that it can provide a more effective method for future research on the health evaluation of sustainable innovation ecosystems and reasonable suggestions for the construction of sustainable innovation ecosystems, promoting the sustainability of development in various regions in the world.

2. Literature Review

The practice of applying the ecological approach to innovation analysis in the field of economic research has been long-standing, but it has been only about 20 years since the sustainable innovation ecosystem was formally put forward as an independent research concept. Saxenian (1996) introduced the ecological perspective into economic management, utilizing it to analyze the competitive advantage of Silicon Valley, and concluded that Silicon Valley's success benefited from a strong knowledge ecosystem. However, for a period of up to 18 years, the academic community had not formed a systematic and normative innovation research paradigm based on this viewpoint. A sustainable innovation ecosystem was not formally introduced as a systematic, standard concept until 2003 by the PCAST. The concept reflects that the focus of innovation research transformed from the composition of elements in the system to the dynamic process between system elements and between the system and the environment. Such a change shows that scholars pay more attention to the long-term development and sustainability of innovation. In the same year, Huang (2003) put forward in his thesis the concept of the regional technological innovation ecosystem for the first time, which refers to "the system formed by the interaction and interdependence between the technological innovation composite organization and the technological innovation composite environment through the flow of innovative materials, energy and information within a certain space". It has become a recognized definition of the regional technological innovation ecosystem in academia.

With further development of practice and theories, the research of the innovation ecosystem in academic circles mainly includes four perspectives: the enterprise innovation ecosystem, industrial innovation ecosystem, regional innovation ecosystem, and national innovation ecosystem. Adner (2006) first put forward the concept of an enterprise innovation ecosystem, pointing out that the integrative development of enterprises and external entities under innovation-driven development can increase the probability of success. Adner and Kapoor (2010) further proposed that understanding the logic of value creation and acquisition is essential for the successful construction of the enterprise innovation ecosystem. At the industrial level, Lin (2012) analyzed the innovation community and innovation environment within the industrial innovation ecosystem, and explored the dependence and symbiosis of innovative materials, energy, and information. At the regional level, Huggins and Williams (2011) proposed that regional innovation ecosystems should replace industrial agglomeration as the national policy priority. Liu and Zhang (2015) further combined the regional characteristics and industrial development needs of the Beijing-Tianjin-Hebei city agglomeration in China, and proposed a regional collaborative innovation path of "strong points, clusters, chains, and networks". Li and Chen (2019) further pointed out that in the development of the national innovation ecosystem, the government should be given full play to promote institutional innovation, thereby promoting the growth of the national economy.

In recent years, the construction of the regional innovation ecosystem as a bridge between national innovation and enterprise innovation has attracted more and more attention. Researches in this respect mainly focus on three aspects: firstly, theory and content analysis of a regional innovation ecosystem; secondly, based on the theory of innovation ecosystem, analyzing the current situation and future development direction of the typical regional innovation system construction from a qualitative perspective; thirdly, drawing on the successful experience of regional innovation ecosystem in other countries to analyze the development direction of typical regions. Representative scholars include Athreye (2001), Estrin (2009), Lee and Lim (2001), *et al.* However, there have been few quantitative studies on the health status of regional innovation ecosystems, with only a few articles adopting mostly the niche suitability model proposed by Li (1998), which was initially applied to the study of crop yields. The model was later optimized and improved by Qin (2011), Hu (2011), Liu (2013), Guo (2015) and other scholars, and was introduced into the evaluation research of innovation ecosystems. The above-mentioned model has been generally adopted in the empirical studies on innovation ecosystem evaluation since then.

However, in terms of constructing the evaluation index system, the existing researches on the regional innovation ecosystem neglected many characteristics of the innovation ecosystem as an ecosystem. There is a problem of mechanistic index selection, in which the status of innovation elements is mechanically evaluated through isolated indicators. Specifically, the above-mentioned researches select either the secondary macro-index from the perspective of the four-innovation behavior driving subjects of "government, industry, learner, user" based on Salmelin's four-helix structure, or the macro-index at the four levels: innovation subject, innovation resources, innovation environment, and innovation achievements. These two methods are used in the evaluation of the innovation system when the innovation paradigm has not received profound exploration. While it is possible to obtain an overall evaluation of the health status of regional innovation ecosystems by applying these methods in studies of regional innovation ecosystems today, it is impossible to further investigate whether there is close cooperation among the various innovation subjects and whether the flow of innovation elements is smooth. Furthermore, it is impossible to objectively evaluate the intrinsic potential and sustainable development capacity of regional innovation ecosystems. Therefore, the mechanical and static characteristics in the above two evaluation index systems proved disadvantageous and unsuitable for the innovation ecosystem with a rapid exchange, symbiosis, and dynamic evolution of material flow, energy flow, and information flow. Researchers not only fail to fully grasp the development of the regional innovation ecosystem but may also make evaluation errors due to ignorance of important influencing factors (indicators) if such index evaluation systems are adopted.

Therefore, this study conducts an in-depth investigation of the unique attributes of the regional innovation ecosystem from the perspectives of system theory and ecology, and formulates a more scientific and reasonable evaluation index system based on the characteristics of subject interaction, factor flow and dynamic development of the regional innovation ecosystem. It is expected to obtain a more accurate evaluation of the health status of the regional innovation ecosystem and put forward more targeted guidance and suggestions.

3. Index for Health Evaluation of Sustainable Regional Innovation Ecosystem

The selection of an index for evaluating the health status of sustainable regional innovation ecosystems should be built on an understanding and analysis of their conceptual connotations and typical characteristics. If the index is simply selected from the perspective of innovation subject or innovation element, we can only obtain an evaluation of regional innovation level, rather than an evaluation of its health from an ecological point of view with innovation activities being placed in a dynamic ecosystem, nor can we assess the sustainability, potential, and transformative power of innovation. Therefore, relevant characteristics of natural ecosystems are taken into full account such as self-organization, openness, growth, diversity, synergy, and sustainability in constructing the health evaluation index of the regional innovation ecosystem. At the same time, combining the observation and research on the characteristics of the innovation ecosystem, a new index for ecosystem health evaluation is designed and selected to measure the health status of regional innovation ecosystem more accurately, to locate the weak links and growth advantages in the development of each regional innovation ecosystem in a comprehensive and multi-faceted way.

