Concept Refinement, Factor Symbiosis, and Innovation Activity Efficiency Analysis of Innovation Ecosystem

Wan-Ming Chen,¹ Sheng-Yuan Wang,² and Xiao-Lan Wu²

¹Nanjing University of Aeronautics & Astronautics, Nanjing, Jiangsu 210016, China
²Nanjing Xiaozhuang University, Nanjing, Jiangsu 211171, China

Correspondence should be addressed to Sheng-Yuan Wang; 56439976@qq.com

Received 12 January 2022; Accepted 23 March 2022; Published 4 April 2022

Academic Editor: Erivelton Geraldo Nepomuceno

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

This paper makes a comprehensive description of the innovation ecosystem from three perspectives, the concept refinement of the innovation ecosystem, factor symbiosis, and system efficiency, since the traditional definition of innovation ecosystem is not sufficient to fully describe the innovation ecosystem. With grounded theory for reference, the concept of innovation ecosystem is reconstructed, and it is discovered that the conceptual model of innovation ecosystem is composed of main categories and subcategories. The main category is the innovation population and innovation habitat category in the innovation ecosystem, and the subcategory is the input and output activities of the innovation subjects in the innovation ecosystem. The concept refinement of the innovation ecosystem based on the Chinese scenario reflects the characteristics of the innovation ecosystem in a specific context. It has been found that, under the Chinese scenario, there is an asymmetric symbiotic relationship between populations and habitats in the innovation ecosystem. The input-output total factor productivity of the entire innovation ecosystem is in a state of decline, and this decline in total factor productivity is mainly due to the decline in technological change. China’s innovation ecosystem is an asymmetric symbiosis system that relies on factor inputs. Due to insufficient technological innovation, the total factor productivity of the innovation ecosystem has declined.

1. Introduction

Under the guidance of the innovation-driven development strategy, appropriate institutional conditions are needed such as an ecosystem that can promote regional innovation, in order to continuously improve the level of innovation and entrepreneurship, accelerate the transformation of regional scientific and technological achievements, and realize the transformation from made in China to created in China. China is accelerating the strategic layout of regional innovation and actively seizing the commanding heights of innovation. Therefore, it has become an important focus of regional innovation practices in particular to link regional innovation activities with the ecosystem and to actively build a regional innovation ecosystem. Regional innovation ecosystem, formed through the interaction and dynamic coordination of innovative entities with the innovation environment, has the key characteristics of multisubjects, strong interaction, and coexistence. A symbiotic and co-prosperity pattern formed between innovative life forms based on benign interactions is the key to the sustainable and healthy development of the system.

However, China currently has insufficient understanding of its ecological and symbiotic characteristics in the practice of innovation ecology. There are a general problem of patchwork of factors, a serious problem of “fragmentation” and “islandization” of innovation, limited application and production of scientific and technological achievements, difficult marketization of innovative products, and a lack of effective market-based supply of technology. As a result, the formation of coordinated community and interactive symbiosis within the innovation ecosystem has become difficult, and the development of innovation ecosystems in some regions lagged behind and was about to collapse.
Therefore, practical problems need to be solved urgently in cultivating and optimizing regional innovation ecosystems, such as following with interest the symbiosis of regional innovation ecosystems, correctly judging the symbiosis level and symbiosis relationship of regional innovation ecosystems, and accurately identifying the development characteristics of regional innovation ecosystems in China.

Building an innovation ecosystem is of great strategic significance for improving national innovation capabilities [1]. In-depth exploration of China’s regional innovation ecosystem has important practical significance in improving the overall effectiveness of China’s innovation ecosystem. Since Adner [2] formally defined the innovation ecosystem in 2006, the innovation ecosystem as a new paradigm has become a research hotspot in academia. Throughout the existing literature, the research results of domestic and foreign scholars in the field of innovation ecosystems can be summarized in the following aspects with the definition of the concept of innovation ecosystems being the first. The existing research mainly focuses on systems [3], network systems [4], synergetics [5], innovative behavior [6–8], and other perspectives to interpret the innovation ecosystem. The second is the basic theoretical research of the innovation ecosystem, including the constituent factors of the innovation ecosystem [9–11] and value cocreation [5, 12]. In terms of value creation in the innovation ecosystem, Ritala et al. [13] discussed the tangible and intangible mechanisms for leading companies to promote value creation. Surie [14] proposed that enterprises need to strengthen their connections with external organizations such as the government to establish an innovation ecosystem, realize their value cocreation, and utilize new technology platforms to enhance interaction.

Different subjects of the innovation ecosystem have both competition and cooperation to obtain competitive advantages in the coevolution as either competition or cooperation alone cannot enable enterprises to cope with the ever-changing environment. Moore [15] believed that the checks and balances of cooperation and competition are conducive to value creation as well as the realization of value acquisition. Adner and Kapoor [11] believed that value creation occupies the dominant position in value capture, and the unstable and unclear relationship between actors evolves in an unpredictable way. This may shift the relationship between actors from cooperation to competition. Species operate in a cooperative and competitive manner to create value. The cooperation and competition in the e-commerce ecosystem have formed a network, rather than a simple bilateral relationship [16]. Value is cocreated in a network of cooperative and competitive companies in different markets or even in the same market [17, 18]. A successful business ecosystem, including mature companies and new enterprises, requires strategic thinking to collaborate and compete using the company’s resources and capabilities. Zahra and Nambisan [19] believed that the business ecosystem provides opportunities for its members to cooperate and compete through radical and continuous innovation at the same time. The huge differences in the organization and business model of the ecosystem affect the strategic choices of incumbents and new businesses, and these choices need to create, shape, and transform the entrepreneurial activities of the competitive landscape. In turn, these changes have stimulated competition for innovation and changed the nature of the ecosystem itself.

Many factors in the innovation ecosystem affect enterprise innovation performance. The open innovation proposed by Chesbrough [20] reduces market uncertainty and risk through the integration and utilization of internal and external innovation resources and improves innovation performance. Tian et al. [21] introduced a role-based paradigm to characterize ecosystem entities to realize the evolution of ecosystems and the value distribution between entities and the evaluation of business model performance in different scenarios. Frankort [22] believed that the performance of the material practices (such as interfirm technology alliances) that constitute the innovation ecosystem may vary over time, and the evolving institutional norms may make the more sustainable governance of technology alliances a reliable alternative to equity ownership, thereby reducing corporate R&D costs and improving performance. Learning, analysis, imitation, regeneration, and technological change are the main components to improve organizational performance and to strengthen competitive advantage [23]. Pierce [24] showed through case studies in the automotive industry that how dynamic capabilities adapt to the behaviors of core companies may improve the complementary performance of certain niche markets. Teece [25] drew on the belief that dynamic capabilities enable companies to not only create, deploy, and protect intangible assets for business performance but also help managers describe relevant strategic considerations and priorities they must adopt to improve corporate performance and avoid zero profit trend in the operation in a market open to global competition. Due to their externalities, the networks have a horizontal exchange mode, interdependent resource flow, and communication through mutual exchange. Therefore, Zhang and Gregory [26] believed that, in the industries of aerospace, automotive, defense, and electronics, the networks can enhance the overall competitiveness of the enterprise by improving the performance of engineering operations from the perspective of effectiveness and efficiency.

In recent years, the research on innovation ecosystem has been gradually deepened. Research on internal resources [27], uncertainty [28], and governance [29] of innovation ecosystem is an example. The discussion of these topics is inseparable from bibliometric analysis [30] and academic origin analysis [31]. Open innovation and its platform innovation ecosystem are also the focus of scholars [32, 33]. The national innovation ecosystem and the relationship between innovation ecosystem and natural ecology are the areas of common concern of scholars and policymakers [34, 35]. The research in the above fields is interesting and practical, but the related research also needs to be based on the concept construction of ecosystem.

