Research on The Symbiotic Relationship and Evolution Mechanism of Urban-rural Integration Innovation Model

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Abstract. The innovative model of urban-rural integration is an important initiative to solve the problems of urban-rural integration and promote high-quality development of urban-rural integration. The symbiotic evolution model of urban-rural integration innovation mode is constructed and simulated with the help of the Logistic Growth Model, taking urban innovation systems and rural innovation systems as research objects. The results show that: (1) The urban-rural integration innovation model is an innovation model in which symbiotic units promote the sharing of innovation resources in a certain symbiotic environment through a certain symbiotic mode to create value together; (2) The magnitude of the symbiotic relationship between the urban innovation system and the rural innovation system determines the stability and equilibrium of the symbiotic evolution of the urban-rural integration innovation model; (3) The reciprocal symbiosis model not only enables the city and the countryside to gain a win-win situation, but also the final innovation outputs are more than the maximum scale under their independent development state, which is the best evolution direction of urban-rural integration innovation mode.

Keywords: urban-rural integration innovation; symbiosis theory; symbiotic relationship; logistic growth model

1 Introduction

The Twentieth National Congress report stresses the need to "insist on the integrated development of urban and rural areas and smooth the flow of urban and rural factors", indicating that the continued promotion of integrated urban and rural development has become a common goal for all sectors of society. At present, China's urban-rural relations have gradually shifted from urban-rural confrontation to urban-rural integration, with the income gap between urban and rural areas further narrowed, rural infrastructure continuously improved, public service integration mechanisms gradually established, and poverty alleviation measures achieving remarkable results. However, a series of bottlenecks such as "hollowing out of the countryside", "scissors difference" between urban and rural products, and poor circulation of factors between urban and rural areas are still hindering the development of urban-rural integration.

With urban-rural integration rising as a national strategy, urban-rural integration has gradually become a research hotspot, while scholars have conducted relevant research on the innovation

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of urban-rural integration. Foreign scholars believe that urbanization cannot solve all the drawbacks encountered in urban-rural relations [1], and put forward the "urban-rural fusion body"[2] "balanced urban-rural development model[3] "reverse urbanization development model[4]"urban-rural development model" [5]， and other urban-rural related theories. and that the implementation of national innovation strategies should be committed to reducing poverty and improving income distribution[6]. There are fewer existing studies on innovation for urban-rural integration, but there is a proliferation of ideas about innovation strategies between urban and rural areas, focusing on three main aspects. First, the research on the importance of innovation strategies for urban-rural integration and development. Fan Siyi[7] argues that scientific and technological innovation can strengthen the foundation of urban-rural integration and development, lead major changes in rural industry, introduce new technologies and products into the countryside, and inject new kinetic energy into high-quality development of urban-rural integration. Second, the study of the driving mechanism of innovation strategies for urban-rural integrated development. Li Keyan[8] found that scientific and technological innovation can reduce the urban-rural income gap by improving the efficiency of agricultural production, thus promoting urban-rural integrated development. Third, the study of the path of innovation strategy to promote urban-rural integrated development. Tong Yujing [9] argues that it is necessary to integrate urban and rural agricultural innovation resources and establish an urban agricultural science and technology innovation community or industrial alliance. Chen Demin[10] analyzes the ideas and tasks of science and technology and innovation for urban and rural development in Chongqing as an example, and argues that innovation resources should be coordinated to improve the scientific and technological radiation capacity of the main urban areas, and to promote the transfer of scientific and technological factors from the city to the countryside.

Summarizing the above studies, it is found that innovation strategies have become an important force in the process of urban-rural integration and development, so this paper focuses on the following questions: What kind of symbiotic relationship is there between urban and rural innovation systems? Can urban-rural integration innovation promote the development of urban-rural integration? And what modes of urban-rural integration innovation can promote the high-quality development of urban-rural integration? Compared with existing studies, the main innovations of this paper are as follows: (1) The concept of urban-rural integration innovation model is proposed, and the research framework of urban-rural integration innovation model is constructed based on the symbiosis theory. (2) The symbiotic evolution model of urban-rural integration innovation is constructed by numerical simulation and based on the logistic symbiosis model, which explains the evolution process and internal mechanisms of the urban-rural integration innovation model.