In general, there are four main characteristics of the regional innovation ecosystem—openness, synergy, growth, and sustainability. The relationship among these four characteristics is portrayed as follows.

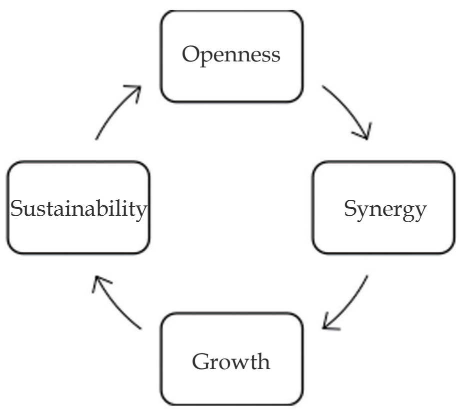

Fig. 1 Relationship among the four characteristics of the regional innovation ecosystem

3.1. Openness

The regional innovation ecosystem is a system far from the equilibrium state. The subjects interact with each other and maintain communication and interaction with the internal and external environment as well as the external system. Only by maintaining the flow and exchange with external innovation resources, information, talents, and products, can a sustainable ecosystem be formed. Compared with open innovation, the innovation ecosystem enjoys a more extensive scope of openness. It is not only reflected at the level of technological innovation but also in breaking the organizational boundary to achieve cross-organizational functional complementation. It involves different economic elements, information systems, and industrial organizations in the market, intending to achieve interaction and flow of information among ecosystem modules. The more open an innovation ecosystem, the more frequent the exchange of talents, knowledge, and funds with the outside world, the greater the development potential. Kobzeva (2012) pointed out in his research that a more open innovation environment is conducive to the burst of innovation activities, and an open innovation environment primarily manifested in the degree of freedom in the flow of funds, technology, personnel, and products between different innovation ecosystems. This study focuses on the study of the regional innovation ecosystem. Therefore, the flow of the above elements should be determined as a cross-regional measure. To measure the innovation elements more accurately, the study narrows the scope down to high-tech industries. Following the principles of representativeness, systematization, operability, and effectiveness in index selection, the following indicators are selected to characterize the openness of a regional innovation ecosystem: expenditure on technology introduction, absorption, and transformation in high-tech industries; regional contract amount of technology export in the technology market; high-tech industry export delivery value; number of foreign-funded enterprises in high-tech industries; and amount of scientific and technological studies in every 10^4 people published in domestic and foreign journals.

3.2. Synergy

Biodiversity is an important feature of natural ecosystems. It is the existence of biodiversity that keeps a natural ecosystem in balance. The more prominent the diversity is, the more dynamic the ecosystem is. There has been a long-term co-existence of multiple innovation subjects and innovation activities in the innovation ecosystem, and the complex connections between different subjects constitute the innovation network. With the evolution of the system, the innovation subjects form a closer tie with the innovation environment. The scientific and technological intermediaries, new industrial organizations, emerging financial organizations, and non-governmental organizations are gradually integrated into the system and become important participants in innovation activities. The diversity of innovation subjects leads to the diversification of innovation activities, and the synergy between subjects gradually enriches accordingly. Adner (2006) noted that the innovation ecosystem is a network of interconnected organizations that create and utilize new value through innovation. The subjects integrate their respective inputs and innovation outputs to produce a coordinated mechanism of commonly agreed-upon, customer-oriented solutions. Synergy in the innovation ecosystem aims to promote the multiple subjects such as government, industry, education, research, and application to exert their respective advantages, integrate complementary resources to realize complementary advantages and innovation cooperation so that the process of technological innovation and industrialization of scientific and technological achievements can be accelerated. Chen (2011) pointed out that innovation synergy can be analyzed from the two dimensions of integration and interaction. In the integration dimension, innovation synergy mainly includes knowledge, resources, actions, and performance; while in the interaction dimension, it mainly refers to the reciprocal knowledge sharing among various innovation subjects, the optimal allocation of resources, the optimal synchronization of actions and the matching degree of the systems. Carayannis (2009) also proposed that the synergy of the innovation ecosystem is mainly reflected in the linear and nonlinear cooperation between universities, governments, and enterprises. Based on previous research, indicators that can measure the flow of innovative elements such as knowledge, resources, products, technology among institutions of higher learning, local governments, and enterprises are identified. Such indicators that can characterize the synergy of regional innovation ecosystems are identified to include enterprise capital in the internal expenditure of R&D funds in research and development institutions and institutions of higher learning, the proportion of education expenditure in GDP, direct financing in the capital market and the amount of science and technology policy issued by the local government.

3.3. Growth

Zeng (2004) noted that an innovation ecosystem must be a self-organizing ecosystem, maintaining the ability to evolve, to promote the growth of new dominant species, and to surpass itself constantly. It can be recognized as a self-organizing system, because the innovation ecosystem presents evolutionary characteristics, and its development goes through different stages of start-up, growth, and maturity. At different stages, the innovation subject and innovation environment change, so do the composition and proportion of elements of the innovation subject and innovation environment. The entire evolution process is a transition from low-level to high-level, from immature to mature, the system performing characteristics of growth. A characteristic inherent to a sustainable system is that it does not rely entirely on the external forces, nor does it rely only on the internal interaction of the innovation ecosystem to produce innovation incentive mechanism; therefore innovation can occur spontaneously in the ecosystem. As a socio-economic organization, the innovation ecosystem grows in response to the common demand for value increment within the system. In other words, there should be sufficient room for value growth for both subjects and participants of the innovation activities, and they can get reasonable distribution on the innovation value chain. Besides, the growth of a innovation ecosystem can also be indicated as the novelty of innovation, that is, the ability to perceive, track and transform new technologies and new business models, reflecting the efficiency and potential of regional innovation. Bramwell (2012) respectively demonstrated the important impact of intellectual property protection and cultural creative industry networks and clusters on the potential of regional innovation ecosystems. Based on the above studies, this study selects the following indicators to reflect innovation novelty and room for value growth, characterizing the evolution and growth characteristics of the regional innovation ecosystems: the number of patent applications of every 104 people, the percentage of new product sales revenue to product sales revenue, the number of national science and technology awards, of national bases for mass innovation, of unicorn enterprises and academic expert workstations based in enterprises.