However, there are still obvious shortcomings in the research on symbiosis of innovation ecosystems. First, it does not take into consideration the characteristics of
regional innovation activities and thus cannot accurately and comprehensively identify the key populations of regional innovation ecosystems. As a result, it is difficult for existing studies on symbiosis and interaction of individual populations to describe the overall picture of system symbiosis. Secondly, the research on interaction and symbiosis between systems is still in the simulation stage of symbiosis interaction law, and the real level of system symbiosis interaction has not been solved yet with a lack of empirical analysis of population interaction. Finally, existing evaluation research lacks measurement and analysis of the ecological potential of the system from the perspective of interaction and symbiosis. Therefore, it is necessary to conduct research on symbiosis issues such as the symbiosis relationship and the level of symbiosis following the law of symbiosis and interaction of the regional innovation ecosystem.

Regarding the above research limitations, the organizational structure of this paper is as follows: (1) In the light of grounded theory, the concept of the innovation ecosystem under the Chinese scenario will be reconstructed. (2) Based on ecological theory and concept refinement of innovation ecosystem, an innovation ecosystem evaluation system will be constructed from the dimensions of species and environment. (3) An evaluation model will be established to evaluate the innovation environment and the synergy of innovation populations and the efficiency of the innovation ecosystem from 2006 to 2019. (4) The relationship between synergy and efficiency will be analyzed.

2. Materials and Methods

The operation of innovation ecosystem is complex; therefore, researchers cannot use any single research method to analyze the innovation ecosystem. This paper develops a series of complex but appropriate methods to evaluate the innovation ecosystem. The research process of this paper is shown in Figure 1.

As shown in Figure 1, this paper comprehensively uses the grounded theory, entropy weight, and weighted scoring method to evaluate the population and habitat of innovation ecosystem. Then, the activity efficiency of innovation population is analyzed by the Lotka-Volterra (LV) model and the Malmquist index method.

2.1. Grounded Theory. Since the grounded theory was designed [36], scholars have made some modifications to the actual operation steps and requirements of the method. Chinese scholars also have a lot of rigorous research and practice concerning grounded theory and have put forward insights with relatively high academic value on the application of this method in China’s unique academic environment. Based on the current research on grounded theory methods, this paper summarizes the general research path of grounded theory. Grounded theory research mainly consists of three steps. The first is data gathering. The data here refers to broad data, including academic research literature, case studies, government regulations, policy documents, and other secondary materials, as well as primary data obtained through in-depth interviews, questionnaire surveys, and other types of field research. The second is the data analysis link, which includes open coding, axial coding, and selective coding. In open coding, one must abandon any preconditions and decompose, check, compare, conceptualize, and generalize data. Axial decoding is to form categories on the basis of open coding and examine the relationship between the categories. The coding paradigm models at this stage can be connected according to the development order. The development sequence of the coding paradigm model is as follows: “Causal Conditions-Phenomenon-Context-Intervening Condition-Strategy-Consequence.” Selective coding is to distinguish between the core category and the subcategory. The last is theory construction, which integrates various theoretical elements through storylines.

2.2. Entropy Method and Coupling Dependency. This study determines the weight by the entropy method. As an objective method [37], entropy weight is popular and always combined with other methods, for example, entropy combined with fuzzy VIKOR [38], entropy combined with GIS and AHP [39], and entropy combined with subjective weight [40]. The entropy weight method is provided as follows [41]. Suppose that $m$ is alternatives ($A_1, A_2, \ldots, A_m$) and $n$ is criteria ($C_1, C_2, \ldots, C_n$) for a decision problem. Then, the initial matrix is

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} = [a_{ij}]_{m \times n}$$

(1)

In this paper, the evaluation index system is constructed based on the concept refinement of innovation ecosystem. In matrix $A$, $a_{ij}$ is the original data of the evaluation index.

Step 1: normalize the evaluation matrix:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}$$

(2)

The dimensions of different indicators in the original data are different. Therefore, in order to facilitate data processing, this step carries out the normalization of the original data.

Step 2: compute entropy:

$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} r_{ij} \ln r_{ij}, \quad j = 1, 2, \ldots, n.$$  

(3)

The entropy calculation in this step is the basis for determining the entropy weight.

Step 3: calculate weights:

$$w_j = \frac{1 - e_j}{\sum_{i=1}^{n} (1 - e_i)}, \quad j = 1, 2, \ldots, n.$$  

(4)
### Research Contents

| Step 1 | Step 2 | Step 3 |
|--------|--------|--------|
| Population and habitat assessment | Construction of evaluation index system | Population and Habitat Evaluation |

| Step 4 | Step 5 |
|--------|--------|
| Element Coupling Analysis | Lotka-Volterra Model |

#### Research Method

- Conceptual refinement of innovation ecosystem
- Grounded theory
- Entropy weight
- Weighted scoring method
- Lotka-Volterra Model
- Malmquist Index

**Figure 1:** Research process.

Build weighted normalized matrix $V$.

$$ v_{ij} = w_j r_{ij}, $$

$$ \sum_{j=1}^{n} w_j = 1, \quad (5) $$

$w_j$ is the weight of $j$th criterion.

Coupling dependency refers specifically to a measure of the mutual dependence of two or more entities on each other, which is a quantitative measure of dependency. This paper introduces the concept of coupling and defines the interdependence and coevolutionary relationship between population and habitat and the input activity and output activity in the innovation ecosystem as a coupling relationship.

Among them, the coupling dependency coefficient is

$$ c = 2 \frac{v_1 v_2}{(v_1 + v_2)^2}. \quad (6) $$

2.3. **Element Coupling Analysis Based on the Population Dynamics Model.** Different innovation subjects can be regarded as different populations in the innovation ecosystem. There are complex symbiotic relationships among populations. The population dynamics model can be used to help us study and solve these problems.

According to the logistic model, the authors constructed an internal dynamic system of population 1 ($P_1$).

$$ g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left(1 - \frac{N_1}{K_1}\right), \quad (7) $$

where $g_1(t)$ is the growth rate in phase $t$. $N_1(t)$ is the population size of period $t$. $K_1$ is the maximum population scale. $\alpha_1$ is the intrinsic growth rate. $(1 - (N_1/K_1))$ is the retardation of growth.

The measurement model is as follows: $dN_1(t) \approx \Delta N_1(t)$, $\Delta N_1(t) = N_1(t) - N_1(t-1)$, and $dt \approx \Delta t = t - (t-1) = 1$.

So $g_1(t) \approx \Delta N(t) = \gamma_1 N_1(t-1) + \gamma_2 N_1^2(t-1). \quad (8)$

Among them, $\gamma_1 = \alpha_1$; usually $\gamma_1 > 1$. It usually represents the synergy within a population. $\gamma_2 = -(\alpha_1/K_1)$; usually, $\gamma_2 < 0$. It refers to the competition effect within a population. It is called the internal competition coefficient or population density inhibition coefficient.

Similarly, the internal relation model of population 2 ($P_2$) can be obtained.

$$ g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left(1 - \frac{N_2}{K_2}\right), \quad (9) $$

The following system shows the impact of the $P_2$ on $P_1$:

$$ g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left(1 - \frac{N_1}{K_1} + \beta_{12} N_2 \right), \quad (10) $$

where $\beta_{12}$ is the influence of population 2 on population 1 ($\beta_{12} > 0$, synergistic effect; $\beta_{12} < 0$, competitive effect). Similarly, the following system shows the impact of $P_1$ on $P_2$:

$$ g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left(1 - \frac{N_2}{K_2} + \beta_{21} N_1 \right), \quad (11) $$

where $\beta_{21}$ is the impact factor of population 1 on population 2. The dynamic system of $P_1$ and $P_2$ is

$$ \begin{cases} 
  g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left(1 - \frac{N_1}{K_1} + \beta_{12} N_2 \right), \\
  g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left(1 - \frac{N_2}{K_2} + \beta_{21} N_1 \right). 
\end{cases} \quad (12) $$

Equation (6) is called the Lotka–Volterra (LV) system. The LV model, based on the logistic model of a single species, considers the dynamic growth of competition and symbiosis of two or more entities simultaneously in the ecosystem [42], which can accurately describe the competition and symbiosis between corporate populations. The LV system can determine the influence of the core population on the evolution of the entire ecosystem [43], thus having better data fitting and prediction expression [44].

