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# Multi-Group Symbiotic Evolution Mechanism in an Innovative Ecosystem: Evidence from China

Wang ZHANG[1], Pingfeng LIU[2], Jingkun ZHANG[3]

## Abstract

The innovation ecosystem is a nonlinear dissipative self-organizing symbiosis system with a progressive evolution mechanism of analog ecosystems. The three major habitat research groups, development groups and application groups are interwoven into a multi-directional and multi-directional communication mechanism that competes and evolves. This paper takes the three populations as the entry point, closely follows the ecological characteristics, introduces the Logistic growth model, constructs a multi-group symbiotic evolution dynamics model, and analyzes the dynamic mechanism and its equilibrium state. Through the combination of numerical simulation and empirical analysis, the symbiotic model is simulated and the evolutionary trend of symbiosis in China in 2050 is predicted. The study shows that symbiotic evolution is the effect of symbiotic unit formation in a certain symbiotic environment according to a certain symbiotic model. Symbiosis is the evolution mechanism of population; the evolutionary dynamic mechanism is summarized as: economic drive, ecological balance, competition synergy, complex adaptation and policy regulation; symbiosis The evolutionary equilibrium state and equilibrium conditions depend on the symbiosis between the populations; the symbiotic evolution in China is at a mature stage, and the evolutionary model is mutually beneficial symbiosis, which is expected to enter saturation in 2030. In order to provide a reference for China's science and technology innovation-driven development strategy, it will lay a theoretical foundation for further research in the academic community.

*Keywords:* innovation ecosystem, symbiotic evolution, dynamic mechanism, symbiotic model, social innovation, social interaction.

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## Introduction

Since 2018, the huge impact of the Sino-US trade war on China's value chain has highlighted the urgency of technological innovation. At present, the problem of China's manufacturing industry is not solved, and it has not been solved for a long time. It is still in the low end of the global value chain for a long time. Therefore, technological innovation is not only the core activity that drives the development of the country and the region, but also enhances the competitive advantage of the industry (Dai & Ye, 2018). It is also the way to improve China's overall national strength and prevent the value chain from entering the low-end path. With the exploration of the times and the changes of the international complex environment, the national innovation strategy has gradually become more collaborative innovation and symbiotic evolution, and competition has also turned to competition between ecosystems (Zhang, 2009). Facing the intricate and innovative environment, the innovation paradigm is constantly changing and upgrading. It has experienced linear innovation 1.0 and system innovation 2.0, and is in the era of ecosystem innovation 3.0. The open features of the innovation ecosystem become more and more obvious. In the process of symbiotic evolution, there are bilateral mechanisms of material, information and energy exchange. With the continuous optimization of the dual-creation environment and the continuous integration of superior resources, the problem of symbiotic evolution mechanism of innovative ecosystems has become one of the research priorities of the academic community. In the complex innovation environment, the selective construction of the innovation ecosystem is based on the realization of internal and external resource sharing and symbiotic evolution to higher-order ecological progress.

The innovation ecosystem includes innovative populations, innovation factors and innovation environments (Wu *et al.*, 2018; Chen, 2018), with collaborative innovation as the evolutionary direction, value creation (Zeng *et al.*, 2013) as the evolutionary core, and superior resource integration as the evolutionary goal. Innovative stocks, innovative factors and innovative environments gather around the knowledge interaction, complementary resources and endogenous interactions as an innovation ecosystem (Liu, 2011). There are not only bilateral two-way exchanges, but also multilateral multi-directional communication mechanisms. According to the theory of evolutionary economics, innovation activities obey the laws of biology, and biological metaphors can reveal the innovation process (Yu, 2013), which is one of the essential differences between innovation ecosystems and innovation systems. Due to space limitations, the innovation ecosystem and biological metaphors are detailed, with reference to Li *et al.* (2014) and other research. The academic community believes that the innovation ecosystem contains three major populations (Freeman, 2010; Estrin, 2008): research groups, development groups, and application groups (*Figure 1*). The close contact between the three groups forms a close symbiosis effect. Just as natural ecosystems require sunlight and water for plant growth, the sustainable development of innovative ecosystems requires appropriate leadership, funding, policy, education and culture. The population interacts with the resource environment and transforms it into the energy and nutrients necessary for survival and innovation. Under the three groups of symbiotic evolution mechanisms, one party provides assistance or competition for the other two parties to facilitate innovation activities, and also obtains help or competition from the other two parties. Organisms of symbiotic evolution include scientists, product developers, merchants, service providers, and consumers. They belong to at least one of the three groups. Evolving sustainable innovation stems from the interaction of these three groups at the organizational, national and world levels. The sustainability of an innovative ecosystem depends on achieving a healthy balance between the three populations mentioned above.

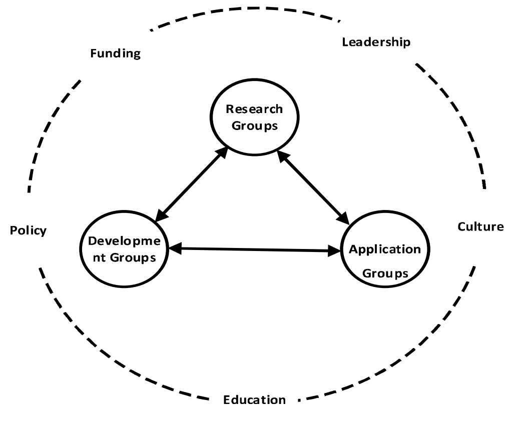


*Figure 1:* Three Groups of Innovative Ecosystems

## Literature Review

Since the accession to the WTO, technological innovation has played a more prominent role in driving economic development and global value chains. The rise of the open innovation paradigm has promoted the development of the innovation ecosystem. The symbiotic evolutionary nature of the innovation ecosystem is the change in the symbiosis pattern between the populations (Krugman, 1991), which can be as subtle as a trickle, or as vast as the ocean. The term eco-system is widely recognized as a source of business ecosystems (Moore, 1993). Since then, scholars from different fields have refined from the micro and meso perspectives, and derived the enterprise innovation ecosystem (Adner, 2006), the industrial innovation ecosystem (Gawer, 2014; Lei *et al.*, 2018; Zhang, 2009), and the cloud manufacturing alliance innovation ecosystem (Wang *et al.*, 2018).

The academic community and the industry have explored the theory and operation of the innovation ecosystem, and fruitful results have emerged. Throughout the existing research, the research on innovation ecosystem mainly involves four aspects: basic concepts, influencing factors, innovation models and evolution mechanisms. (1) In terms of concept. Wu *et al.* (2017) explained the concept and characteristics of the innovation ecosystem. Summarizing the shortcomings of the current research is that it does not fully demonstrate the unique advantages of ecology; Fan *et al.* (2018) and Mei *et al.* (2014) adopted the scientific measurement method and systematically discussed Innovative ecosystem theory origin, knowledge evolution, theme evolution law, and propose the latest evolution theme is open innovation, value creation and collaborative innovation. (2) In terms of influencing factors, Lv *et al.* (2015) and Song and Lu (2017) both believe that the symbiotic effect formed by the mutual benefit of heterogeneous subjects is essential, and the system value that can be generated is greater than the sum of individual subjects; Zhu *et al.* (2018), Liu & Yan (2013) analyzed the competitive advantages and synergistic innovation mechanism of the innovation ecosystem from the perspective of network environment, and demonstrated that the two key elements of the healthy development of the system are the system and mechanism (Adner & Kapoor, 2010; Chen & Chang, 2012). Wang Inventor (Wang & Zhu, 2018) agreed that the energy exchange between the populations in the innovation ecosystem is the source of technological innovation, and complementing the advantages of external partners can achieve value creation. (3) In terms of innovation model, Zhao and Zeng (2014) proposed a central-peripheral model of multi-level innovation ecosystem, revealing the connotation, structure and behavior of different innovation levels, and providing new ideas for follow-up research (Wu *et al.*, 2018), Huang and Zhuang (2012) proposed the innovation ecosystem "Government+Enterprise+Study Unit" collaborative innovation triple helix model, which provided a theoretical basis for multi-agent collaborative innovation evolution; Ou *et al.* (2017) and other models through the establishment of innovative ecosystem symbiotic evolution and simulation analysis A symbiotic evolution model, which considers the mutual benefit symbiosis model as the best direction for the symbiotic evolution of core enterprises and supporting organizations. (4) In terms of evolution mechanism, Sun *et al.* (2016) and Fan (2017) divided the innovation ecosystem into four stages: creation, protection, selection and diffusion of technology, and proposed the co-evolution of core enterprises and government to the innovation ecosystem. It has a decisive role; Zhang (2015) empirically innovates the coupling relationship of the main body of the ecosystem technology by introducing the biological evolution density dependence model, and believes that the stronger the mutual interaction of the subjects, the greater the coupling strength between the subjects. Yin (2014), Zhang (2015) and Wang *et al.* (2016) used interpretive case study methods to explore the evolution mechanism of the innovation ecosystem, and believed that development opportunities, competition factors and demand preferences led to different evolution processes.