3.4. Sustainability

Compared with concepts of the innovation system and innovation cluster, the innovation ecosystem emphasizes that the subjects of innovation activities not only integrate with the physical and social environments but also coordinately transform the environment to achieve co-evolution. If the co-creation of the value of an innovation ecosystem manifests itself in its synergy and growth, the characteristic of co-evolution with the environment lies in its sustainability. The sustainability of an innovation ecosystem is embodied in three dimensions. One is the dimension of the system itself. Sustainability means that the innovation ecosystem is capable of resisting risks and self-repair. Iansiti (2004) believed that a healthy innovation ecosystem is robust and sustainable. It can maintain its structure and withstand external shocks. The second is the dimension of the system and nature. Sustainability means that the composition of an innovation ecosystem depends on regional environmental conditions, which require harmony with nature and green development. The third dimension lies in the system and society. Sustainability means that the culture of social innovation and entrepreneurship serves as lasting boosts to the evolution of the system. It means that any creation, spread and use of innovation should be closely linked to civil society. Therefore, the sustainability of the innovation ecosystem is reflected upon the innovation elements and innovation environment support. This study selects indicators that characterize the environment's support for innovation to reflect the sustainability of regional innovation ecosystems. Such indicators include per capita consumption, growth rate of regional GDP, per capita library book volume, the balance of deposits in local and foreign currencies in financial institutions, the percentage drop in comprehensive energy consumption per GDP, and subjective well-being of the people.

Finally, an index for health evaluation of regional innovation ecosystems composed of 4 primary indicators and 34 secondary indicators is formed, as is shown in Table 1.

Table 1 Index for health evaluation of a regional innovation ecosystem

Primary Indicators	Secondary Indicators	Unit
Openness	Expenditure on technology introduction in high-tech industries	10^4 yuan
	Expenditure on technology absorption in high-tech industries	10^4 yuan
	Expenditure on technology transformation in high-tech industries	10^4 yuan
	The regional contract amount of technology export in the technology market	10^4 yuan
	High-tech industry export delivery value	10^6 yuan
	Foreign-funded enterprises amount in high-tech industries	-
Synergy	The proportion of education expenditure in GDP	%
	Number of scientific and technological papers published in domestic and foreign journals of every 10^4 people	-
	Direct financing in capital market	10^6 yuan
	Amount of science and technology policy issued by local government	-
	Enterprise capital in the internal expenditure of R&D funds in institutions of higher learning	10^4 yuan
	Enterprise capital in the internal expenditure of R&D funds in research and development institutions	10^4 yuan
Growth	The number of patent applications of every 10^4 people	-
	The percentage of new product sales revenue to product sales revenue	%
	Number of national science and technology awards	-
	Number of national bases for mass innovation	-
	Number of listed companies on the New Third Board	-
	Number of unicorn enterprises	-
	Number of enterprises above designated size	-
	Number of enterprise academician expert workstations	-
	Per capita fiscal expenditure of local government	yuan
Sustainability	Per capita consumption	yuan
	The growth rate of regional GDP	%
	Per capita library books volume	-
	The average number of mobile phones per 10^2 population	-
	Internet penetration rate	%
	The percentage of the employed population with a bachelor degree or above	%
	Balance of deposits in local and foreign currencies in financial institutions	10^6 yuan
	Percentage drop in comprehensive energy consumption per GDP	%
	The capacity of industrial sewage treatment facilities per day	10^4 t
	The capacity of industrial waste gas treatment facilities per day	10^4 m^3
	Subjective well-being of the people	-
	Unemployment rate (reverse)	%
	Regional average pension	yuan

4. Improved Evaluation Model for Sustainable Innovation Ecosystem Suitability

In Section 3, we have constructed an index for health evaluation of the sustainable regional innovation ecosystem composed of 4 primary indicators and 34 secondary indicators. However, these indicators are not equally important when measuring the health of regional innovation ecosystems, and some of them are collinear. Simple standardization and giving equal weight to those elements can cause deviations in the evaluation results. To solve this problem, the study adopts Principal Component Analysis (PCA) to process 34 secondary indicators. In this way the differences in the importance of different elements can be captured from the data composition in the health evaluation of regional innovation ecosystems to provide more guidance for the construction and development of sustainable innovation ecosystems in various regions.

After weighting the secondary indicators, we must realize that the 34 secondary indicators do not bear a simple linear relationship. Although it is convenient to use the Analytic Hierarchy Process (AHP) to measure a sustainable regional innovation ecosystem, the result might not reflect the latter's ecological characteristics. To examine the health status of the sustainable regional innovation ecosystems more accurately, this study introduces the concept of niche and uses the method of niche suitability to construct a health evaluation model for the sustainable regional innovation ecosystems.

As mentioned above, the suitability of a sustainable innovation ecosystem refers to the degree of closeness between the optimal resource level required by the innovation subjects and the actual resource level provided by the innovation environment when the innovation subjects carry out innovation activities in a certain area. Proposed by Li (1998) and improved by many other scholars, this method has become a common model for innovation ecosystem evaluation. In this study, the niche suitability model is selected as the basic framework and is improved against the existing deficiencies. The improved niche suitability model is used in evaluating the health status of sustainable regional innovation ecosystems.