2 The Concepts of Innovative models of urban-rural integration

Urban-rural integration innovation is defined as the realisation of the sharing of innovative knowledge, innovative talents, innovative technology, infrastructure and other innovative factors between cities and villages in innovative activities for the common benefit under the value orientation of national strategies such as urban-rural integration, common wealth and sustainable development. The framework diagram of urban-rural integration innovation model constructed in this paper is shown in Fig. 1, which aims to narrow the gap between urban and

rural areas, promote the equal exchange of urban and rural innovation factors, and solve the main contradiction between urban and rural areas, so as to establish an urban-rural integration innovation model with a clear definition of the subject, a clear division of rights and responsibilities, a fair distribution of benefits, and the sharing of innovation resources. As an innovation intermediary, the urban-rural integration innovation model builds a communication bridge between the urban innovation system and the rural innovation system, resolves obstacles in the process of urban-rural integration and co-innovation, and promotes the flow and sharing of innovation resources such as labour, land, and technology between urban and rural areas, so that the innovation model between urban and rural areas can achieve the transition from "urban with rural areas" to "urban with rural areas", and from "urban with rural areas" to "urban with rural areas". This will enable the innovation model between urban and rural areas to develop from "urban-led countryside" to "urban-rural integration" and then to "comprehensive integration".

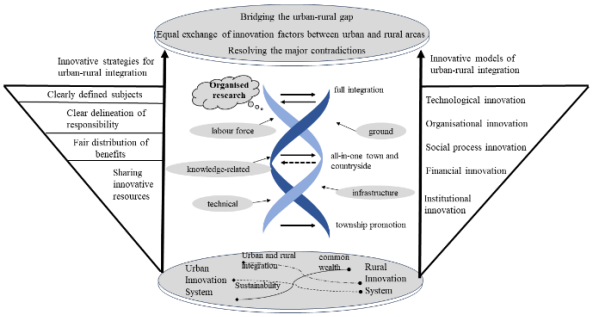

Figure 1. Framework diagram of urban-rural integration innovation model

3 Symbiotic evolutionary model of urban-rural integration innovation system

In recent years, many scholars have adopted the Logistic Growth Model (LGM) in exploring the evolution of the innovation ecosystem, which can well describe the dynamic evolution of the system under the conditions of resource constraints. The process of symbiotic evolution of urban-rural integration innovation model is also the process of gradual increase of innovation output of the two symbiotic units of urban innovation system and rural innovation system, and the change in innovation output will be affected by the external environment such as innovation resources, innovation policy, social environment, etc. The logistic growth model can intuitively and accurately describe the symbiotic evolution characteristics of the urban-rural integration innovation model. Therefore, this paper analyzes the symbiotic evolution process of urban-rural integration innovation systems by using the logistic growth model of biology on the basis of symbiosis theory.

3.1 Model assumptions

In recent years, many scholars have adopted the Logistic Growth Model (LGM) in exploring the evolution of the innovation ecosystem, which can well describe the dynamic evolution of

the system under the conditions of resource constraints. The process of symbiotic evolution of urban-rural integration innovation model is also the process of gradual increase of innovation output of the two symbiotic units of urban innovation system and rural innovation system, and the change in innovation output will be affected by the external environment such as innovation resources, innovation policy, social environment, etc. The logistic growth model can intuitively and accurately describe the symbiotic evolution characteristics of the urban-rural integration innovation model. Therefore, this paper analyzes the symbiotic evolution process of urban-rural integration innovation systems by using the logistic growth model of biology on the basis of symbiosis theory.