The innovation ecosystem focuses on the open cooperation of innovative populations, the complementary resources of innovative factors, the optimization and upgrading of innovation environment, the dynamic mechanism of multi-group symbiosis evolution, stable and stable conditions, and the symbiotic model. Throughout the above studies, it is regrettable that there is no relevant literature. Based on this, this paper draws on the theory of evolutionary economics, symbiosis theory and ecology theory, introduces the logistic model of ecological population growth for the weak links of existing research, constructs three groups of symbiotic evolution dynamics models, and analyzes the dynamic mechanism of symbiotic evolution and its equilibrium. State, through numerical simulation to simulate different combinations of symbiotic modes, empirical analysis to verify the scientific nature of the model, and propose policy recommendations to promote the mutual benefit of population symbiosis. In theory, it will comprehensively interpret the dynamic mechanism and path of multi-group symbiosis evolution, enrich the theory of multi-group collaboration value creation of innovation ecosystem, and lay a foundation for further research in the academic field; in application, provide policy for China's science and technology innovation-driven development strategy Enlightenment, in turn, promotes synergy and innovation of multiple groups in the innovation ecosystem to prevent the value chain from being locked into the low-end path.

## Symbiotic evolution dynamic mechanism

Symbiotic evolution refers to the changes in population size, symbiosis mode, and state over time (Leng *et al.*, 2017). It is an evolutionary process from low order to high order, from simple to complex, from imperfect to gradually perfect. The symbiotic evolution meets the needs of technological innovation through continuous self-adjustment and continuous spiraling. The symbiotic evolution process is influenced by many factors such as economic level, resource environment and government regulation. The evolutionary dynamic mechanism can be summarized into five mechanisms: economic driven mechanism, ecological balance mechanism, competitive coordination mechanism, complex adaptation mechanism and policy regulation. mechanism.

### *Economic driving mechanism*

The economic driving mechanism is the driving force for the evolution of the innovation ecosystem, and the economic and social innovation-driven development is inseparable from the economic driving mechanism. Due to insufficient or absent innovation factors, single-population innovation activities are not fully utilized, and core competitiveness is difficult to be cultivated. In the early stage of the development of the innovation ecosystem, it was driven by the economic driving mechanism, and the population development showed a nonlinear and exponential upward trend. After a certain period of development, it is affected by external resources and its own density, forcing the growth rate of the population to slow down and gradually reach saturation.

*Ecological balance mechanism*

In a certain resource environment, the carrying capacity of the innovation ecosystem is limited, and the population innovation activity is a dynamic game process. The ecological balance mechanism is a self-organizing mechanism of population symbiosis evolution. There is also a non-linear, negative feedback ecological symbiosis between the existing, new and output of the population. The ecological balance mechanism plays a decisive role in the overall stability and balance of the system to promote the symbiotic evolution and sustainable development of the population.

*Competitive synergy mechanism*

Competition and synergy are two contradictory but interacting processes in the process of symbiotic evolution of innovative ecosystems. They alternate or simultaneously appear in the process of symbiotic evolution. The competition forms a partial fluctuation of the system, and synergistically forms a system-wide fluctuation, thereby promoting the system to a higher order evolution. The competition synergy mechanism directly leads to a spiral of population symbiosis evolution, which is the source of survival of the fittest population.

*Complex adaptation mechanism*

The innovation ecosystem is a typical complex adaptation system whose evolution and development follow the basic mechanisms of ecology, namely: complex adaptation mechanisms. The evolution and development of the whole system is much more complicated than the growth of single-population biomass. The constraints are not only ecological and environmental factors, but also affected by the scale of the population and macro-control. Under the control of this complex adaptive mechanism, the evolution of the innovation ecosystem grows in a compound curve with periodic and multi-factors, and the evolutionary situation presents complex behaviors and trajectories.

*Policy regulation mechanism*

The symbiotic evolutionary potential of the innovation ecosystem is endless. In the process, the population development presents a series of rising steps, which are: rising, gradual, rising again, and gradual again. When it is restricted by environmental resource constraints and balance mechanisms, it reaches saturation. Under the control of macroeconomic policies, the system has further developed space and entered the next stage. This process of repeated cycles has indirectly caused the evolution of the system to rise step by step.

## Symbiotic evolution dynamic model

*Symbiosis theory*

Symbiosis refers to the relationship between symbiotic units in a certain symbiotic environment according to a certain symbiotic pattern, and symbiosis is the mechanism of population evolution (Bennett & Moran, 2015). Symbiotic elements include symbiotic units, symbiotic patterns, and symbiotic environments. A symbiotic unit is a unit of basic energy production and exchange that constitutes a symbiotic or symbiotic model. It is the basic material condition for the formation of a symbiotic organism. In the symbiosis analysis of different symbionts and different levels, the nature and characteristics of symbiotic units are different. The symbiotic unit is relative to a specific analysis object. In the innovation ecosystem, the research group, the application group and the development group are all symbiotic units.

The symbiotic mode is a way of symbiotic unit interaction or a combination of forms. It reflects the material information exchange relationship between symbiotic units and the energy exchange relationship between symbiotic units. There are many symbiotic modes, and the degree of symbiosis varies widely (Chunqing, 1998). From the way of behavior, there are parasitic symbiosis, competitive symbiosis, partial symbiosis and mutual benefit. From the perspective of organization, there are many situations such as symbiosis, intermittent symbiosis, continuous symbiosis and integrated symbiosis. Any complete symbiosis model is a specific combination of behavior and symbiosis. The symbiotic mode changes with the change of the nature of the symbiotic unit and the change of the symbiotic environment mentioned later. The parasitic symbiosis can evolve into partial symbiosis or even mutual symbiosis. The symbiotic environment refers to the external condition in which the symbiotic model develops, and refers to the sum of all factors except the symbiotic unit. The environment in which the symbiotic model exists is often diverse, and the impact of different types of environments on the symbiotic model is also different. The symbiotic environment is exogenous to the symbiotic unit and the symbiotic model, and is often irresistible.