To sum up, there are two methodological innovations in this study. First, in the design of the evaluation index, the study makes a shift from the past practice of selecting an evaluation index from the perspective of innovation subject or innovation element. Based on the analysis of the innovation ecosystem's characteristics, the study chose ecological factors as evaluation indicators from the four dimensions of openness, synergy, sustainability, and growth. Such an index can authentically reflect the organic and evolutionary nature of innovation ecosystems. Second, in weighting the ecological factors, instead of the previous practice of equal weighting and entropy weighting, the study adopts the PCA method. It focuses more on the typical characteristics of sustainable innovation ecosystems and solves the collinearity problem of ecological factor selection.

Since it is difficult to obtain the optimal demand niche of its research object through a large number of experiments when applying the ecological health model in the field of social science, this study turns to the common practice to determine the best niche by using a set of maximum or minimum values in the evaluation index. In other words, when the current regional resource condition fully meets the development requirements, the niche suitability is 1; when it fails to meet the corresponding resource requirements, the niche suitability is 0. Assuming that there are m innovation ecosystems, then EF_{ij} (i=1, 2, ..., m; j=1, 2, ..., n) represents the observed data value of the i^{th} innovation ecosystem on ecological factor j. The model is constructed as follows:

(1) Dimensionless processing of data

Due to the differences among indicators' evaluation units, the data should first be dealt with non-dimensional processing to eliminate the influence. The calculating function is as follows:

$$EF_{ij} = \frac{EF_{ij} - EF_{jmin}}{EF_{jmax} - EF_{jmin}} \quad (1)$$

where EF_{max} represents the maximum value of the j^{th} ecological factor sequence in EF_{ij} (i=1, 2, ..., m; j=1, 2, ..., n), and EF_{jmin} represents the minimum value of the j^{th} ecological factor sequence in EF_{ij} (i=1, 2, ..., m; j=1, 2, ..., n).

(2) Optimal niche EF_{aj} of niche factors

Let EF'_{ij} represent the actual ecology of the i^{th} ecological factor j in the innovation ecosystem, then EF_{aj} (j=1, 2, ..., n) represents the optimal niche of the j^{th} niche factor, that is:

$$EF_{aj} = \max(EF'_{ij}), \ (j=1, 2, ..., n) \quad (2)$$

(3) Measuring the ecosystem suitability: $Suita_i$

The ecosystem suitability is calculated by formula (3):

$$Suita_i = \sum_{j=1}^{n} w_j \frac{\min\{|\ EF' - EF_{aj}\ |\} + \varepsilon \max\{|\ EF' - EF_{aj}\ |\}}{|\ EF' - EF_{aj}\ | + \varepsilon \max\{|\ EF' - EF_{aj}\ |\}} \quad (3)$$

where $Suita_i$ indicates the suitability of the i^{th} innovation ecosystem. The larger the value, the better the health of the innovation ecosystem and the more active the innovation activities of the innovation subjects in the region.

(4) Calculating ε

ε is a model parameter, the value of which is calculated by formula (4):

$$\frac{\min\{|\ EF' - EF_{aj}\ |\} + \varepsilon \max\{|\ EF' - EF_{aj}\ |\}}{(\frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}|\ EF' - EF_{aj}\ |) + \varepsilon \max\{|\ EF' - EF_{aj}\ |\}} = 0.5 \quad (4)$$

(5) Ecological factor weight vector based on PCA

W_j is the weight of the j^{th} ecological factor, which reflects the degree of influence of this factor on the suitability of innovation ecosystems. To introduce the importance of different ecological factors into the evaluation of regional innovation ecosystems and solve the problem of collinearity of ecological factors to the greatest extent, this study uses the PCA method to determine the weight of each ecological factor.

Assuming that there are m innovation ecosystems, then EF_{ij} (i=1, 2, ..., m; j=1, 2, ..., n) represents the observed data value of the i^{th} innovation ecosystem on the ecological factor j, thus forming an $m \times n$ dimensional matrix. After non-dimensional processing of the matrix, principal component analysis is carried out by SPSS to obtain the correlation matrix and characteristic roots of the dimensionless matrix. The first p principal components are selected according to the principle that the principal component characteristic root is greater than 1 and the cumulative contribution rate reaches more than 85%. The linear weighted values of principal components in the first p sample are further obtained to construct a comprehensive evaluation function.

(6) Calculating evolutionary momentum (EM)

Let the actual niche of the innovation ecosystem be $EF'_{ij} = (EF'_{i1}, EF'_{i2}, ..., EF'_{in})$, and the optimal niche be $EF_{aj} = (EF_{a1}, EF_{a2}, ..., EF_{an})$, then EM can be determined as in formula (5). The evolutionary momentum represents the evolution space for evaluating the suitability of the target niche and is calculated by formula (5):

$$EM_i = \sqrt{\frac{\sum_{j=1}^{n} | EF'_{ij} - EF_{aj} |}{n}} (i = 1,2,\ldots,m; j = 1,2,\ldots,n) \tag{5}$$

So far, the quantitative tool for evaluating the health status of regional innovation ecosystems have been constructed.

5. An Empirical Analysis of Health Evaluation for Sustainable Regional Innovation Ecosystems

To verify the evaluation ability of the above model and compare the health status of innovation ecosystems and capacity for sustainable development in representative provinces and representative cities in the four regional plates of the east, middle, west, and northeast of China, this study conducts an empirical analysis at two levels. At the provincial level, this study selects Guangdong, Hunan, Sichuan, and Liaoning, which are recognized as provinces with relatively high-level innovation development among the four regional plates; at the urban level, this study selects eight first- and second-tier cities with high innovation-driven development capabilities including Beijing, Shanghai, Shenzhen, Dalian, Nanjing, Wuhan, Xi'an and Chengdu as samples. The relevant data are derived from *China Provinces and Cities Economy Development Yearbook 2019, China Statistical Yearbook 2019, China High-tech Industry Statistical Yearbook 2019, Report on Science and Technology Innovation Development in China Cities 2019*, and the statistical yearbooks and bulletins of each province and city in 2019.