The measurement model is as follows:

| Step 4 | Step 5 |
|--------|--------|
| Element Coupling Analysis | Lotka-Volterra Model |
into two parts, namely, efficiency (effch) and technology changes (techch); namely, efficiency changes (sech); namely, input-based Total Factor Productivity Index (tfpch) can be expressed by the Malmquist index; namely,

\[
M_{t+1}^{t+1} = \frac{D'(x_{0}^{t+1}, y_{0}^{t+1})}{D'(x_{0}^{t}, y_{0}^{t})} \times \frac{D'(x_{1}^{t+1}, y_{1}^{t+1})}{D'(x_{1}^{t}, y_{1}^{t})}.
\]

The Malmquist index can be combined with the Data Envelopment Analysis (DEA) method to measure changes in population productivity, and the index can be decomposed into two parts, namely, efficiency (effch) and technology (techch). The Malmquist index formula can be expressed as follows:

\[
MI = \frac{D'(x_{0}^{t+1}, y_{0}^{t+1})}{D'(x_{0}^{t}, y_{0}^{t})} \times \frac{D'(x_{1}^{t+1}, y_{1}^{t+1})}{D'(x_{1}^{t}, y_{1}^{t})} = \text{effch} \times \text{techch}.
\]

Total factor productivity changes can be decomposed into technology changes (techch) and efficiency changes (effch), and efficiency changes can be decomposed into pure technical efficiency changes (pech) and scale efficiency changes (sech); namely,

\[
\text{tfpch} = \text{effch} \times \text{techch},
\]
\[
\text{effch} = \text{pech} \times \text{sech}.
\]

Here, effch > 1 means efficiency improvement, and effch < 1 means efficiency reduction; techch > 1 means technological progress, and techch < 1 means technological decline.

2.4. Malmquist Index. In order to make a further analysis, Total Factor Productivity is used as a measure of technological progress, and the Malmquist index is measured. The input-based Total Factor Productivity Index (tfpch) can be used as a measure of technological progress, and the index can be decomposed into technology changes (techch) and efficiency changes (sech); namely,

\[
geffch(t) = \Delta N_1(t) = \gamma_1 N_1(t-1) + \gamma_2 N_1^2(t-1) + \gamma_3 N_1(t-1)N_2(t-1),
geffch(t) = \Delta N_2(t) = \gamma_1 N_2(t-1) + \gamma_2 N_2^2(t-1) + \gamma_3 N_1(t-1)N_2(t-1).
\]

The relevant parameters were estimated by the least-square method.

2.5. Concept Refinement of the Innovation Ecosystem. In order to improve the validity of the study, this paper mainly adopts the semistructured interview method, which constitutes the triangular verification of evidence sources from in-depth interviews, direct observation, and other written materials [45]. The specific methods of this paper are as follows: (1) In-depth interview. This paper adopts a semistructured interview to ensure that the interview is closely related to the research topic. The content of the interview mainly involves three aspects: firstly, the respondents were asked to introduce the current situation of the enterprise and its operation activities; secondly, the respondents were asked to describe the specific implementation process of the innovation activities of their enterprises and further introduce the relevant key events; finally, the respondents were asked to describe how the new ecosystem helps enterprises gain competitive advantage. The respondents mainly include middle and senior managers or heads of relevant departments. Each interview lasts about 30 to 80 minutes. During the interview, 2 to 3 researchers participated in the whole process of recording and then summarized and sorted out the recorded data information after the interview. (2) Direct observation. During the investigation, the researcher went deep into the enterprise to observe the worksite, recording and sorting it into information materials, which can be used to supplement and confirm other materials. (3) Literature. Researchers collected internal publications, activity plans, meeting minutes, research reports, and other materials. For example, they logged into the official website of the enterprise to catch the basic information, business scope, major minutes, and other pieces of information about the enterprise. (4) Academic papers. Researchers searched relevant databases and collected published papers in relevant fields. In the process of data collection, in order to reduce the error caused by the bias of respondents, it is emphasized to take the key events of “innovation ecosystem” as the context in the interview process and gradually restore the full picture of the key events, so as to strengthen the accuracy of qualitative data materials. At the same time, real-time qualitative data materials are regularly tracked and updated to supplement longitudinal retrospective qualitative data materials [46].

This study takes the relatively well-developed and representative science and technology parks in China and the innovation ecosystem of famous enterprises as the key level of the sample, namely, Suzhou National High tech Zone, Changzhou National High tech Zone, and Shanghai National High tech Zone as the main sample source range. The study also selects the representative high-tech enterprises, research institutions, colleges, and universities as the sample and then selects some middle and senior managers with bachelor’s degree or above as the respondents.

From the perspective of organization type, this paper includes 19 large- and medium-sized high-tech enterprises, 8 research institutions, and 5 colleges and universities. In terms of positions, there are 4 general managers, 3 general manager assistants, 15 heads of R&D departments, 2 directors of the research institute, 4 directors of the Science and Technology Department, 5 presidents, and 3 vice presidents from colleges. From the educational level of the respondents, among the 36 respondents, 11 have doctoral degrees, 13 have master’s degrees, and 12 have bachelor’s degrees. In order to extract more representative key factors, it is preliminarily proposed to select the word frequency that appears more than 3 times in the coding as the initial concept to define the category so as to prevent the excessive spread of the number of main categories.

In this paper, we openly code the data provided in interview materials, case materials, and academic research materials. These documents have been repeatedly and...
carefully read before being conceptualized and abstracted. Through constant comparison, concepts are refined, and categorization is made. The case of open coding is shown in Table 1.

As shown in Table 1, we can find examples of category-related sentences in the respondents’ answers. The coding in the initial stage is wider, and then it is gradually reduced until the number is saturated. Data is openly coded with the theme of “innovation ecosystem,” and the level of open coding is set according to the logical relationship. A total of 288 first-level codes and 92 second-level codes are obtained, and 52 concepts are refined on this basis. The concepts are classified into their respective phenomena, forming 11 categories, the detail of which is shown in Table 2.

As shown in Table 2, through the analysis of the open coding, it can be found that the innovation ecosystem involves many environmental factors such as political factor, economic factor, legal factor, market, investment and financing, and stakeholders in which innovative organizations and individuals are located. The complexity of the innovation ecosystem is thus self-evident. Isolated concepts and categories are still not enough to clearly explain the innovation ecosystem.

Each category is relatively independent, and the relationship between categories needs to be analyzed in depth through axial coding technology. The categories are divided into main and subcategories, and the analytical framework of the model is constituted by causal conditions, phenomenon, context, intervening condition, strategy, and consequence. The model can better illustrate the relationship between the main category and the subcategory. The results of the axial coding are shown in Table 3.

As shown in Table 3, through the analysis of the main categories and models, it can be found that the innovation ecosystem mainly includes 6 main categories: political and legal environmental governance, economic environmental governance, technological environmental governance, innovative enterprises, scientific research institutions, and universities and colleges.

The first main category is politics and law, which consists of a legal environment and a policy environment. This shows that innovation cannot be separated from the support and protection of the legal environment, and innovation cannot be separated from the incentive and promotion of related policies either. Intellectual property protection and market conduct norms are particularly important for innovative enterprises and innovative activities. Legal environmental governance is the basic guarantee for innovative ecological governance. System reforms, supply-side reforms, innovation and entrepreneurship policies, taxation policies, and talent policies provide specific policy support for innovation. The macroscopic legal system directly affects innovation and entrepreneurial activities through specific policy measures. The political and legal environment in the context of China’s national conditions is a distinctive feature of China’s innovation ecosystem.

The second main category is economic basis, which is composed of economic basic environment, market environment, investment and financing environment, and stakeholder environment. Innovative activities under the market economy system must be supported by a certain amount of profit and capital investment. The macroeconomic environment determines the market environment, investment and financing environment, and the relationship between stakeholders in the market. Improving the profitability and viability of innovation entities is conducive to the realization of sustainable innovation.

The third main category is technology. Only with the help of innovative infrastructure and service systems can innovation activities achieve better technological innovation. Technological innovation activities cannot be done alone. The innovation resource networks should be made full use of to achieve collaborative innovation.

The fourth main category is enterprise. The enterprise is the subject of market competition and innovation activities. Market competition activities and innovation activities between enterprises complement each other. Innovative enterprises gather to form an innovative population of enterprises. The symbiotic relationship within the enterprise innovation population can be expressed as collaboration, competition, or both.