*Symbiotic evolution model description*

In the ecosystem, the growth law of population is Malthus (Zhang & Lam, 2013) growth and Logistic (Schwarzer & Peukert, 2005) growth, namely the Malthus model and the Logistic model. The former assumes that the growth rate within the population is constant (regardless of J-type growth under resource constraints), while the latter assumes that the resource environment can only support a certain number of populations (considering S-type growth under resource constraints), thus introducing a competition term. Since the symbiotic evolution of the innovation ecosystem is constrained by economic, technical, resource and environmental conditions, the population growth law is assumed to satisfy the Logistic model, and the empirical analysis in Section 4.2 proves the hypothesis scientific. Mainly presented as the larger the population size, the greater the density, the more sparse the resources, forcing the growth rate to slow down and gradually reach saturation. This paper makes the following assumptions about the symbiotic evolution of the population:

Hypothesis 1: The number of individual populations should be taken as discrete values. Since the population size is generally large, the population size is a continuous variable, and the individual life cycle difference is not considered in the population evolution stage.

Hypothesis 2: In a certain resource environment, the population is allowed to have a maximum value called environmental capacity or load, which is represented by N. When the population reaches the N value, the population no longer increases.

Hypothesis 3: Under certain environmental resources, the increase in population density has no time-delay effect on the decrease of its growth rate.

Based on the above assumptions, the ecological ecosystem logistic model of the ecosystem of innovative ecosystems is:

$$\begin{cases} \dfrac{dy(t)}{dt} = ry(t)\left\{1 - \dfrac{y(t)}{N}\right\} \\ y(0) = y_0 \end{cases} \tag{1}$$

Where r is the growth rate within the population; N is the maximum population of the resource environment; 1/N is the average resource consumption of the population; y(0) is the number of individuals at the initial moment; y(t) is the total population at time t; y(t)/N represents the total resource consumption of the population; 1-y(t)/N is the residual resource limitation item of the system, reflecting the relative distance of the population relative to the maximum carrying population.

Property 1: When $t=\ln(N/y_0-1)^{1/r}$;y(t)=N/2, the population evolution curve reaches the inflection point (*Figure 2*). When $t\to 0$, $y(t)\to y_0$, the resource environment has not been utilized, and the population grows exponentially; when

$t \to +\infty$, $y(t) \to N$, the resource environment is fully utilized, and the population reaches saturation state. The relative growth rate of the population is proportional to the amount of resources remaining at that time.

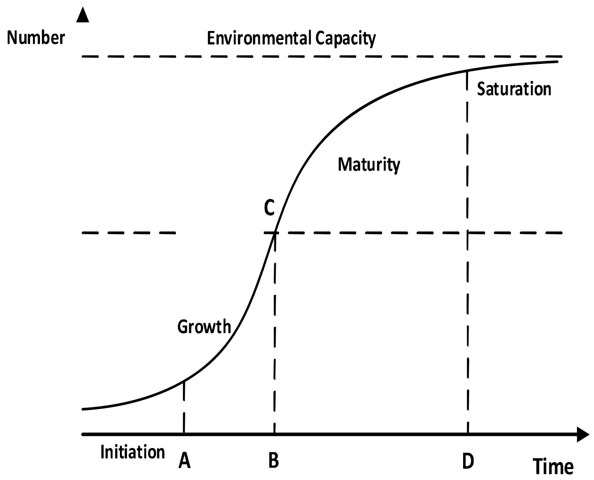


*Figure 2:* Population Evolution Logistic Curve

It is easy to know that population evolution has experienced four stages of initiation, growth, maturity and saturation. In the first two periods, the population was small, the resources were abundant, and the resource and environment constraints were small. With the continuous development of the population, the growth of the number of innovative populations has gradually accelerated, showing an exponential rising pattern. After entering the maturity period, the environmental capacity is tight, the demand supply is balanced, the growth rate of the innovative population is slowed down, and the population growth is stable in saturation.

*Construction of multi-group symbiotic evolution model*

Under certain resource environments, multiple groups of innovative ecosystems form multilateral multi-directional communication mechanisms with different degrees of mutual influence, thus reflecting different symbiotic effects. Therefore, the corresponding symbiotic effect term should be subtracted from the remaining resources (Tian *et al.*, 2013). The symbiotic effect is directly proportional to the number of symbiotic populations and inversely proportional to the maximum capacity of the population. Therefore, under the symbiotic effect of multiple groups, the population evolution dynamics model is:

$$\begin{cases} \Phi_1(y_1(t),t) = \dfrac{dy_1(t)}{dt} = r_1 y_1(1 - \dfrac{y_1}{N_1} + \delta_{12}\dfrac{y_2}{N_2} + \cdots + \delta_{1i}\dfrac{y_i}{N_i}),\ y_1(0) = y_{10} \\ \Phi_2(y_2(t),t) = \dfrac{dy_2(t)}{dt} = r_2 y_2(1 - \dfrac{y_2}{N_2} + \delta_{21}\dfrac{y_1}{N_1} + \cdots + \delta_{2i}\dfrac{y_i}{N_i}),\ y_2(0) = y_{20} \\ \vdots \\ \Phi_i(y_i(t),t) = \dfrac{dy_i(t)}{dt} = r_i y_i(1 - \dfrac{y_i}{N_i} + \delta_{i1}\dfrac{y_1}{N_1} + \cdots + \delta_{i\,i-1}\dfrac{y_{i-1}}{N_{i-1}}),\ y_i(0) = y_{i0} \end{cases} \quad (1)$$

Where $y_i(t)$ represents the number of population i at time t; $r_i$ is its growth rate; $N_i$ is the maximum capacity; symbiosis $\delta_{mn}$ represents the symbiosis of n populations to m populations, indicating the mechanism of symbiotic weakness, m, n$\in$[1, i ], m$\neq$n. The positive and negative meaning of symbiosis, as shown in *Table 1*.

*Table 1:* Population symbiosis

| $\delta_{mn}$ / $\delta_{nm}$ | + | 0 | - |
|---|---|---|---|
| + | Mutualism | Partial symbiosis | Parasitic symbiosis |
| 0 | Partial symbiosis | Independent symbiosis | Symbiotic symbiosis |
| - | Parasitic symbiosis | Symbiotic symbiosis | Competitive symbiosis |
| *According to the data | | | |

If $\delta_{mn}=\delta_{nm}$, it means that population n is symmetric and mutually beneficial to population m.

If $\delta_{mn}\neq\delta_{nm}$, it means that population n is asymmetric and mutually beneficial to population m.

If $\delta_{mn}=\delta_{nm}<0$, it means that population n is symmetrically symbiotic with respect to population m.

If $\delta_{mn}\neq\delta_{nm}<0$, it means that population n is asymmetrically symbiotic with respect to population m.

*Definition 1*: The symbiotic coefficient of population n and population m is $\theta_m^n$, and the symbiosis coefficient of population m and population n is $\theta_n^m$. Then c and s are expressed as follows.

$$\theta_m^n = \frac{|\delta_{mn}|}{|\delta_{mn}| + |\delta_{nm}|} \quad (2)$$

$$\theta_n^m = \frac{|\delta_{nm}|}{|\delta_{mn}| + |\delta_{nm}|} \tag{3}$$

Obviously $\theta_m^n + \theta_n^m = 1$, in the case of symmetric symbiosis, then $\theta_m^n = \theta_n^m = \frac{1}{2}$.

If $\theta_m^n = 0$, then population n has no symbiotic effect on population m, only population m has symbiotic effect on population n

If $\theta_m^n = 1$, then population m has no symbiotic effect on population n, only population n has a symbiotic effect on population m.