5.1. Health evaluation of provincial innovation ecosystems

5.1.1. Data processing

The raw data of the four provinces constitute a 4×34 order judgment matrix, and the original data are firstly dealt with non-dimensional processing by formula (1). Then we use SPSS to perform PCA on the original data, finding that the characteristic roots of the first three principal components are greater than 1 and the cumulative contribution rate is as high as 100%, so the first three principal components are selected for calculation. The contribution rates of the first three principal components are respectively 63.06%,

Table 2 Weight of ecological factors at the provincial level

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17
Weight	0.031	0.027	0.031	0.031	0.031	0.031	0.029	0.028	0.031	0.031	0.032	0.026	0.031	0.030	0.031	0.031	0.028
	X18	**X19**	**X20**	**X21**	**X22**	**X23**	**X24**	**X25**	**X26**	**X27**	**X28**	**X29**	**X30**	**X31**	**X32**	**X33**	**X34**
Weight	0.031	0.029	0.028	0.032	0.031	0.028	0.030	0.027	0.031	0.023	0.031	0.025	0.028	0.032	0.031	0.024	0.029

24.14%, and 12.81%. The weights of ecological factors obtained through calculation are shown in Table 2.

Through the analysis of the weight of ecological factors, we can see that the enterprise capital in the internal expenditure of R&D funds in institutions of higher learning (X11), the per capita fiscal expenditure of local government (X21), per capita consumption (X22), the balance of deposits in local and foreign currencies in financial institutions (X28), and the capacity of industrial waste gas treatment facilities per day (X31) have a greater impact on the health status of regional innovation ecosystems. In terms of primary indicators, sustainability is the most important consideration in the evaluation of the health status of regional innovation ecosystems. Therefore, when evaluating the regional innovation ecosystem, it should not be limited to its current static level of innovation. Attention should also be paid to its development potential and sustainability. This offers yet another confirmation of the limitations of the previous evaluation index system which ignored the organic and dynamic nature of innovation ecosystems.

5.1.2. Data analysis

After determining the weights of ecological factors, formula (3) is used to calculate the niche suitability and evolutionary momentum of the innovation ecosystems in four provinces, among whichis calculated by formula (4). By substituting the results into the ecological niche suitability and evolutionary quantitative formulas, the results of the four provinces regarding the four dimensions of openness, synergy, growth and, sustainability can be obtained, as is shown in Table 3.

Table 3 Score and Ranking of Sustainable Innovation Ecosystems in Sample Provinces

Province	Openness	Ranking	Synergy	Ranking	Growth	Ranking	Sustainability	Ranking	Niche suitability	Ranking	Evolutionary momentum
Guangdong	0.182	1	0.142	1	0.252	1	0.295	1	0.873	1	0.428
Hunan	0.090	2	0.075	4	0.121	3	0.188	4	0.527	2	0.865
Sichuan	0.083	3	0.090	3	0.154	2	0.201	2	0.484	3	0.795
Liaoning	0.075	4	0.107	2	0.111	4	0.193	3	0.475	4	0.866

5.1.3. Results analysis

To present the comparison of the health status of the sustainable innovation ecosystems in the sample provinces in a more straight-forward way and identify the improvement space of the niche suitability of the innovation ecosystem in the respective regions, information in Table 3 is visualized in Figure 2 for illustration. As a major innovation province in the eastern region, Guangdong is far ahead in the health evaluation of the sustainable innovation ecosystem. In contrast, the rest three provinces - Hunan in the central region, Sichuan in the western region and Liaoning in the northeast region – lag behind with a large gap with Guangdong, but the difference among the latter three is not significant. Each of them enjoys certain advantages in the four characteristics. This study made a concrete analysis of the weights of principal component ecological factors and the calculation results.

In the evaluation of openness, the ecological factors with higher empowerment are the expenditures on technology introduction and transformation in high-tech industries. It indicates that compared with the absorption of foreign technology into the region, the regional ability to introduce and internalize foreign technology is more valued in the consideration of openness. For example, Hunan scores approximately four times in the ecological factor of expenditure on technology introduction in high-tech industries as that of Liaoning, but it scores less than Liaoning in the above two high-weighting ecological factors, so its innovation ecosystem openness is only slightly superior to Liaoning. It can be seen that high investment in technology absorption is not necessarily an efficient and long-term way to enhance the function of a sustainable regional innovation ecosystem. The key is to transform and internalize technology into regional R&D innovation capabilities while introducing foreign technology. In addition, the ecological factor weight of the regional contract amount of technology export in the technology market is relatively high, indicating that in the evaluation of openness, the importance of the transformation of scientific and technological achievements is higher than that of R&D investment.

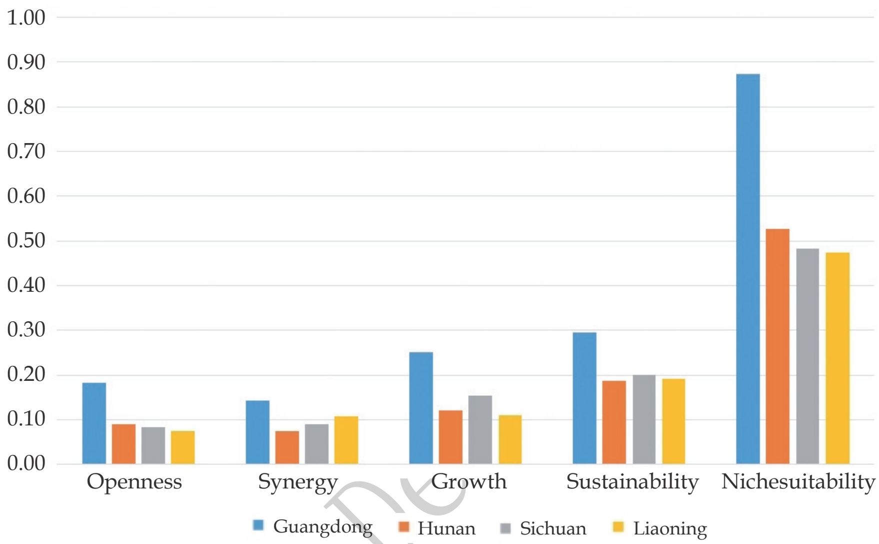

Fig. 2 Comparison of the health status of sustainable innovation ecosystems in sample provinces