The fifth main category is scientific research institutions, which gather to form an innovative population of scientific research institutions. The symbiotic relationship within the innovation population of scientific research institutions can be expressed as collaboration, competition, or both. The symbiotic relationship between scientific research institutions and enterprise innovation populations can be expressed as synergy, competition, or both.

The sixth major category is universities and colleges, which gather to form an innovative population of colleges and universities. There is a complex symbiotic relationship between the innovation populations of universities and between the scientific research population of universities and the innovation population of scientific research institutions and enterprises.

The construction of the regional innovation ecosystem has changed the regional innovation ecology, created a new innovation environment, and put pressure on innovation organizations to carry out organizational innovation and reform. Innovators and innovative organizations turn external pressure into motivation, actively carry out organizational and management changes, and actively adapt themselves to the new environment. The activities such as management innovation activities, business innovation activities, and system innovation activities also show that the innovation ecosystem is not limited to technological innovation. The innovation activities, including innovation input activities and innovation output activities of various main categories in the innovation ecosystem, constitute the subcategories of the innovation ecosystem.

As shown in Table 4, through the analysis of the subcategories, it can be found that there are seven subcategories in the innovation activities in the innovation ecosystem: talents, funds, infrastructure, service organizations, product development, applied research, and basic research. They are all innovation activities in the innovation ecosystem,
Table 1: Open coding case.

| Interviewee no. (statement no.) | Example of statement source data | Categorization |
|---------------------------------|----------------------------------|----------------|
| 17 (20)                         | Our R&D center is a new type of research institution. It is guided by the government and jointly built by universities, scientific research institutes, and the city. Government policies are very important for the establishment of our new type of research institution. | A1 policy |
| 6 (8)                           | There is a national characteristic industrial base, with many enterprises of the same type, which can jointly develop new products, and the support of the local government is powerful. At that time, we thought that the financial support policy provided by the science and technology park here was better. Under the dual pressure of the continuous downturn of the construction machinery market and the sluggish economic development of the old industrial base, the group’s sales and profits have been seriously affected, and strategic transformation and innovation are imminent. By implementing the innovation ecosystem strategy, the group has formed an innovation-based business model. | A2 laws and regulations |
| 8 (5)                           | Our products are similar to the main products of the Beijing X research institute. We need to cooperate with the outside world as soon as possible to update our products before them and seize the market opportunity. | A3 economic basis |
| 9 (13)                          | Now the technology update is too fast. To quickly update the product performance, we cannot avoid seeking external support. Although our company is now a medium-sized high-tech enterprise, we still need to learn in many cutting-edge technology fields and quickly catch up with top companies, and cooperation in R&D projects is undoubtedly the fastest way to obtain and catch up with each other’s core technology achievements. | A4 market |
| 15 (6)                          | The company has gradually established an “enterprise-university and research institution” partnership, mainly including Tsinghua University, Southeast University, and Microelectronics Research Institute, so as to expand its own innovation ecosystem. | A5 technology |
| 18 (9)                          | We still have technical bottlenecks in the development of the Internet of Things product system, and we cannot do without cooperation. | A6 innovation core population |
| 13 (15)                         | Our company has invested a lot of money in cooperation with colleges and universities every year, and it is increasing every year. In cooperation with company X, we can provide corresponding hardware equipment and experimental sites for the development of intelligent wearable products. Some technologies in colleges and universities can still be transformed and implemented. I think that they can cooperate to launch products through joint laboratories jointly built with enterprises. | A7 innovative subpopulation |
| 1 (11)                          | In cooperation with company X, we can provide corresponding hardware equipment and experimental sites for the development of intelligent wearable products. Some technologies in colleges and universities can still be transformed and implemented. I think that they can cooperate to launch products through joint laboratories jointly built with enterprises. | A8 intellectual capital |
| 24 (20)                         | In cooperation with company X, we can provide corresponding hardware equipment and experimental sites for the development of intelligent wearable products. Some technologies in colleges and universities can still be transformed and implemented. I think that they can cooperate to launch products through joint laboratories jointly built with enterprises. | A9 R&D funding and investment |
| 28 (12)                         | Communication; communication and information; innovation facility; urban infrastructure; library and information center; environmental protection | A10 infrastructure |

Table 2: Open coding result.

| Conceptualization                                      | Categorization |
|---------------------------------------------------------|----------------|
| a1 reform of economic system; a2 innovation policy; a3 entrepreneurship policy; a4 tax policy; a5 personnel policy; a6 supply-side reform | A1 policy |
| a7 regulations; a8 intellectual property protection; a9 industrial and commercial enterprise administration | A2 laws and regulations |
| a10 output value; a11 employment; a12 revenue; a13 corporate profits; a14 new economic normal | A3 economic basis |
| a15 resident consumption; a16 private enterprise; a17 state-owned enterprise; a18 fiscal expenditure; a19 import; a20 export | A4 market |
| a21 technology market; a22 patents and inventions; a23 research paper | A5 technology |
| a24 technology enterprise; a25 leading enterprise; a26 research institutes; a27 institution of higher education | A6 innovation core population |
| a28 law office; a29 accounting firm; a30 human resources service company; a31 technical service company | A7 innovative subpopulation |
| a32 researcher; a33 entrepreneur; a34 engineer; a35 practitioners; a36 highly educated population; a37 education investment | A8 intellectual capital |
| a38 government R&D investment; a39 enterprise R&D investment; a40 university R&D investment; a41 R&D investment in research institutes; a42 credit rating system; a43 financial support system | A9 R&D funding and investment |
| a44 communication; a45 communication and information; a46 innovation facility; a47 urban infrastructure; a48 library and information center; a49 environmental protection | A10 infrastructure |
| a50 new product; a51 patent; a52 scientific papers | A11 innovation output |
including innovation input activities, innovation auxiliary activities, and innovation output activities.

The main work in this part is to construct relevant grounded theoretical models based on the analysis of categories and their relationships and then to describe storylines. The innovation ecosystem and its governance path in the Chinese context can be described by the following storyline.

The subjects of innovation (innovators and innovation organizations) live in a certain innovation ecosystem, which consists of 6 subsystems (main categories). The subsystem guarantees the transmission of material and information in the ecosystem. They are coordinated and connected to each other to form a nonlinear innovation activity support environment. The software subsystem not only provides feedback and adaptation to the hardware subsystem but also coordinates and leads the hardware subsystem. There is an interactive relationship between each subsystem. Good interactions between the subsystems promote the adaptive and collaborative evolution of the innovation ecosystem. These six subsystems can be divided into two categories: innovation environment and innovation population. The collaboration and interaction of innovation environment and innovation population is an important condition for the sound development of the innovation ecosystem.

A good innovation ecosystem environment can promote the development of innovation activities and increase innovation output. Therefore innovative ecosystems with low levels of operation need improving with corresponding measures. Innovators and innovation organizations in a certain economic system carry out innovative activities with the help of innovative infrastructure and service systems. By improving the effectiveness of innovation system through management, the enterprise organization realizes the match with the external innovation system through internal management innovation. The political and legal environment and economic and market environment jointly determine the boundaries of innovative activities. The innovation ecosystem has its own boundaries, but there is an exchange of material, information, energy, and talents between the system and the external environment, as the system is characteristic of openness. The output of the innovation ecosystem is a variety of innovative products and services, which in turn have an impact on the economic foundation, legal system, innovative ecological management, social culture, and other major categories. The interaction between variables in the system eventually forms multiple closed feedback loops.