If $0 < \theta_m^n < \frac{1}{2}$, the symbiosis effect of population m on population n is greater than the symbiosis effect of population n on population m

If $\theta_m^n = \frac{1}{2}$, the population m has the same symbiosis effect on the population n as the population n is the same as the population m

If $\frac{1}{2} < \theta_m^n < 1$, the symbiotic effect of population n on population m is greater than population m versus population n

*Analysis of the equilibrium state of three groups of symbiotic evolution*

The symbiosis evolution of the three groups of the innovation ecosystem is a dynamic game process, and the evolutionary equilibrium state (Guo & Wang, 2018) trajectories issued in any small field that needs to satisfy an equilibrium state eventually evolve to the equilibrium state. According to the multi-group symbiotic evolution model in Section 3.3, the three groups of symbiotic evolution dynamics models are known as:

$$\begin{cases} \Phi_1(y_1(t),t) = \dfrac{dy_1(t)}{dt} = r_1 y_1(1 - \dfrac{y_1}{N_1} + \delta_{12}\dfrac{y_2}{N_2} + \delta_{13}\dfrac{y_3}{N_3}),\ y_1(0) = y_{10} \\ \Phi_2(y_2(t),t) = \dfrac{dy_2(t)}{dt} = r_2 y_2(1 - \dfrac{y_2}{N_2} + \delta_{21}\dfrac{y_1}{N_1} + \delta_{23}\dfrac{y_3}{N_3}),\ y_2(0) = y_{20} \\ \Phi_3(y_3(t),t) = \dfrac{dy_3(t)}{dt} = r_3 y_3(1 - \dfrac{y_3}{N_3} + \delta_{31}\dfrac{y_1}{N_1} + \delta_{32}\dfrac{y_2}{N_2}),\ y_3(0) = y_{30} \end{cases} \tag{4}$$

The local stability of the equilibrium state in the qualitative analysis system according to the Jacobian matrix. The three-population symbiotic evolution dynamics model Jacques matrix J is:

$$J=\begin{bmatrix} \frac{\partial\Phi_1}{\partial y_1} & \frac{\partial\Phi_1}{\partial y_2} & \frac{\partial\Phi_1}{\partial y_3} \\ \frac{\partial\Phi_2}{\partial y_1} & \frac{\partial\Phi_2}{\partial y_2} & \frac{\partial\Phi_2}{\partial y_3} \\ \frac{\partial\Phi_3}{\partial y_1} & \frac{\partial\Phi_3}{\partial y_2} & \frac{\partial\Phi_3}{\partial y_3} \end{bmatrix} = \begin{bmatrix} r_1(\delta_{12}\frac{y_2}{N_2}-2\frac{y_1}{N_1}+\delta_{13}\frac{y_3}{N_3}+1) & \delta_{12}\frac{r_1 y_1}{N_1} & \delta_{13}\frac{r_1 y_1}{N_1} \\ \delta_{21}\frac{r_2 y_2}{N_1} & r_2(\delta_{21}\frac{y_1}{N_1}-2\frac{y_2}{N_2}+\delta_{23}\frac{y_3}{N_3}+1) & \delta_{23}\frac{r_2 y_2}{N_3} \\ \delta_{31}\frac{r_3 y_3}{N_1} & \delta_{32}\frac{r_3 y_3}{N_2} & r_3(\delta_{31}\frac{y_1}{N_1}-2\frac{y_3}{N_3}+\delta_{32}\frac{y_2}{N_2}+1) \end{bmatrix} \quad (5)$$

Let the equations $\Phi_1(y_1(t),t)=0, \Phi_2(y_2(t),t)=0, \Phi_3(y_3(t),t)=0$ hold, and there are 8 special equilibrium points in the three groups of symbiotic evolution models: $G_1, G_2, G_3, G_4\ G_5, G_6, G_7, G_8$ constitutes the boundary of the symbiotic evolution system. As shown in table 2.

*Table 2:* Equilibrium States and Equilibrium Conditions of Symbiotic Evolution of Three Populations

| Equilibrium state | Eigenvalues | Equilibrium condition |
|---|---|---|
| $G_1(0,0,0)$ | Positive values | Not equilibrium |
| $G_2(N_1,0,0)$ | Negative values | $\delta_{21}<-1, \delta_{31}<-1$ |
| $G_3(0,N_2,0)$ | Negative values | $\delta_{12}<-1, \delta_{32}<-1$ |
| $G_4(0,0,N_3)$ | Negative values | $\delta_{13}<-1, \delta_{23}<-1$ |
| $G_5\left\{0,\frac{N_2(1+\delta_{23})}{1-\delta_{23}\delta_{32}},\frac{N_3(1+\delta}{1-\delta_{23}\delta}\right.$ | Partial positive value | Not equilibrium |
| $G_6\left\{\frac{N_1(1+\delta_{13})}{1-\delta_{13}\delta_{31}},0,\frac{N_3(1+}{1-\delta_{13}}\right.$ | Partial positive value | Not equilibrium |
| $G_7\left\{\frac{N_1(1+\delta_{12})}{1-\delta_{12}\delta_{21}},\frac{N_2(1+\delta_{21})}{1-\delta_{12}\delta_{21}}\right.$ | Partial positive value | Not equilibrium |

<table>
<tr>
<td>$G_8\left\{g_{81}, g_{82}, g_{83}\right\}$</td>
<td>Negative values</td>
<td>$\begin{cases} \dfrac{\delta_{12}+\delta_{13}+\delta_{12}\delta_{23}+\delta_{13}\delta_{32}-\delta_{23}\delta_{32}+}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}} \\ \dfrac{\delta_{21}+\delta_{23}+\delta_{13}\delta_{21}+\delta_{23}\delta_{31}-\delta_{13}\delta_{31}+}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}} \\ \dfrac{\delta_{31}+\delta_{32}+\delta_{12}\delta_{31}+\delta_{21}\delta_{32}-\delta_{12}\delta_{21}+}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}} \end{cases}$</td>
</tr>
<tr>
<td colspan="3">$$g_{81}=\frac{-N_1(\delta_{12}+\delta_{13}+\delta_{12}\delta_{23}+\delta_{13}\delta_{32}-\delta_{23}\delta_{32}+1)}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}\delta_{32}-1}$$
$$g_{82}=\frac{-N_2(\delta_{21}+\delta_{23}+\delta_{13}\delta_{21}+\delta_{23}\delta_{31}-\delta_{13}\delta_{31}+1)}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}\delta_{32}-1}$$
$$g_{83}=\frac{-N_3(\delta_{31}+\delta_{32}+\delta_{12}\delta_{31}+\delta_{21}\delta_{32}-\delta_{12}\delta_{21}+1)}{\delta_{12}\delta_{21}+\delta_{13}\delta_{31}+\delta_{23}\delta_{32}+\delta_{12}\delta_{23}\delta_{31}+\delta_{13}\delta_{21}\delta_{32}-1}$$</td>
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*Proposition 1*: Under certain resource environments, the equilibrium point $G_1, G_5, G_6, G_7$ must not be a progressive equilibrium state of the symbiotic evolution dynamics model.

Prove:

(1) It is easy to know that the Jacobian matrix of the symbiotic evolution model at $G_1$ point is: $J=\begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix}$, the eigenvalue of the $J=\begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix}$ point is: $\lambda=\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix}$, and the eigenvalues are positive numbers. Then, $G_1$ must not be stable.