In evaluating synergy, the three ecological factors of direct financing in capital market, amount of science and technology policy issued by local government and enterprise capital in the internal expenditure of R&D funds in institutions of higher learning have higher weights and the weight of the number of scientific and technological papers published in domestic and foreign journals by every 104 people is lower. This phenomenon shows that the synergy of the innovation ecosystem mainly depends on the support of other innovation actors to institutions of higher learning and research and development institutions, which means financial power and political power significantly contribute to scientific and technological achievements. For example, Sichuan scores far higher than Hunan in two ecological factors, namely the direct financing in capital market and the amount of science and technology policy issued by local government. As a result, despite Hunan's higher scores in other ecological factors in this category, the synergy evaluation for Hunan is still lower than that for Sichuan.

In the evaluation of growth, the number of patent applications of every 104 people, number of unicorn enterprises, number of national bases for mass innovation, number of national science and technology awards and other ecological factors that reflect the regional independent innovation capabilities and innovation achievements are highly weighted, and the above ecological factors have higher empowerment in all indicators. It suggests that the efficiency and quality of innovation within the region is critical to the growth and health of the sustainable innovation ecosystem. For example, Hunan scores lower on the above ecological factors than Sichuan, so the innovation ecosystem growth evaluation for Hunan is lower than that for Sichuan.

In the evaluation of sustainability, per capita consumption, the balance of deposits in local and foreign currencies in financial institutions, the capacity of industrial waste gas treatment facilities per day and other ecological factors have higher weights. It indicates that the sustainability of regional innovation ecosystems is more closely related to regional economic development, financial support and, green development. Since these three ecological factors are highly correlated with the overall development status of the region, and the overall weight of the sustainability evaluation index accounts for the most in the overall evaluation, it can explain the phenomenon that the health status of the regional innovation ecosystem is close to the level of the regional development.

From the calculation results of evolutionary momentum, the evolutionary momentum of Hunan and Liaoning is more than twice that of Guangdong, which indicates that these two provinces have great potential to optimize the innovation ecosystem. Close attention needs to be paid to such key ecological factors for targeted adjustment.

5.2 Health evaluation of urban innovation ecosystems

5.2.1. Index adjustment

Compared with provinces, cities are only smaller administrative areas. The internal structure of their sustainable innovation ecosystems is similar, so the evaluation index system constructed in this study can be adopted. However, due to a certain gap between the statistical calibers of macro and micro data between cities and provinces, when evaluating the health status of urban innovation ecosystems, it is necessary to make certain adjustments within a reasonable range. Therefore, for the reason of data accessibility, when constructing the health evaluation index of urban innovation ecosystems, some low-weighted or inaccessible indicators are deleted, such as expenditures on technology introduction, absorption, and transformation in high-tech industries and direct financing in the capital market. For some important but unavailable indicators, equivalent measurement indicators are used in substitution. For example, the number of foreign-funded enterprises' in high-tech industries is replaced by foreign investment attracted by every 104 people, and the percentage drop in comprehensive energy consumption per GDP is replaced by indicators such as the harmless disposal rate of domestic waste and city air quality grade. The adjusted index for health evaluation of the urban innovation ecosystems is shown in Table 4. In general, there are not too many changes in the evaluation index system for cities compared to that for provinces. The index adjustment is made based on the characteristics of the sustainable regional innovation ecosystem, that is, openness, synergy, growth, and sustainability. It also shows that the evaluation index system constructed in this study can be universally extended to similar conditions.

5.2.2. Data processing

The 27 ecological factors in 8 sample cities are firstly dealt with non-dimensional processing. Then SPSS is used to perform PCA on the original data. The cumulative contribution rate of the first four principal components is 100%, therefore, the first four principal components are selected for analysis and calculation in this study. The contribution rates of the first to fourth principal components are 56.14%, 25.28%, 12.37% and 6.21% respectively. With the same steps of determining the weight of ecological factors in the empirical study on provinces, the weight of each ecological factor can be obtained by the coefficient of each ecological factor and the contribution rate of the principal components. The final weight of each ecological factor can be obtained by normalizing all ecological factor weights, as shown in Table 5.

Table 4 Index for health evaluation of sustainable urban innovation ecosystems

Primary Indicators	Secondary Indicators
Openness	Foreign investment attracted by every 104 people
	The proportion of total imports and exports of high-tech products to regional GDP
	Number of Fortune Global 500 and China Top 500 enterprises
Synergy	The proportion of local financial science and technology investment to local financial expenditure
	Number of scientific and technical personnel in every 104 employed people
	Number of SCI/SSCI/A&HCI papers of every 104 people
	Patent grants amount of every 104 people
	Labor productivity in the secondary industry
	The percentage of additional value produced by the tertiary industry to regional GDP
	Number of national model institutions for technology transfer
Growth	Number of listed companies on the New Third Board
	The growth rate of loan balances at year-end in financial institutions
	Number of enterprises listed on GEM
	Corporate tax burden
Sustainability	Level of urbanization
	Per capita disposable income of urban residents
	GDP per square kilometer
	Number of undergraduate students per 104 population
	Library books volume of every 102 people
	Number of mobile phone users of every 104 people
	Number of users accessible to Internet broadband of every 104 people
	The proportion of local financial education investment to local financial expenditure
	Urban sewage treatment rate
	Domestic waste harmless treatment rate
	City air quality grade
	Number of hospital beds for every 104 people
	Per capita city public green area

Table 5 Weights of ecological factors

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
Weight	0.036	0.036	0.038	0.038	0.037	0.038	0.038	0.037	0.038	0.038	0.037	0.037	0.037	0.035
	X15	**X16**	**X17**	**X18**	**X19**	**X20**	**X21**	**X22**	**X23**	**X24**	**X25**	**X26**	**X27**	
Weight	0.038	0.039	0.038	0.037	0.037	0.035	0.036	0.038	0.039	0.038	0.034	0.038	0.035	