There are two types of possible innovation ecosystem optimization paths: single path and composite path. There are several single paths as follows: Path 1: the development of the economic subsystem promotes the improvement of the market environment as well as the investment and financing environment and promotes the expansion of the boundaries of the innovation ecosystem. Path 2: political and economic system reform promotes the expansion of the boundaries of

---

### Table 3: Main category: model of the innovation ecosystem.

| Core category | Innovation habitat | Innovation population |
|---------------|--------------------|-----------------------|
| **Main category** | Politics and law | Economy | Technology | Enterprise |
| Factor | \(a_1-a_9\) | \(a_{10}-a_{20}\) | \(a_{21}-a_{33}\) | \(a_{34}-a_{25}\) |
| Phenomenon | Policy driven | Market driven | Technology driven | Focal enterprise |
| Context | Laws and regulations | Improving the ability to innovate and protect the legal system | Economy | Technology transaction |
| Consequence | Improving the ability to innovate and protect the legal system | Improving the profitability and survivability of innovative entities | Improving technological innovation capabilities | Building corporate competitiveness with product innovation |

### Table 4: Subcategory: innovation activities in the innovation ecosystem.

| Support category | Innovation investment | Subpopulation | Innovation output |
|------------------|-----------------------|---------------|-------------------|
| **Subcategory** | Talents | Funds | Infrastructure | Service organization | Product development | Applied research | Basic research |
| Factors | \(a_{37}-a_{17}\) | \(a_{38}-a_{43}\) | \(a_{44}-a_{49}\) | \(a_{50}\) | \(a_{51}\) | \(a_{52}\) |
| Phenomenon | Talent development | Funding | Facilities use | The booming service industry | New product | Patents | Scientific papers |
| Context | Incentives | Multiple inputs | Facility construction | Associated service development | Enhance competitiveness | Applied research | Basic research |
| Consequence | Talent support | Financial support | Material support | Service support | Business profit | Continuous innovation | Scientific breakthrough |
the innovation ecosystem through the introduction of new laws, regulations, and policies. Path 3: social and cultural construction leads to the optimization of social norms and provides spiritual motivation for innovation. Path 4: the construction of innovation network nodes such as innovation technology parks and incubators at different levels optimizes the innovation network, promotes the management reform and system innovation of enterprises and other innovative organizations, and improves the efficiency of innovation. Path 5: resources are directly invested in intellectual capital development, focal enterprise support, innovation infrastructure, and service system construction so as to enhance scientific and technological innovation capabilities. This is also a relatively common practice at present. A composite path is a combination of two or more of the above 5 single paths.

The theoretical saturation test is an important step to ensure the reliability of grounded research. The test is conducted from two aspects in this paper. The first is to conduct literature research and consult influential monographs, important academic journals, and famous corporate innovation cases in this research field. After qualitatively screening the data from the above literature, it is found that the refined concepts already exist in the 11 categories studied in the previous parts. Secondly, by conducting supplementary interviews with scholars, scientific researchers, and business managers in related fields, the concepts discovered are also included in the scope of the previous research.

2.6. Evaluation of the Innovation Ecosystem. In summary, based on the previous research and existing literature [47–49] and considering the availability of data, we can construct a niche suitability evaluation system (Table 5).

As shown in Table 5, the innovation population is a collection of innovation species, that is, innovation subjects. This paper divides the innovation subjects into three main dimensions: enterprises, universities and colleges, and scientific research institutions. The habitat concept of innovative ecological environment mainly refers to the environmental requirements of species, and it is a collection of ecological factors related to the growth and development of species. In this paper, the concept is mapped to the innovation ecosystem, so the research environment refers to the collection of ecological environmental factors related to innovation, which mainly includes three dimensions: economic environment, policy environment, and technological environment. The input resources mainly reflect the situation of the innovation unit’s possession and utilization of resources in the innovation ecosystem. This paper measures the three aspects of human resources, funding, and infrastructure. Technological output characterizes the state of technological resources owned by the innovation subjects in the innovation ecosystem. Based on the types of technological resources owned by innovation entities, this study divides the technological niche into two dimensions: new product output and scientific and technological achievements. This study uses China’s data from the “China Statistical Yearbook” for 14 years, from 2006 to 2019, for verification.

As shown in Table 6, the entropy method is very effective in measuring the factor levels of populations and habitats, as well as the corresponding weights of different factors in the system. Through observation of the relevant data, we can find that the relevant factor indicators of populations and habitats have been increasing year by year.

As shown in Table 7, the entropy method is effective in measuring the factor level of input and output activities, as well as the corresponding weights of different factors in the system. Through the observation of the relevant data, we can find that the relevant factor indicators of input and output activities have shown an increasing trend year by year. Through the transformation of the original data, we can get the weighted normalized matrix V.

As shown in Table 8, the coupling coefficients of populations and habitats and of input-output activities are comparatively good, and the coupling coefficients of input-output activities are better than that of populations and habitats. The values of these two coupling coefficients are very close, and the coupling dependency is very high. In the innovation ecosystem, the degree of interdependence between variables is high. According to the research results of this paper, it can be found that the interdependence between population and habitat is very high, and the interdependence between input activities and output activities is also very high. This shows that the dependence between various variables in China’s innovation ecosystem is very high.

In order to further analyze the interaction mechanism between the population and the innovation habitat in the innovation ecosystem, this paper analyzes them from two aspects: single-population dynamics model and dual-population interaction model, in the light of the related models of population dynamics. The logistic equation is used in the single-species dynamic model, and the LV equation is mainly used in the analysis of the interaction mechanism of the double population. The least-square method is used when estimating the coefficients of different models. This paper gives the corresponding regression coefficients and test parameters, as shown in Table 9.

As shown in Table 9, the dynamic analysis within the innovation population shows that the relevant regression coefficients are not significant. The dynamic analysis within the innovation habitat shows that the population growth mechanism is significant, while the population inhibition mechanism is not significant. The dynamic mechanism within the innovation population and the innovation habitat has no significant return effect.

From the analysis of the dynamic mechanism between the two populations, it can be found that the regression effect of the dual-population model of the influence of the innovation habitat on the innovation population is better. The regression analysis of the impact of innovation populations on innovation habitat is not good.

According to the above analysis, it can be found that the innovation habitat has a very good synergistic effect on the innovation population. In terms of influencing mechanism, the relationship between populations in China’s innovation ecosystem is mainly reflected in the support of innovation habitats to innovation populations. Conversely, the growth
of the innovation population, the improvement of the innovation habitat, or the evolution of the innovation habitat does not exhibit particularly significant characteristics of the population dynamics mechanism.

As shown in Table 10, the regression effect of the dynamic growth mechanism inside the input system is significant, and the regression effect of the dynamic growth mechanism inside the output system is also significant. Meanwhile, the regressive effect of the dynamic symbiosis mechanism of the impact of output on input is also significant. This means that the output system has played a role in traction on inputs. However, the dynamic influencing
mechanism of input on output is not significant in the regression system. This shows that the relationship between input and output is more of an output-driven ecosystem. As shown in Table 11, changes in total factor productivity of populations and habitat systems are mainly caused by technological changes. Changes in efficiency have certain volatility. Moreover, the change in total factor productivity is less than 1, and the total factor productivity of the sample has been decreasing. The effect of habitat on population growth is mainly synergistic, but its efficiency is decreasing. The main reason for the decrease in efficiency is the decrease in the rate of technological change.

As shown in Table 12, the changes in the total factor productivity of the input-output system are mainly caused

| Year | I1 | I2 | I3 | I4 | I5 | O1 | O2 | O3 |
|------|----|----|----|----|----|----|----|----|
| 2006 | 150| 3003| 1863| 1772| 465| 31233| 268002| 106|
| 2007 | 174| 3710| 2453| 1819| 521| 40976| 351782| 114|
| 2008 | 197| 4616| 3096| 2131| 718| 51292| 411982| 119|
| 2009 | 229| 5802| 3655| 2544| 1084| 65838| 581992| 136|
| 2010 | 255| 7063| 4421| 2393| 1269| 72864| 814825| 142|
| 2011 | 288| 8687| 6846| 2174| 1680| 100583| 960513| 150|
| 2012 | 325| 10298| 7999| 2691| 2476| 110530| 1255138| 152|
| 2013 | 353| 11847| 9247| 3085| 3133| 128461| 1313000| 154|
| 2014 | 371| 13016| 10123| 4103| 4219| 142895| 1302687| 157|
| 2015 | 376| 14170| 10271| 5516| 4752| 150857| 1718192| 164|
| 2016 | 388| 15677| 11766| 6319| 5568| 174604| 1753763| 165|
| 2017 | 403| 17606| 13498| 6987| 5933| 191569| 1836434| 170|
| 2018 | 438| 19678| 14987| 7267| 6739| 197094| 2447460| 184|
| 2019 | 480| 22144| 16986| 7892| 7946| 212060| 2591607| 195|