(2) Taking the equilibrium point $G_5$ as an example, it is easy to know that the Jacobian matrix of the symbiotic evolution model at $G_5$ is:

$$J=\begin{bmatrix} \frac{r_1(\delta_{12}+\delta_{13}+\delta_{12}\delta_{23}+\delta_{13}\delta_{32}-\delta_{23}\delta_{32}+1)}{1-\delta_{23}\delta_{32}} & 0 & 0 \\ \frac{r_2\delta_{21}(\delta_{23}+1)}{1-\delta_{23}\delta_{32}} & \frac{-r_2(\delta_{23}+1)}{1-\delta_{23}\delta_{32}} & \frac{r_2\delta_{23}(\delta_{23}+1)}{1-\delta_{23}\delta_{32}} \\ \frac{r_3\delta_{31}(\delta_{32}+1)}{1-\delta_{23}\delta_{32}} & \frac{-r_3\delta_{32}(\delta_{32}+1)}{1-\delta_{23}\delta_{32}} & \frac{-r_3(\delta_{32}+1)}{1-\delta_{23}\delta_{32}} \end{bmatrix} \tag{6}$$

Solved, the eigenvalues at $G_5$ point are:

$$\lambda_1=\frac{r_1(\delta_{12}+\delta_{13}+\delta_{12}\delta_{23}+\delta_{13}\delta_{32}-\delta_{23}\delta_{32}+1)}{1-\delta_{23}\delta_{32}}$$

$$\lambda_2=\frac{r_2(1+\delta_{23})+r_3(1+\delta_{32})+\sqrt{2(2\delta_{23}^2\delta_{32}^2+2\delta_{23}^2\delta_{32}+2\delta_{23}\delta_{32}^2+\delta_{23}\delta_{32}-\delta_{23}-\delta_{32}-1)r_2r_3+(\delta_{23}+1)^2r_2^2+(\delta_{32}+1)^2r_3^2}}{-2\,(1-\delta_{23}\delta_{32})}$$

$$\lambda_2=\frac{r_2(1+\delta_{23})+r_3(1+\delta_{32})-\sqrt{2(2\delta_{23}^2\delta_{32}^2+2\delta_{23}^2\delta_{32}+2\delta_{23}\delta_{32}^2+\delta_{23}\delta_{32}-\delta_{23}-\delta_{32}-1)r_2r_3+(\delta_{23}+1)^2r_2^2+(\delta_{32}+1)^2r_3^2}}{-2\,(1-\delta_{23}\delta_{32})}$$

Discussion $\lambda_1$, $\lambda_2$, $\lambda_3$ symbols:

Easy to know, $\lambda_2\lambda_3=\frac{r_2r_3(1+\delta_{23})(1+\delta_{32})}{1-\delta_{23}\delta_{32}}$;

$$\lambda_2+\lambda_3=\frac{r_2(1+\delta_{23})+r_3(1+\delta_{32})}{-(1-\delta_{23}\delta_{32})}$$

When $1-\delta_{23}\delta_{32}<0$, if the $\lambda_2$ and $\lambda_3$ symbols are both negative, then $\lambda_2\lambda_3>0$ and $\lambda_2+\lambda_3<0$ must be established at the same time. It is easy to prove that when

$\lambda_2+\lambda_3 < 0$ is established, $\lambda_2\lambda_3 > 0$ is not established; on the contrary, it is not established.

When $1-\delta_{23}\delta_{32} > 0$, $\lambda_1 = \dfrac{r_1(\delta_{12}+\delta_{13}+\delta_{12}\delta_{23}+\delta_{13}\delta_{32}-\delta_{23}\delta_{32}+1)}{1-\delta_{23}\delta_{32}} > 0$ must be established。

In summary, the eigenvalues of the symbiotic evolution model at $G_5$ point must have at least one positive value, so the $G_5$ point must not be the steady state of the symbiotic evolution model. Similarly, $G_6$ and $G_7$ are not asymptotically stable states of the symbiotic evolution model.

Proposition 1 is proved.

Proposition 2: Under certain resource environment, the equilibrium point $G_2, G_3, G_4, G_8$ is a gradual stable state of the symbiotic evolution dynamics model under certain conditions.

Prove:

(1) Taking the equilibrium point $G_2$ as an example, it is easy to know that the Jacobian matrix of the symbiotic evolution model at the $G_2$ point is:

$$J = \begin{bmatrix} -r_1 & r_1\delta_{12} & r_1\delta_{13} \\ & r_2(\delta_{21}+1) & \\ & & r_3(\delta_{31}+1) \end{bmatrix} \tag{7}$$

Solving the $G_2$ point eigenvalue: $\lambda = \begin{bmatrix} r_2(1+\delta_{21}) \\ r_3(1+\delta_{31}) \\ -r_1 \end{bmatrix}$

If $\delta_{21} < -1, \delta_{31} < -1$ is satisfied at the same time, then the three eigenvalues satisfy the negative condition, so $G_2$ is a gradual stable state. Similarly, both $G_3$ and $G_4$ are asymptotically stable states of the symbiotic evolution model.

(2) It is easy to know that the coordinates of the symbiotic evolution model at G8 point:

$$\begin{cases} g_{81} = \dfrac{-N_1(\delta_{12} + \delta_{13} + \delta_{12}\delta_{23} + \delta_{13}\delta_{32} - \delta_{23}\delta_{32} + 1)}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} \\ g_{82} = \dfrac{-N_2(\delta_{21} + \delta_{23} + \delta_{13}\delta_{21} + \delta_{23}\delta_{31} - \delta_{13}\delta_{31} + 1)}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} \\ g_{83} = \dfrac{-N_3(\delta_{31} + \delta_{32} + \delta_{12}\delta_{31} + \delta_{21}\delta_{32} - \delta_{12}\delta_{21} + 1)}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} \end{cases} \quad (8)$$

Derivation of the symbiotic evolution dynamics model (Equation 4):

$$\begin{cases} \dfrac{\partial\Phi_1(y_1,t)}{\partial y_1} = -r_1(1 + \delta_{12}\dfrac{y_2}{N_2} + \delta_{13}\dfrac{y_3}{N_3}) \\ \dfrac{\partial\Phi_2(y_2,t)}{\partial y_2} = -r_2(1 + \delta_{21}\dfrac{y_1}{N_1} + \delta_{23}\dfrac{y_3}{N_3}) \\ \dfrac{\partial\Phi_3(y_3,t)}{\partial y_3} = -r_3(1 + \delta_{31}\dfrac{y_1}{N_1} + \delta_{32}\dfrac{y_2}{N_2}) \end{cases} \quad (9)$$

It is known from the theory of the stability of the dynamic system (Chang *et al.*, 1995).

When 1+1=2 and 1+1<3 are satisfied, G2G3 is a stable state of the symbiotic evolution model. Then there are:

When $\begin{cases} \Phi_1(y_1(t),t) = 0 \\ \Phi_2(y_2(t),t) = 0 \\ \Phi_3(y_3(t),t) = 0 \end{cases}$ and $\begin{cases} \left.\dfrac{\partial\Phi_1(y_1,t)}{\partial y_1}\right|_{y_1=g_{81}} < 0 \\ \left.\dfrac{\partial\Phi_2(y_2,t)}{\partial y_2}\right|_{y_2=g_{82}} < 0 \\ \left.\dfrac{\partial\Phi_3(y_3,t)}{\partial y_3}\right|_{y_3=g_{83}} < 0 \end{cases}$ are satisfied,

$G_8(g_{81}, g_{82}, g_{83})$ is a stable state of the symbiotic evolution model. Then there are:

$$\begin{cases} \left.\dfrac{\partial\Phi_1(y_1,t)}{\partial y_1}\right|_{y_1=g_{81}} = r_1\left\{\dfrac{\delta_{12} + \delta_{13} + \delta_{12}\delta_{23} + \delta_{13}\delta_{32} - \delta_{23}\delta_{32} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1}\right\} < 0 \\ \left.\dfrac{\partial\Phi_2(y_2,t)}{\partial y_2}\right|_{y_2=g_{82}} = r_2\left\{\dfrac{\delta_{21} + \delta_{23} + \delta_{13}\delta_{21} + \delta_{23}\delta_{31} - \delta_{13}\delta_{31} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1}\right\} < 0 \\ \left.\dfrac{\partial\Phi_3(y_3,t)}{\partial y_3}\right|_{y_3=g_{83}} = r_3\left\{\dfrac{\delta_{31} + \delta_{32} + \delta_{12}\delta_{31} + \delta_{21}\delta_{32} - \delta_{12}\delta_{21} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1}\right\} < 0 \end{cases}$$

Proposition 2 is proved.