3.2 Construction of a symbiotic evolutionary model for urban-rural integration innovation model

Let $M_1(t)$ and $M_2(t)$represent the innovation output of the urban innovation system and the rural innovation system at the moment *t*; r_1、$r_2$represent the inherent growth rate of the two; and N_1、N_2 represent the maximum value of innovation output that they develop independently under environmental constraints. The relationship between changes in innovation output and environmental resources in urban and rural innovation systems is shown as follows:

$$\frac{dM_1(t)}{dt} = r_1 M_1(1 - \frac{M_1}{N_1}) \quad (1)$$

$$\frac{dM_2(t)}{dt} = r_2 M_2(1 - \frac{M_2}{N_2}) \quad (2)$$

Where $\frac{dM}{dt}$ reflects the innovation output of the symbiotic unit at moment *t*; $\frac{M}{N}$ denotes the percentage amount of innovation resources consumed; and $\left(1 - \frac{M}{N}\right)$ denotes the blocking effect of the symbiotic unit due to the consumption of innovation resources.

Model (1) (2) represents the situation that urban innovation systems and rural innovation systems are independent of each other and do not influence each other, but in the state of natural development, urban and rural areas do not develop independently of each other, and under the condition of limited innovation resources, there are behaviors such as sharing, trading, sharing, and competing for innovation resources in the double reverse. Therefore, considering that urban and rural areas influence each other in the process of innovation, the symbiosis coefficient should be added to $\left(1 - \frac{M}{N}\right)$ to establish the symbiosis evolution model shown below.

$$\frac{dM_1(t)}{dt} = r_1 M_1(1 - \frac{M_1}{N_1} - \alpha\frac{M_2}{N_2}) \quad (3)$$

$$\frac{dM_2(t)}{dt} = r_2 M_2(1 - \frac{M_2}{N_2} - \beta\frac{M_1}{N1}) \quad (4)$$

In models (3) and (4), α represents the symbiosis coefficient of rural innovation systems to urban innovation systems, and β represents the symbiosis coefficient of urban innovation systems to rural innovation systems. $\alpha\ (M_2/N_{2)}$ is the percentage of the amount of innovation resources consumed by the countryside targeting the city, and $\beta(M_1/N_1)$ is the percentage of the amount of innovation resources consumed by the city targeting the countryside. If α、β are negative, the two are in a synergistic symbiotic relationship, and the magnitude of the absolute value of α、β indicates the strength of the symbiotic relationship; if α、β are equal to zero, the two do not affect each other; if α、β are positive, then the magnitude of α、β

represents the intensity of competition between the two. The specific range of values and the correspondence between symbiosis modes are shown in Table 1.

Table 1. Range of values of symbiosis coefficients and corresponding symbiosis patterns

Range of values of α and β	symbiotic model	diagnostic property
$\alpha = 0,\ \beta = 0$	interdependent	Cities and villages are independent and do not affect each other
$\alpha > 0,\ \beta > 0$	competitiveness	There has been competition between the city and the countryside
$\alpha > 0,\ \beta < 0$ $or\ \alpha < 0,\ \beta > 0$	Mutualistic symbiosis	Damage to one party (coefficient of coexistence greater than zero) and benefit to the other party (coefficient of coexistence less than zero) between urban and rural areas
$\alpha < 0,\ \beta = 0$ $or\ \alpha = 0,\ \beta < 0$	Para-symbiosis	One party benefits (coefficient of coexistence less than zero) and the other party is not affected (coefficient of coexistence equal to zero) between urban and rural areas
$\alpha < 0,\ \beta < 0$	Parasitic symbiosis	When$\alpha = \beta$,urban and rural areas receive an equal distribution of benefits, which is a symmetric reciprocal symbiosis; When $\alpha \neq \beta$, both rural and urban areas benefit, but the benefits are unequally distributed, with those with larger values benefiting more.