| Year | Innovative population | Innovation habitat | Population and habitat coupling coefficient | Input | Output | Input-output coupling coefficient |
|------|-----------------------|--------------------|-------------------------------------------|-------|--------|----------------------------------|
| 2006 | 0.202                 | 0.105              | 0.949                                     | 0.079 | 0.109  | 0.988                            |
| 2007 | 0.205                 | 0.121              | 0.966                                     | 0.091 | 0.125  | 0.988                            |
| 2008 | 0.221                 | 0.139              | 0.974                                     | 0.109 | 0.138  | 0.993                            |
| 2009 | 0.231                 | 0.158              | 0.982                                     | 0.132 | 0.168  | 0.993                            |
| 2010 | 0.234                 | 0.183              | 0.993                                     | 0.147 | 0.189  | 0.992                            |
| 2011 | 0.236                 | 0.211              | 0.999                                     | 0.175 | 0.220  | 0.994                            |
| 2012 | 0.247                 | 0.231              | 0.999                                     | 0.209 | 0.243  | 0.997                            |
| 2013 | 0.256                 | 0.252              | 1.000                                     | 0.239 | 0.258  | 0.999                            |
| 2014 | 0.268                 | 0.267              | 1.000                                     | 0.275 | 0.269  | 1.000                            |
| 2015 | 0.278                 | 0.295              | 1.000                                     | 0.303 | 0.301  | 1.000                            |
| 2016 | 0.293                 | 0.318              | 0.999                                     | 0.337 | 0.318  | 1.000                            |
| 2017 | 0.308                 | 0.348              | 0.998                                     | 0.370 | 0.336  | 0.999                            |
| 2018 | 0.306                 | 0.387              | 0.993                                     | 0.404 | 0.382  | 1.000                            |
| 2019 | 0.329                 | 0.426              | 0.992                                     | 0.453 | 0.406  | 0.999                            |

| Year | Internal relationship | Variable | Coefficients | Standard error | t-stat | p value |
|------|-----------------------|----------|--------------|----------------|--------|---------|
| 2006 | Innovation population | γ1       | 0.030        | 0.060          | 0.506  | 0.623   |
|      |                       | γ2       | 0.034        | 0.226          | 0.150  | 0.884   |
|      |                       | γ3       | 0.134        | 0.027          | 4.922  | p≤0.01  |
| 2017 | Innovation environment| γ1       | -0.113       | 0.091          | -1.242 | 0.240   |
|      |                       | γ2       | -0.538       | 1.056          | -0.524 | 0.224   |
|      |                       | γ3       | 1.081        | 1.056          | 1.024  | 0.330   |

| Year | Relationship between innovation population and environment | Variable | Coefficients | Standard error | t-stat | p value |
|------|-----------------------------------------------------------|----------|--------------|----------------|--------|---------|
| 2006 | Impact of environment on population | γ1       | 0.483        | 0.160          | 3.023  | 0.013   |
|      |                       | γ2       | -2.837       | 0.986          | -2.877 | 0.016   |
|      |                       | γ3       | 1.173        | 0.397          | 2.957  | 0.014   |
| 2019 | Impact of population on environment | γ1       | -0.040       | 0.173          | -0.232 | 0.821   |
|      |                       | γ2       | -0.538       | 0.425          | -1.266 | 0.234   |
|      |                       | γ3       | 1.081        | 1.056          | 1.024  | 0.330   |
Changes in efficiency have certain volatility. Moreover, the change in total factor productivity is less than 1, and the total factor productivity of the sample has been decreasing. The effect of output on input is mainly synergy, but its efficiency is decreasing. The main reason for the decrease in efficiency is the decrease in the rate of technological change.

The calculation of innovation ecosystem efficiency made in this paper shows the following facts: the research results fully illustrate the importance of synergy between different innovation populations. When there is significant synergy between innovation populations, the innovation activity efficiency of the whole innovation ecosystem will be relatively high. When there is insignificant synergy between innovation populations, the efficiency of innovation activities of the whole innovation ecosystem will be relatively low. At the same time, the operation of the innovation ecosystem is also affected by the whole socioeconomic environment. When the social and economic system operates well, the development of innovation ecosystem is also in a good state.

### 3. Results and Discussion

#### 3.1. Results

In this paper, the conceptual model of the innovation ecosystem is reconstructed in the light of grounded theory. The conceptual model describes the innovation ecosystem from two perspectives: the main category and the subcategory. The innovation ecosystem has six main categories: political and legal environmental governance, economic environmental governance, technological environmental governance, innovative enterprises, scientific research institutions, and institutions of higher education. These six main categories can be further divided into innovation population and innovation habitat. The subcategories are different kinds of innovation activities in the innovation ecosystem, including innovation input activities, innovation support activities, and innovation output activities.

The interactive relationship between the innovation population and the innovation habitat is not balanced, and the innovation habitat has a very good synergistic effect on the innovation population. The synergistic effect of the innovative population on the innovative habitat is not obvious. The changes in total factor productivity of populations and habitat systems are mainly caused by technological changes. Changes in efficiency have certain volatility. The effect of habitat on population growth is mainly synergy, but its efficiency is decreasing. The main reason for the decrease in efficiency is the decrease in the rate of technological change. There is a coupling relationship between innovation populations. Affected by technological heterogeneity, the coupling relationship between these innovation populations is asymmetric. The stronger the technology interaction is, the greater the coupling strength between technology

### Table 10: Analysis of the dynamic mechanism of input and output.

| Variable | Coefficients | Standard error | t-stat | p value |
|----------|--------------|----------------|--------|--------|
| γ₁       | 0.194        | 0.024          | 8.200  | ≤0.01  |
| γ₂       | -0.242       | 0.074          | -3.259 | ≤0.01  |
| γ₁       | 0.164        | 0.046          | 3.590  | ≤0.01  |
| γ₂       | -0.259       | 0.155          | -1.673 | 0.122  |

### Table 11: M index of population and habitat system efficiency.

| Year | effch | techch | pech | sech | tfpch |
|------|-------|--------|------|------|-------|
| 2007 | 1     | 0.881  | 1    | 1    | 0.881 |
| 2008 | 1     | 0.938  | 1    | 1    | 0.938 |
| 2009 | 1     | 0.920  | 1    | 1    | 0.920 |
| 2010 | 1     | 0.875  | 1    | 1    | 0.875 |
| 2011 | 1     | 0.875  | 1    | 1    | 0.875 |
| 2012 | 1     | 0.956  | 1    | 1    | 0.956 |
| 2013 | 1     | 0.950  | 1    | 1    | 0.950 |
| 2014 | 1     | 0.988  | 1    | 1    | 0.988 |
| 2015 | 1     | 0.939  | 1    | 1    | 0.939 |
| 2016 | 1     | 0.978  | 1    | 1    | 0.978 |
| 2017 | 1     | 0.961  | 1    | 1    | 0.961 |
| 2018 | 1     | 0.893  | 1    | 1    | 0.893 |
| 2019 | 1     | 0.977  | 1    | 1    | 0.977 |
| Mean | 1     | 0.932  | 1    | 1    | 0.932 |

### Table 12: M index of input-output system efficiency.

| Year | effch | techch | pech | sech | tfpch |
|------|-------|--------|------|------|-------|
| 2007 | 1     | 0.996  | 1    | 1    | 0.996 |
| 2008 | 1     | 0.922  | 1    | 1    | 0.922 |
| 2009 | 1     | 1.005  | 1    | 1    | 1.005 |
| 2010 | 1     | 1.010  | 1    | 1    | 1.010 |
| 2011 | 1     | 0.978  | 1    | 1    | 0.978 |
| 2012 | 1     | 0.925  | 1    | 1    | 0.925 |
| 2013 | 1     | 0.928  | 1    | 1    | 0.928 |
| 2014 | 1     | 0.906  | 1    | 1    | 0.906 |
| 2015 | 1     | 1.016  | 1    | 1    | 1.016 |
| 2016 | 1     | 0.950  | 1    | 1    | 0.950 |
| 2017 | 1     | 0.962  | 1    | 1    | 0.962 |
| 2018 | 1     | 1.041  | 1    | 1    | 1.041 |
| 2019 | 1     | 0.948  | 1    | 1    | 0.948 |
| Mean | 1     | 0.967  | 1    | 1    | 0.967 |
populations will be; the more important the technology is, the greater the coupling strength of other technology populations to this technology population will be; the more concentrated the technology ownership is, that is, the higher the degree of technology monopoly is, the greater the coupling strength of other technical populations on this technology population will be. At the same time, the stronger the interaction between technology and habitat is, the greater the coupling dependency between technology population and habitat will be. The stronger the dependence of technology on the habitat is, the greater the coupling dependency between the technological population and the habitat will be.