In summary, the symbiotic evolutionary equilibrium of the three groups of innovative ecosystems depends on the mechanism of symbiosis between populations. Among the eight equilibrium points of the three population symbiosis evolution, $G_1$,$G_5$,$G_6$,$G_7$ must not be an equilibrium state. $G_2$,$G_3$,$G_4$,$G_8$ is an equilibrium state, where $G_{2,}G_3$,$G_4$satisfies

$$\delta_{21} < -1; \delta_{31} < -1$$

$$\delta_{12} < -1; \delta_{32} < -1$$

$$\delta_{13} < -1; \delta_{23} < -1$$

and $G_8$ satisfies.

$$\begin{cases} \dfrac{\delta_{12} + \delta_{13} + \delta_{12}\delta_{23} + \delta_{13}\delta_{32} - \delta_{23}\delta_{32} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} < 0 \\ \dfrac{\delta_{21} + \delta_{23} + \delta_{13}\delta_{21} + \delta_{23}\delta_{31} - \delta_{13}\delta_{31} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} < 0 \\ \dfrac{\delta_{31} + \delta_{32} + \delta_{12}\delta_{31} + \delta_{21}\delta_{32} - \delta_{12}\delta_{21} + 1}{\delta_{12}\delta_{21} + \delta_{13}\delta_{31} + \delta_{23}\delta_{32} + \delta_{12}\delta_{23}\delta_{31} + \delta_{13}\delta_{21}\delta_{32} - 1} < 0 \end{cases}$$

*Three-group symbiosis mode numerical simulation*

From *Table 1*, it is easy to know that the three group symbiosis modes depend on different combinations of symbiosis. Through numerical simulation and image display methods, the symbiotic evolution trajectories of the three groups can be visualized in different symbiotic modes. Therefore, this paper assumes that the natural growth rates of research groups, application groups and development groups are: 0.05, 0.1, 0.15, and the initial scale is 100. Under certain resource environments, the maximum development scale of the three groups is 1000, and the evolution period is 400. Three groups of evolutionary dynamics models were simulated to explore the symbiotic evolutionary path of populations under different symbiosis combinations. As shown in Figure 3-7.

(1) Independent symbiosis mode. The symbiosis between the research group, the application group and the development group is zero, and the three groups have no effect and develop independently. When the three groups are in equilibrium, their upper limit is the largest scale in independent development. As shown in *Figure 3*.

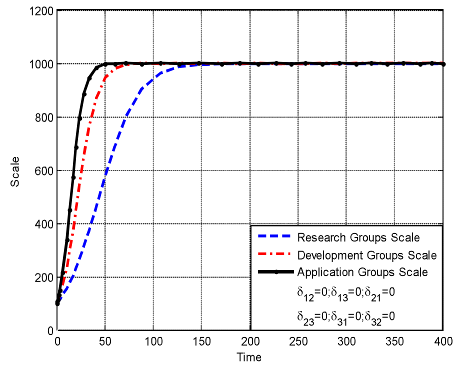


*Figure 3:* Independent Symbiosis Mode

(2) Competitive symbiosis mode. The competitive symbiosis model is divided into two types: equal competition symbiosis mode and vicious competition symbiosis mode. Equal competition and symbiosis need to meet the symbiosis of less than 0 and greater than -1, as shown in Figure 4 (a-b). On the contrary, the vicious competition symbiosis only needs to satisfy the symbiosis of one of the two populations to less than -1, and the latter two groups are the first to consume a large amount of resources and the first population to survive and develop. If at least one of the latter two groups has a greater symbiosis to the former population than the former, the former population will be consumed by the latter two groups and eventually die. As shown in *Figure 4* (c-d).

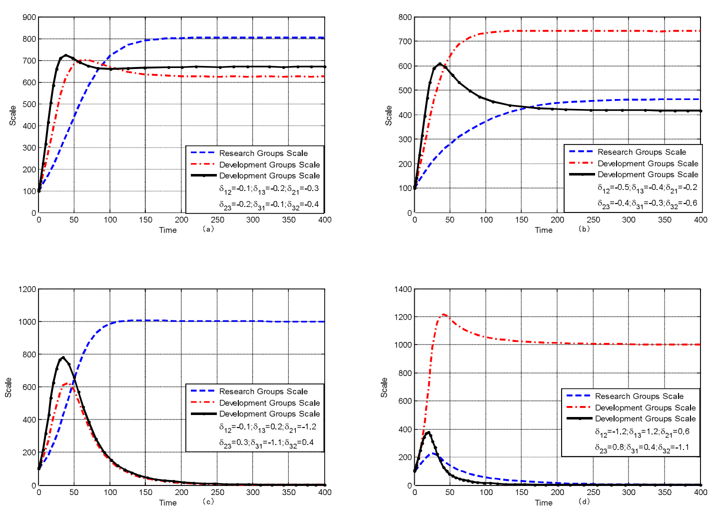


*Figure 4:* Competitive Symbiosis Mode

(3) Parasitic symbiosis mode. The parasitic symbiosis needs to satisfy the opposite of the symbiosis between any two groups, and the parasitic population is consumed by the parasitic population, and the final stable scale is smaller than the maximum scale. Parasitic populations benefit from parasitic populations, and the final stable scale is higher than the largest under independent symbiosis. As shown in *Figure 5* (a-d).

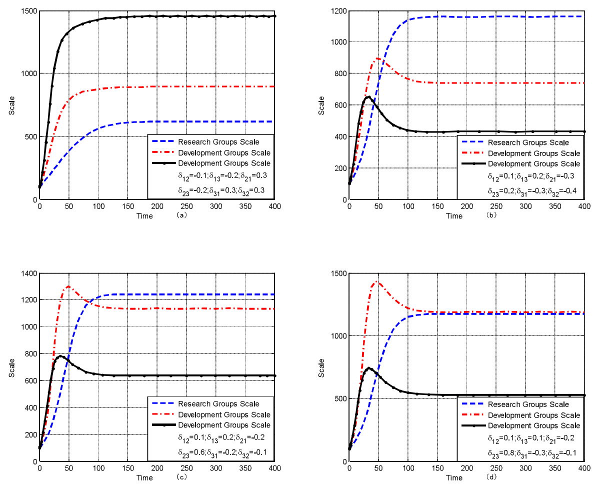


*Figure 5:* Parasitic Symbiosis Mode

(4) Partial symbiosis mode. The partial symbiosis mode has two types: partial symbiosis mode and partial symbiosis mode. Partial symbiosis requires any two groups of symbiosis to be equal to zero, one greater than zero, as shown in *Figure 6* (a-b). Conversely, the symbiosis of any two groups requires one of the two groups of symbiosis to be equal to zero and one to be less than zero. As shown in *Figure* 6 (c-d).