Through the analysis of the weight of ecological factors of the urban innovation ecosystems, a great influence on the health status of urban innovation ecosystems was displayed related to the number of Fortune Global 500 and China Top 500 enterprises (X3), the proportion of local financial science and technology investment to local financial expenditure (X4), the percentage of the tertiary industry additional value to regional GDP (X9), level of urbanization (X15), per capita disposable income of urban residents (X16) and the urban sewage treatment rate (X23) and other factors. Comparing the weights of ecological factors of provincial innovation ecosystems, we find that sustainability is an important factor that affects the evaluation of innovation ecosystems at both levels, while synergy has more influence in innovation ecosystem evaluation at the urban level than at the provincial level. This shows that compared with those at the provincial level, the flow of elements between the actors of a urban innovation ecosystem should be freer and more rapid, and the allocation of resources should be more flexible.

The niche suitability of the sustainable innovation ecosystem in 8 sample cities is determined by formula (3), where is calculated by formula (4). Substituting the results into niche suitability and evolution quantitative formulas, we can get the calculation results of 8 cities in the four dimensions of openness, synergy, growth, and sustainability, as shown in Table 6.

Table 6 Health evaluation of the urban innovation ecosystems

City	Openness	Ranking	Synergy	Ranking	Growth	Ranking	Sustainability	Ranking	Niche suitability	Ranking	Evolutionary momentum
Beijing	0.088	1	0.082	1	0.191	2	0.300	1	0.713	1	0.095
Shanghai	0.047	2	0.063	2	0.188	3	0.294	2	0.643	2	0.104
Shenzhen	0.043	3	0.034	3	0.236	1	0.235	3	0.529	3	0.242
Nanjing	0.022	4	0.019	6	0.056	4	0.197	4	0.333	4	0.228
Wuhan	0.021	5	0.022	4	0.052	5	0.178	5	0.284	5	0.232
Chengdu	0.019	7	0.019	5	0.048	6	0.140	6	0.269	6	0.234
Xi'an	0.017	8	0.008	8	0.034	7	0.135	7	0.253	7	0.229
Dalian	0.020	6	0.014	7	0.033	8	0.105	8	0.247	8	0.237

5.2.3. Result analysis

To better illustrate the comparison of the health status of the sustainable innovation ecosystems in the sample cities and identify the improvement space of the niche suitability of the innovation ecosystem in the respective regions, information in Table 8 is visualized in Figure 3. The health status of the innovation ecosystems in sample cities generally shows a gradual weakening from the coast to the inland. Beijing, Shanghai and Shenzhen are far ahead of the other five cities in terms of the health status of the innovation ecosystems. The differences in the health status between the innovation ecosystems in Nanjing, Wuhan, Chengdu, Xi'an and Dalian, cities ranked 4 to 8, are not significant.

In evaluating openness, the ranking of the openness of each city's innovation ecosystem corresponds roughly with that of niche suitability except that the performance of Chengdu and Xi'an in the openness evaluation is not as good as their overall ranking. This is due to the absolute values of their two ecological factors, the number of Fortune Global 500 and China Top 500 enterprises and foreign investment attracted by every 104 people are not high. At the same time, Beijing scores far more than the other 7 cities in the number of Fortune Global 500 and China Top 500 enterprises. Since this ecological factor has a large weight in the evaluation of openness, the openness evaluation of Beijing's innovation ecosystem is much better than that of the other cities.

In the evaluation of synergy, Beijing ranks first because of its developed service industry, followed by Shanghai, Shenzhen, Wuhan and Chengdu. Nanjing falls behind in the ranking in synergy due to its low scores in the two factors: the number of national model institutions for technology transfer and the number of scientific and technical personnel in every 104 employed people. Xi'an and Dalian lag behind in the ranking. In the evaluation of growth, the two ecological factors of the number of listed companies on the New Third Board and the number of enterprises listed on GEM have greater weights, indicating that innovation output is significant in the growth of the urban innovation ecosystems. The growth rate of loan balances at year-end in financial institutions also plays a significant part. In evaluating sustainability, a great section of factors such as level of urbanization, per capita disposable income of urban residents, GDP per square kilometer, the proportion of local financial education investment to local financial expenditure, urban sewage treatment rate and other factors have relatively higher weights, explaining the phenomenon that the ranking of the sustainability of each city's innovation ecosystem corresponds with that of niche suitability.

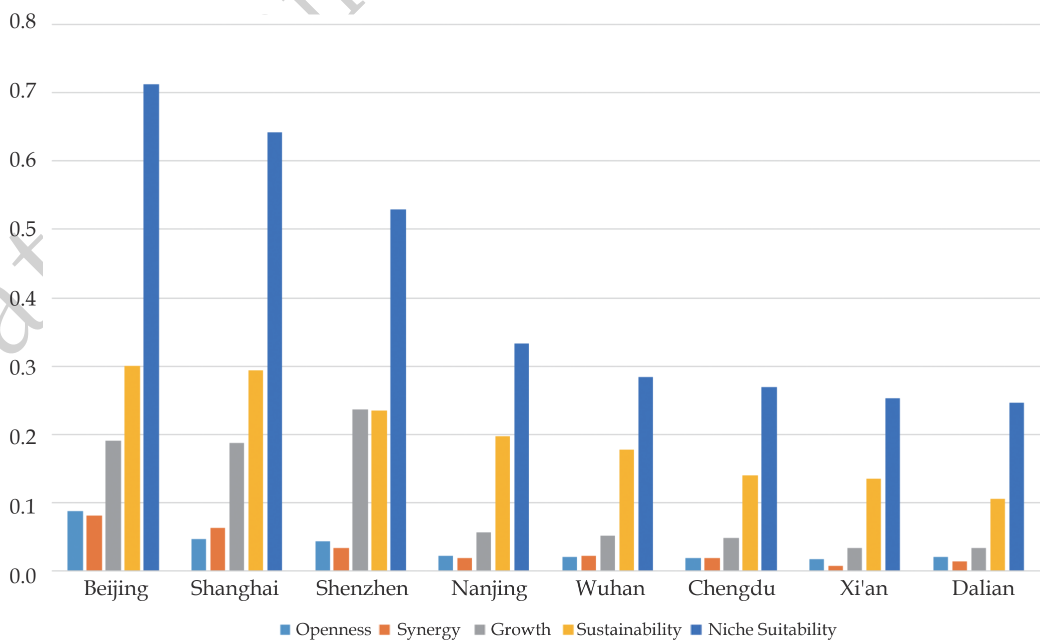

Fig. 3 Comparison of the health status of sustainable innovation ecosystems in sample cities