3.2. Discussion. The research in this paper once again proves the rationality of adopting a systematic approach in innovation analysis. This systematic analysis method was developed by scholars in the 1980s and 1990s. They have published literature on various types of innovation systems [50]. Does the research need a clear concept of innovation ecosystem [51–53]? This paper believes that it is necessary to interpret the concept of innovation ecosystem in different contexts, especially since the innovation ecosystem has not yet been clearly defined.

The current definition of innovation ecosystem usually focuses on the subjects of innovation and rarely includes innovation habitat, innovation activities, and the level of coupling between these factors. The definition and main contribution of this paper are that it focuses on the complementary (substitution) and cooperative (competitive) relationships between innovation populations and between innovation populations and habitats (herein referred to as symbiotic relationships). Compared with the classic definition, this study conducts an in-depth analysis of the common, often mixed, and intertwined symbiotic relationships. The focus on symbiotic relationships provides a more precise, comprehensive, and balanced view of the innovation activities that are taking place in the innovation ecosystem. In addition, the symbiosis relationship also realizes the operability of research through the use of established economics and management concepts. Undoubtedly, the symbiosis relationship is the core relationship between strategy and management decision-making, about disruptive innovation [54], complementary assets [55], or the modularity of platforms [56, 57], for example. Different from the existing research on innovation efficiency [58–61], this paper has embedded the synergy mechanism in efficiency research.

Compared with the traditional definition of innovation ecosystem, this paper gives a new paradigm for the description of innovation ecosystem. This description of the innovation ecosystem from the perspective of complexity starts from the concept definition of the innovation ecosystem and moves on to fully consider the heterogeneous characteristics of the innovation ecosystem in different contexts. This study believes that when introducing an innovation ecosystem under a specific background, it is necessary not only to describe its structural elements but also to give an analysis of the symbiosis relationship between the elements and the overall efficiency of the system.

4. Conclusions

The research objectives of this paper have been achieved. The concept of the innovation ecosystem under the Chinese scenario is reconstructed. An innovation ecosystem evaluation system is constructed from the dimensions of species and environment. An evaluation model is established to evaluate the innovation environment and the synergy of innovation populations and the efficiency of the innovation ecosystem. The relationship between synergy and efficiency will be analyzed. The research route and method proposed in this paper are feasible. The research has achieved the expected results. Practice shows that the research path constructed in this paper can well study the composition, evaluation index system, and element synergy evaluation of innovation ecosystem. The highlights of the research in this paper are as follows: (1) A set of description paradigms are constructed for the innovation ecosystem from concept refinement and factor symbiosis to system efficiency analysis. (2) In this paper, the synergy mechanism is embedded in the efficiency evaluation model of innovation ecosystem, which can better reflect the ecological characteristics of innovation system. As a result, the research on the evaluation of the innovation ecosystem level is deepened; a theoretical reference is provided for promoting the healthy development of the innovation ecosystem.

Data Availability

The experimental data used to support the findings of this study are included within the paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Social Science Foundation of China (Grant no. 20BGL203).

References

[1] K. Fukuda, “Science, technology and innovation ecosystem transformation toward society 5.0,” International Journal of Production Economics, vol. 220, pp. 1–14, 2020.
[2] R. Adner, “Match your innovation strategy to your innovation ecosystem,” Harvard Business Review, vol. 84, no. 4, pp. 98–148, 2006.
[3] M. Holgerason, O. Granstrand, and M. Bogers, “The evolution of intellectual property strategy in innovation ecosystems: Uncovering complementary and substitute appropriability regimes,” Long Range Planning, vol. 51, no. 2, pp. 303–319, 2018.
[4] P. Witte, B. Slack, M. Keesman, J.-H. Jugie, and B. Wiegmans, “Facilitating start-ups in port-city innovation ecosystems: a case study of Montreal and Rotterdam,” Journal of Transport Geography, vol. 71, pp. 224–234, 2018.
[5] O. Granstrand and M. Holgersson, “Innovation ecosystems: a conceptual review and a new definition,” Technovation, vol. 90-91, no. 102098, pp. 1–12, 2020.

[6] L. Ding and J. Wu, “Innovation ecosystem of CNG vehicles: a case study of its cultivation and characteristics in Sichuan, China,” Sustainability, vol. 10, no. 1, pp. 39–55, 2018.

[7] B. Walrave, M. Talmar, K. S. Podoymitsyna, A. G. L. Romme, G. P. J. Verbong, and G. P. J. Verbong, “A multi-level perspective on innovation ecosystems for path-breaking innovation,” Technological Forecasting and Social Change, vol. 136, pp. 103–113, 2018.

[8] M. Tsujimoto, Y. Kajikawa, J. Tomita, and Y. Matsumoto, “A review of the ecosystem concept - towards coherent ecosystem design,” Technological Forecasting and Social Change, vol. 136, pp. 49–58, 2018.

[9] M.-R. Yan, K.-M. Chien, L.-Y. Hong, and T.-N. Yang, “Evaluating the collaborative ecosystem for an innovation-driven economy: a systems analysis and case study of science parks,” Sustainability, vol. 10, no. 3, pp. 887–900, 2018.

[10] L. A. D. V. Gomes, A. L. F. Facin, M. S. Salerno, and R. K. Ikenami, “Unpacking the innovation ecosystem construct: evolution, gaps and trends,” Technological Forecasting and Social Change, vol. 136, pp. 30–48, 2018.

[11] R. Adner and R. Kapoor, “Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations,” Strategic Management Journal, vol. 31, no. 3, pp. 306–333, 2010.

[12] X. Xie and H. Wang, “How can open innovation ecosystem modes push product innovation forward? An fsQCA analysis,” Journal of Business Research, vol. 108, pp. 29–41, 2020.

[13] P. Ritala, V. Agouridas, D. Assimakopoulos, and O. Gies, “Value creation and capture mechanisms in innovation ecosystems: a comparative case study,” International Journal of Technology Management, vol. 63, no. 3-4, pp. 244–265, 2013.

[14] G. Surie, “Creating the innovation ecosystem for renewable energy via social entrepreneurship: insights from India,” Technological Forecasting and Social Change, vol. 121, pp. 184–195, 2017.

[15] J. F. Moore, “Predators and prey: a new ecology of competition,” Harvard Business Review, vol. 71, no. 3, pp. 75–86, 1993.

[16] R. Gao, Z. Zhang, and Z. Tian, “Modelling the emergence and evolution of e-business ecosystems from a net-work perspective,” Studies in Informatics and Control, vol. 22, no. 4, pp. 339–348, 2013.

[17] B. J. Nalebuff, A. Brandenburger, and A. Maulana, Co-operation, Harper Collins Business, London, 1996.

[18] K. Miller and A. Rajala, “Rise of strategic nets-New modes of value creation,” Industrial Marketing Management, vol. 36, no. 7, pp. 895–908, 2007.

[19] S. A. Zahra and S. Nambisan, “Entrepreneurship and strategic thinking in business ecosystems,” Business Horizons, vol. 55, no. 3, pp. 219–229, 2012.

[20] H. W. Chesbrough, Open Innovation: The New Imperative for Creating and Profiting from Technology, Harvard Business Press, Boston, MA, USA, 2006.

[21] C. H. Tian, B. K. Ray, J. Lee, R. Cao, and W. Ding, “BEAM: a framework for business ecosystem analysis and modeling,” IBM Systems Journal, vol. 47, no. 1, pp. 101–114, 2008.