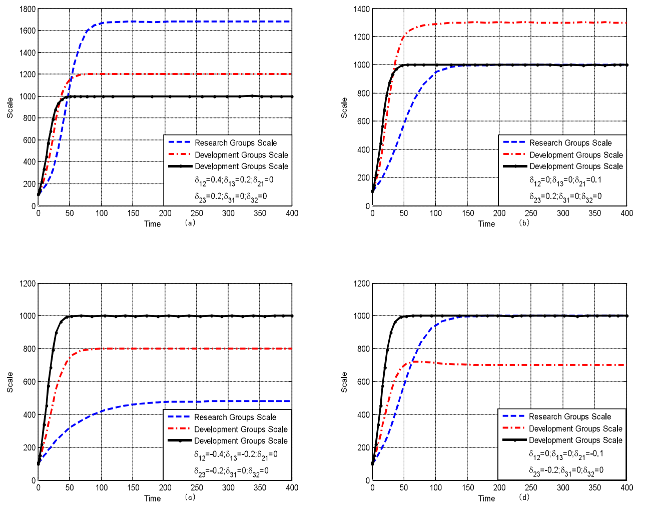


*Figure 6:* Partial Symbiosis Mode

(5) Mutual benefit symbiosis mode. The symbiosis between any two groups is positive, and the final stable maximum size is larger than the maximum size under independent symbiosis, as shown in Figure 7. Mutual benefit and symbiosis fully embodies the synergistic innovation of the population, which can promote the value of more than a single subject, which is consistent with the conclusions of Lu Yibo (Lv *et al.*, 2015) and Song & Lu (2017). At the same time, the mutual benefit symbiosis model can break the organizational boundaries, break through the environmental resource constraints, and achieve technological innovation and value co-creation, which is consistent with Adner (Adner & Kapoor, 2010), Chen Ning (Chen & Chang, 2012), Wang invention (Wang & Zhu, 2018) and other conclusions.

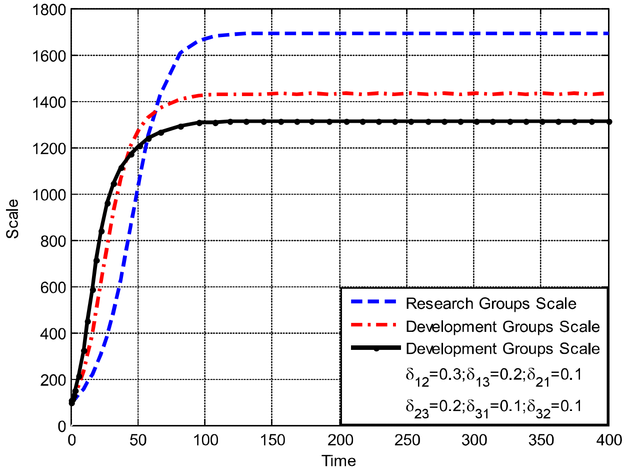


*Figure 7:* Mutual Benefit Symbiosis Mode

## Empirical analysis

On the one hand, empirical analysis can verify the scientific and practicality of multi-group symbiotic evolution dynamics models and predict future evolutionary trends. On the other hand, it is possible to dissect the symbiotic evolutionary mechanism of the population and complement the symbiotic model simulation. This paper takes China's innovation ecosystem as an empirical analysis and focuses on fitting three groups of symbiotic evolutionary logistic models. Due to the lack of data in previous years, 1990-2017 was selected as the inspection period.

### *Data source and indicator selection*

Since the accession to the WTO, China's economic transformation through technological innovation has achieved remarkable results and has become the world's second largest economy after the United States. Coincidentally, many developed and developing economies have spent a lot of time on innovation and strive to cultivate new momentum for economic growth. China's innovation not only brings new vitality to the global economy and technology development, but also the Chinese economy is bringing new opportunities to the world.

Fully combining China's contribution to international status and economic transformation, this paper selects four indicators in the research group, development group and application group as factors to measure the degree of symbiosis evolution of various groups. The data comes from the China Statistical Yearbook, the China

Science and Technology Statistical Yearbook and the China Industrial Economics Statistical Yearbook. The unit is based on the statistical yearbook. The symbiotic evolution of the three groups of innovative ecosystems has formed 12 secondary indicators, and the indicator names are based on statistical yearbooks.

Among them, the four indicators $x_1, x_2, x_3, x_4$ of the research group are: R&D personnel (10,000 years), R&D expenditures (100 million yuan), the number of higher education institutions (s), and the number of R&D projects (items). The four indicators $x_5, x_6, x_7, x_8$ of the development group are: the number of development institutions (s), the number of new product development projects (items), the expenditure on new product development (100 million yuan), and the sales revenue of new products (100 million yuan). The four indicators of application group $x_9, x_{10}, x_{11}, x_{12}$ are: publishing scientific papers (10,000 articles), enterprise R&D numbers (s), publishing scientific works (species), and patent authorizations (pieces).

*Calculation of symbiotic evolution*

In this paper, the statistical analysis software SPSS Statistics 25.0 is used to analyze the principal components of the three groups of symbiotic evolutionary raw data. Each population has a main factor, and a total of three main factors are obtained. According to the principal component analysis, the correlation between the 12 indicators is above 0.85, and the three main factor loads are: 96.486%, 84.408% and 91.842%, and the eigenvalues are: 3.859, 3.376 and 3.674 respectively. Each principal component factor is rotated separately, and the obtained information contribution rate is used as the sum of the weight and the annual principal factor score, which is the total score of various groups of symbiotic evolution in each year (Shao *et al.*, 2018). The statistical factor scores are normalized (Formula 10) due to the different dimensions between the various principal factors of the various groups. The comprehensive scores of various groups of symbiotic evolution factors are shown in Table 3. In a certain resource environment, the greater the score value, the higher the symbiotic evolution. Conversely, the lower the symbiotic evolution. Under certain resource environments, under various resource environments, various groups can evolve to an independent symbiosis model with a maximum degree of evolution of 1.

$$E = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (10)$$

Among them, E is the symbiosis evolution degree of population; x is the comprehensive score of a certain group of symbiotic evolution factors in each year; $x_{min}$ is the lowest comprehensive score of a certain group of symbiotic evolution factors in each year; $x_{max}$ is the highest comprehensive score of a certain group of symbiotic evolution factors in each year.

*Table 3:* Symbiotic Evolution Scores of Innovative Ecosystems From 1990 to 2017

| Year | Research Groups | | Development Groups | | Application Groups | |
|---|---|---|---|---|---|---|
| | Factor score | Normalized | Factor score | Normalized | Factor score | Normalized |
| 1990 | -1.36574 | 0 | -1.46309 | 0 | -1.72551 | 0 |
| 1995 | -1.31116 | 0.01796 | -1.40841 | 0.01667 | -1.47385 | 0.07246 |
| 2000 | -1.19151 | 0.05732 | -1.24088 | 0.06773 | -1.05706 | 0.19246 |
| 2001 | -1.07546 | 0.09550 | -1.13149 | 0.10107 | -0.95451 | 0.22198 |
| 2002 | -0.93283 | 0.14243 | -0.90378 | 0.17048 | -0.82595 | 0.25900 |
| 2003 | -0.83242 | 0.17546 | -0.72774 | 0.22413 | -0.65639 | 0.30782 |
| 2004 | -0.65344 | 0.23435 | -0.59547 | 0.26445 | -0.52816 | 0.34474 |
| 2005 | -0.55432 | 0.26696 | -0.42879 | 0.31525 | -0.45719 | 0.36517 |
| 2006 | -0.44096 | 0.30425 | -0.29733 | 0.35532 | -0.35709 | 0.39399 |
| 2007 | -0.28145 | 0.35673 | -0.12929 | 0.40654 | -0.23591 | 0.42888 |
| 2008 | 0.00791 | 0.45193 | 0.02640 | 0.45399 | -0.04938 | 0.48259 |
| 2009 | 0.20133 | 0.51556 | 0.16513 | 0.49627 | 0.25751 | 0.57095 |
| 2010 | 0.38664 | 0.57653 | 0.23807 | 0.51851 | 0.31721 | 0.58814 |
| 2011 | 0.58517 | 0.64185 | 0.53674 | 0.60954 | 0.44910 | 0.62611 |
| 2012 | 0.81969 | 0.71900 | 0.77735 | 0.68288 | 0.78034 | 0.72148 |
| 2013 | 1.01959 | 0.78477 | 1.01182 | 0.75434 | 0.85848 | 0.74398 |
| 2014 | 1.17990 | 0.83751 | 1.17774 | 0.80491 | 0.98135 | 0.77935 |
| 2015 | 1.32247 | 0.88442 | 1.11801 | 0.78671 | 1.38450 | 0.89543 |
| 2016 | 1.44280 | 0.92400 | 1.45723 | 0.89010 | 1.54481 | 0.94158 |
| 2017 | 1.67379 | 1 | 1.81780 | 1 | 1.74770 | 1 |
| *Factor score less than 0 means below average | | | | | | |

According to *Table 3*, various group symbiotic evolution actual curves and nonlinear logistic fitting curves are drawn, as shown in Fig. 8. The scatter plot represents the true trend of symbiosis evolution of various groups, and the solid line graph represents the logistic fit curve of various groups of symbiotic evolution. Obviously, the true trend and the fitted curve are basically consistent, and the goodness of fit are: 0.9983, 0.9896, and 0.9935, respectively. Therefore, through empirical analysis, it can be concluded that the symbiotic evolution of the population of innovative ecosystems is consistent with the ecological Logistic model.