Generally, among the eight sample cities, Beijing, Shanghai and Shenzhen, as the most economically developed cities in China, have gathered numerous innovative resources, funds, and talents. Their innovation input, innovation output, and innovation performance are significantly higher, resulting in positive health evaluation of the innovation ecosystem. However, the weak growth of the innovation ecosystem in Beijing and Shanghai, which might set limitations in their development, call for future attention. Nanjing, Wuhan, Chengdu, Xi'an and Dalian still fall behind with a significant gap in the construction of innovation ecosystems compared with Beijing, Shanghai and Shenzhen, but the strong evolutionary momentum of these five cities shows their great potential to improve and optimize their sustainable innovation ecosystems.

6. Conclusions and Recommendations

To remedy the problem of insufficient objectivity, this paper seeks to improve the traditional niche-fitness model by reconstructing a new evaluation index system based on the inherent characteristics of openness, diversity and synergy, sustainability, evolution, and growth of sustainable regional innovation ecosystems from the perspective of ecology and system theory. The PCA method is used to weight the secondary indicators to solve the collinearity problem. Furthermore, the concept of niche suitability in ecology is introduced. By measuring the distance between the actual ecological factor of each system and the optimal value, a new model for health evaluation of the sustainable regional innovation ecosystems is constructed. The model is empirically tested using data of Chinese provinces and cities. It is found that the model can be effectively applied to the evaluation research of sustainable regional innovation ecosystems, and the newly constructed evaluation index system can be adjusted according to different levels of administrative regions without affecting the accuracy of the empirical results.

Following conclusions can be drawn from the results of the health evaluation of sustainable innovation ecosystems in the sample provinces and cities: the health status of a sustainable regional innovation ecosystem is strongly correlated with the level of the regional economic development; there is a great imbalance between innovation capacity and innovation niche suitability in various regions of China; the health status of the sustainable innovation ecosystem presents a gradient difference from the coast to the inland and from the east to the mid-west. Therefore, countries and regions should adopt different ideas and approaches to construct and improve regional innovation ecosystems. To this end, the study puts forward some suggestions on how to cultivate and optimize the sustainable regional innovation ecosystems.

First, it takes a long time to cultivate and optimize sustainable innovation ecosystems. The innovation ecosystem has a high degree of similarity with the natural ecosystem. The occurrence of innovation behavior and the creation of an innovation environment require long-term accumulation and evolution. It can never be realized in a hurry. Therefore, continuous efforts should be made and time should be invested by different regions in the construction and optimization of sustainable innovation ecosystems. By constant adjustments in the main environmental factors that affect the health of the innovation ecosystems, the evolution of sustainable the innovation ecosystems can be promoted continuously.

Second, focus on key points is necessary for the cultivation and optimization of the sustainable innovation ecosystems. According to the empirical analysis of China's provincial and urban samples selected in this study, the imbalance of regional development and that of the innovation-driven development level in China have been fully demonstrated in the assessment of the health of innovation ecosystems at provincial and urban levels. The Pearl River Delta, Yangtze River Delta and, Beijing-Tianjin-Hebei city agglomerations in the eastern region enjoy a good innovation ecology far exceeding what is provided in the vast central, western, and the northeast regions. Therefore, to foster a sustainable regional innovation ecosystem, we should focus on the key points and then further promote the development of surrounding areas. In provinces and central cities that have access to relatively concentrated innovation resources and a solid innovation foundation, efforts should be made in strengthening weak points to further optimize the innovation ecosystems by building the national innovation centers. In areas where there are still weak links in the innovation chain, we should maximize the advantages, cultivating the innovation ecology systems by giving play to the specific comparative advantages.

Third, it requires endogenous dynamics to cultivate and optimize the sustainable innovation ecosystems. The evolution of a sustainable innovation ecosystem needs diversity, self-organization, synergy, and other characteristics to play a full role. In other words, its evolutionary power must be endogenous, with external driving forces only contributing to environmental creation. The endogenous power largely depends on emerging industries or high-growth enterprises to become "new growth poles". Previous analysis shows that the environmental factors such as unicorn enterprises, listed companies on the New Third Board, bases for mass innovation, the percentage of new product sales revenue to gross product sales revenue, and the percentage of the tertiary industry additional value to regional GDP are highly empowered. Unicorn enterprises and listed companies on the New Third Board are the main bearers of current regional innovation. The bases of mass innovation are incubators of future innovation. New product sales revenue and tertiary industry development reflect the changes in market demands and the growth of innovation. Therefore, the key to endogenous power lies in promoting key industries and enterprises to become the new kinetic energy for regional development.

Fourth, cultivating and optimizing the sustainable innovation ecosystem requires integration and symbiosis. A healthy innovation ecosystem should be an organism with continuous interaction and integration of innovation subjects and innovation elements. The interaction of information, capital, and technology can stimulate innovation subjects to achieve greater potential. These cannot be realized without a strong helping hand from the government in creating a free environment from system and policy that encourages the free flow of elements and promoting the coordination between communities of the universities, enterprises, research institutions, and the government. Such a diverse and efficient system to be built can avoid the "island effect" resulting from the lack of communication and cooperation between innovative subjects or the decrease in the frequency of innovation factor flow.

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