[22] H. T. W. Frankort, “Open innovation norms and knowledge transfer in interfirm technology alliances: evidence from information technology, 1980-1999,” Advances in Strategic Management, vol. 30, pp. 239–282, 2013.

[23] J. G. March, “Exploration and exploitation in organizational learning,” Organization Science, vol. 2, no. 1, pp. 71–87, 1991.

[24] L. Pierce, “Big losses in ecosystem niches: how core firm decisions drive complementary product shakeouts,” Strategic Management Journal, vol. 30, no. 3, pp. 323–347, 2009.

[25] D. J. Teece, “Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance,” Strategic Management Journal, vol. 28, no. 13, pp. 1319–1350, 2007.

[26] Y. Zhang and M. Gregory, “Managing global network operations along the engineering value chain,” International Journal of Operations & Production Management, vol. 31, no. 7, pp. 736–764, 2011.

[27] T. Könnölä, V. Eloranta, T. Turunen, and A. Salo, “Transformative governance of innovation ecosystems,” Technological Forecasting and Social Change, vol. 173, Article ID 121106, 2021.

[28] L. A. V. Gomes, A. L. F. Facin, and M. S. Salerno, “Managing uncertainty propagation in innovation ecosystems,” Technological Forecasting and Social Change, vol. 171, Article ID 120945, 2021.

[29] A. Marcon and J. L. D. Ribeiro, “How do startups manage external resources in innovation ecosystems? A resource perspective of startups’ lifecycle,” Technological Forecasting and Social Change, vol. 171, Article ID 120965, 2021.

[30] S. Y. Wang, W. M. Chen, R. Wang, and X. L. Wu, “Multi-objective evaluation of Co-evolution among innovation populations based on lotka-volterra equilibrium,” Discrete Dynamics in Nature and Society, vol. 2021, Article ID 5569108, 14 pages, 2021.

[31] F. Asplund, B. Björk, M. Magnnussson, and A. J. Patrick, “The genesis of public-private innovation ecosystems: bias and challenges,” Technological Forecasting and Social Change, vol. 162, Article ID 120378, 2021.

[32] V. Vlaisavljevic, C. C. Medina, and B. V. Looy, “The role of policies and the contribution of cluster agency in the development of biotech open innovation ecosystem,” Technological Forecasting and Social Change, vol. 155, Article ID 119987, 2020.

[33] Y. Inoue, “Indirect innovation management by platform ecosystem governance and positioning: toward collective ambidexterity in the ecosystems,” Technological Forecasting and Social Change, vol. 166, Article ID 120652, 2021.

[34] V. Prokop, P. Hájek, and J. Stejskal, “Configuration paths to efficient national innovation ecosystems,” Technological Forecasting and Social Change, vol. 168, Article ID 120787, 2021.

[35] P. A. Nylund, A. Brem, and N. Agarwal, “Enabling technologies mitigating climate change: the role of dominant designs in environmental innovation ecosystems,” Technovation, vol. 2021, Article ID 102271, 2021.

[36] B. Glaser and A. Strauss, The Discovery of Grounded Theory: Strategies for Qualitative Research, Aldine Publishing Company, Chicago, IL, USA, 1967.

[37] H.-C. Lee and C.-T. Chang, “Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan,” Renewable and Sustainable Energy Reviews, vol. 92, pp. 883–896, 2018.

[38] O. Mohsen and N. Fereshteh, “An extended VIKOR method based on entropy measure for the failure modes risk assessment - a case study of the geothermal power plant (GPP),” Safety Science, vol. 92, pp. 160–172, 2017.
[39] R. Shad, M. Khorrami, and M. Ghaemi, “Developing an Iranian green building assessment tool using decision making methods and geographical information system: case study in Mashhad city,” Renewable and Sustainable Energy Reviews, vol. 67, pp. 324–340, 2017.

[40] A. Hafezalkotob and A. Hafezalkotob, “Extended MULTI-MOORA method based on Shannon entropy weight for materials selection,” Journal of Industrial Engineering International, vol. 12, no. 1, pp. 1–13, 2016.

[41] F. H. Lotfi and R. Fallahnejad, “Imprecise Shannon’s entropy and multi attribute decision making,” Entropy, vol. 12, no. 1, pp. 53–62, 2010.

[42] V. Volterra, “Fluctuations in the abundance of a species considered Mathematically1,” Nature, vol. 118, no. 2972, pp. 558–560, 1926.

[43] G. L. Zhang, A. Daniel, and V. M. Adams, “Technology evolution prediction using Lotka-Volterra Equations,” Journal of Mechanical Design, vol. 140, no. 6, pp. 61–101, 2018.

[44] T. Modis, “Technological forecasting at the stock market,” Technological Forecasting and Social Change, vol. 62, no. 3, pp. 173–202, 1999.

[45] R. K. Yin, Case Study Research: Design and Methods, Sage Publication, Thousand Oaks, 3rd edition, 2002.

[46] K. M. Eisenhardt and M. E. Graebner, “Theory building from cases: opportunities and challenges,” Academy of Management Journal, vol. 50, no. 1, pp. 25–32, 2007.

[47] M. K. Litvak and R. I. C. Hansell, “A community perspective on the multidimensional niche,” Journal of Animal Ecology, vol. 59, no. 3, pp. 931–940, 1990.

[48] P.-C. Chen and S.-W. Hung, “An actor-network perspective on evaluating the R&D linking efficiency of innovation ecosystems,” Technological Forecasting and Social Change, vol. 112, pp. 303–312, 2016.

[49] Z. Li and H. Lin, “The niche-fitness model of crop population and its application,” Ecological Modelling, vol. 104, no. 2-3, pp. 199–203, 1997.

[50] B. Carlson, S. Jacobsson, M. Holmén, and A. Rickne, “Innovation systems: analytical and methodological issues,” Research Policy, vol. 31, no. 2, pp. 233–245, 2002.

[51] D.-S. Oh, F. Phillips, S. Park, and E. Lee, “Innovation ecosystems: a critical examination,” Technovation, vol. 54, pp. 1–6, 2016.

[52] P. Ritala and A. Alamanopoulou, “In defense of ‘eco’ in innovation ecosystem,” Technovation, vol. 60-61, no. 61, pp. 39–42, 2017.

[53] A. Baiyere, “Fostering innovation ecosystems - note on the 2017 ISPIM innovation forum,” Technovation, vol. 69, p. 1, 2018.

[54] C. M. Christensen, The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail, Harvard Business School Press, Boston, MA, USA, 1997.

[55] D. J. Teece, “Profiting from innovation in the digital economy: enabling technologies, standards, and licensing models in the wireless world,” Research Policy, vol. 47, no. 8, pp. 1367–1387, 2018.

[56] C. Y. Baldwin and J. Henkel, “Modularity and intellectual property protection,” Strategic Management Journal, vol. 36, no. 11, pp. 1637–1655, 2015.

[57] M. G. Jacobides, C. Cennamo, and A. Gawer, “Towards a theory of ecosystems,” Strategic Management Journal, vol. 39, no. 8, pp. 2255–2276, 2018.

[58] S. Wang, J. Wang, C. Wei, X. Wang, and F. Fan, “Collaborative innovation efficiency: from within cities to between cities-Empirical analysis based on innovative cities in China,” Growth and Change, vol. 52, no. 3, pp. 1330–1360, 2021.

[59] F. Fan, S. Dai, K. Zhang, and H. Ke, “Innovation agglomeration and urban hierarchy: evidence from Chinese cities,” Applied Economics, vol. 53, no. 54, pp. 6300–6318, 2021.

[60] F. Fan, H. Lian, and S. Wang, “Can regional collaborative innovation improve innovation efficiency? An empirical study of Chinese cities,” Growth and Change, vol. 51, no. 1, pp. 440–463, 2019.

[61] H. Ke, S. Dai, and F. Fan, “Does innovation efficiency inhibit the ecological footprint? An empirical study of China’s provincial regions,” Technology Analysis & Strategic Management, vol. 22, pp. 1–15, Article ID 101536, 2021.