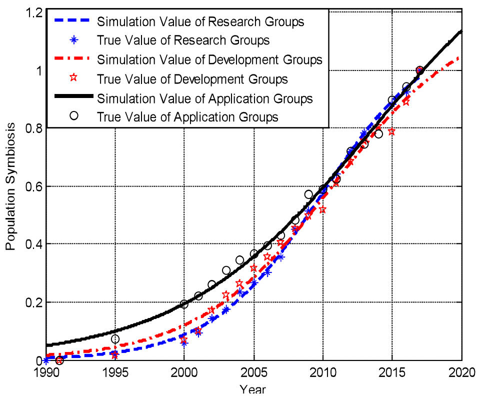


*Figure 8:* Symbiotic Evolution Curve of the Innovation Ecosystem From 1990 to 2017

After the logistic fitting goodness test of the real values, the three groups of symbiotic evolution dynamics models of the innovation ecosystem are derived:

$$\begin{cases} y_1(t) = \dfrac{1.138}{1 + 117.3e^{-0.2526(t-1990)}} \\ y_2(t) = \dfrac{1.201}{1 + 57.81e^{-0.2062(t-1990)}} \\ y_3(t) = \dfrac{1.561}{1 + 26.46e^{-0.1468(t-1990)}} \end{cases} \qquad (11)$$

According to the three groups of symbiotic evolution dynamics model of the innovation ecosystem, the symbiotic evolution prediction curve of China's innovative ecosystem population in 2050 can be obtained, as shown in *Figure 9*. Through the evolution of various groups of symbiotic evolution, under the constraints of resources and environment, various groups of symbiotic evolution will experience four stages of start-up, growth, maturity and saturation, and eventually remain relatively stable, with various groups of symbiosis Their respective evolutionary mechanisms. As shown in Figure 9. This is consistent with the conclusion of Section 3.2, Nature 1. The dynamic mechanism and focus of the dominant population evolution in each period are not the same, and the analysis is carried out in four periods.

First, the starting period (1990-2000). In the early stage of development, it was mainly dominated by economically driven mechanisms. As single populations and core competitiveness were difficult to be cultivated, population development showed an exponential upward trend.

Second, the growth period (2000-2010). The growth stage is mainly influenced by the competition synergy mechanism and the complex adaptation mechanism.

As the population's own stock increases, the competition and synergy effect begin to occur inside and outside the population, and the evolutionary trajectory is more complicated.

Third, during the maturity period (2010-2030), China is at a mature stage and is dominated by policy regulation mechanisms. Among them, the development potential of the application group is huge, the evolution trend of the research group and the development group is basically synchronized, and all enter the saturated state in 2030, and the application group will enter the saturated state in 2040. It fully shows that the application group is the source of scientific and technological innovation, which is in line with the meaning of the dual-invasive activities, and then the rate of development of various groups tends to stagnate.

Fourth, during the saturation period (2030-2050), the saturation period is mainly dominated by the ecological balance mechanism and policy regulation mechanism. The innovation ecosystem will reach the maximum carrying capacity, the ecological balance mechanism is needed to stabilize the entire system balance, and the policy macro regulation is needed. Mechanisms to stimulate the symbiotic evolutionary system to advanced.

In summary, since the accession to the WTO, along with various innovation incentive policies and other measures, the innovation ecosystem has experienced a growth period and is in a mature stage. It is easy to know that the symbiotic evolution of all groups tends to be saturated above 1.1, which exceeds the maximum evolution under the independent symbiosis mode. It shows that the current symbiotic evolution model of China's innovation ecosystem is a mutually beneficial symbiosis model. Under the macro-control of policies, there will still be room for synergy between population synergy innovation and value creation. In the next 25 years, the innovation ecosystem will be a hot spot. . In a certain resource environment, the government's macro-control needs to conform to the symbiotic evolution of the innovation ecosystem to achieve a healthy and orderly development of the innovation ecosystem.

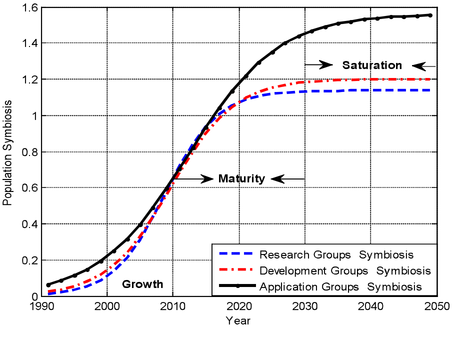


*Figure 9:* Prediction Curve of Symbiotic Evolution of Innovative Ecosystems From 1990 to 2050

## Conclusion

This paper fully integrates evolutionary economics theory, symbiosis theory and ecological theory to construct a multi-group symbiotic evolution dynamic model of innovative ecosystem. Taking the research group, application group and development group as the entry point, this paper discusses the ecological characteristics of the innovation ecosystem by combining the numerical simulation and the empirical analysis for the existing weak links. The main conclusions are as follows:

First, there are five main dynamic mechanisms for the symbiotic evolution of innovative ecosystems. The five dynamic mechanisms are: economic driven mechanism, ecological balance mechanism, competitive coordination mechanism, complex adaptation mechanism and policy regulation mechanism.

Second, there are five symbiotic evolution models of innovative ecosystems, independent symbiosis mode, competitive symbiosis mode, parasitic symbiosis mode, partial symbiosis mode and mutual benefit symbiosis mode. According to different combinations of symbiosis, it can be judged which symbiosis mode. For example, if the symbiosis is negative, it is competition symbiosis, and the symbiosis is regular, which is mutual benefit and symbiosis. The mutual benefit symbiosis model is the best direction for multi-group symbiosis evolution, which is consistent with the conclusions of Ou Zhonghui (Ou *et al.*, 2017).

Third, the symbiosis and evolutionary state of the multi-group of innovative ecosystems depends on the positive and negative and strong-weak mechanisms of population symbiosis. The trajectory of population evolution is in full accord with the Logistic law of ecosystem population growth. The symbiotic evolution process is divided into four stages: start, growth, maturity and saturation. The key mechanism of anatomy is the dynamic mechanism that plays a leading role in different periods.

Fourth, the multi-group symbiosis evolution of China's innovation ecosystem is at a mature stage, and the various symbiosis evolution models are mutually beneficial symbiotic evolution models (comparison of numerical simulation and empirical analysis), which is benefited from the continuously optimized dual-invasive environment and incentive policies. Through the Logistic fitting curve prediction, it is expected that the symbiotic evolution of China's innovation ecosystem will enter a saturated state in 2030.

*Acknowledgments*

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