4 Stability analysis of coevolutionary models

In order to further explore the symbiotic evolution process of the urban-rural integration innovation model, it is necessary to analyze its equilibrium conditions and stability so that (3) and (4) are equal to zero, and the solution can be obtained as the four equilibrium points of the symbiotic evolution: $P_1(0,0)$, $P_2(N_1,0)$, $P_3(0,N_2)$, $P_4\left(\frac{N_1(1-\alpha)}{1-\alpha\beta},\frac{N_2(1-\beta)}{1-\alpha\beta}\right)$.To determine the stability of the above equilibrium point, the Jacobi matrix J is constructed as follows:

$$J=\begin{bmatrix} r_1\left(1-2\frac{M_1}{N_1}-\alpha\frac{M_2}{N_2}\right) & -r_1\alpha\frac{M_1}{N_2} \\ -r_2\beta\frac{M_2}{N_1} & r_2\left(1-2\frac{M_2}{N_2}-\beta\frac{M_1}{N_1}\right) \end{bmatrix}$$

Denote the determinant of the Jacobi matrix as $Det(J)$; the trace of the matrix is $Tr(J)$. The conditions for determining the stability of the equilibrium points are $Det > 0$, $Tr(J) < 0$.

Substituting the equilibrium points P_1、P_2、P_3、P_4 into the Jacobi matrix, the stability conditions of the equilibrium points are obtained as shown in Table 2.

Table 2. Coevolutionary model equilibria and their stability conditions

Balance point	$Det(J)$	$Tr(J)$	Stability conditions
$P_1(0,0)$	$r_1 r_2 M_1 M_2$	$r_1 M_1 + r_2 M_2$	Instability
$P_2(N_1,0)$	$-r_1 r_2(1-\beta)$	$1-r_1+r_2(1-\beta)$	$\beta > 1$
$P_3(0,N_2)$	$-r_1 r_2(1-\alpha)$	$-r_2+r_1(1-\alpha)$	$\alpha > 1$
$P_4\left(\frac{N_1(1-\alpha)}{1-\alpha\beta},\frac{N_2(1-\beta)}{1-\alpha\beta}\right)$	$\frac{r_1 r_2(\alpha-1)(\beta-1)}{1-\alpha\beta}$	$\frac{r_1(\alpha-1)+r_2(\beta-1)}{1-\alpha\beta}$	$\alpha < 1$， $\beta < 1$

Equilibrium point P_1, whose $Det(J)$ and $Tr(J)$ are both greater than zero, does not satisfy the stability condition of the equilibrium point and is therefore not discussed. Equilibrium point P_2 ultimately reflects the trend of good development of urban innovation systems and gradual decline of rural innovation development, while P_3 reflects the trend of good development of rural innovation systems and decline of urban innovation development, both of which are not in line with the characteristics of urban-rural integration and development and will not be discussed in detail in this paper. The equilibrium point P_4 has the most comprehensive stabilization conditions, so this paper focuses on P_4 for analysis.

5 Analysis of the results of the symbiotic evolutionary dynamics model of urban-rural integration innovation systems

Based on the above analysis, to further reveal the law of the evolution process between urban and rural areas in the process of urban-rural integration and innovation, in the absence of empirical time-series data, it is more effective to adopt the method of simulation, and this paper applies the Matlab software to simulate the symbiotic evolution process of the dynamics between the urban innovation system and rural innovation system. According to the economic significance of the parameters and the requirements of the model, combined with the actual situation of urban and rural innovation, drawing on some scholars in the simulation of the parameter setting law, this paper will set the maximum size of the urban innovation system as 1000 and the maximum size of the rural innovation system as 800. In view of the fact that the city's innovation infrastructure and the efficiency of the information circulation have a significant advantage, the innovation capacity is stronger than that of the countryside; therefore, the urban innovation system is more efficient than that of the countryside. Innovation ability is stronger in the countryside, so set the growth rate r_1 of the urban innovation system as 0.03, and the growth rate r_2 of the rural innovation system as 0.01, and iterate 900 times for observation.

When the coefficient of symbiosis between the symbiotic units is 0, that is, the innovation output of the urban innovation system and the rural innovation system is only affected by their own

growth rate, they do not affect each other, are independent of each other, and there is no symbiotic relationship. As shown in Figure 2, with the growth of the number of iterations, the innovation output of the two grows gradually, and the innovation output of the city and the countryside reaches the maximum scale, respectively.

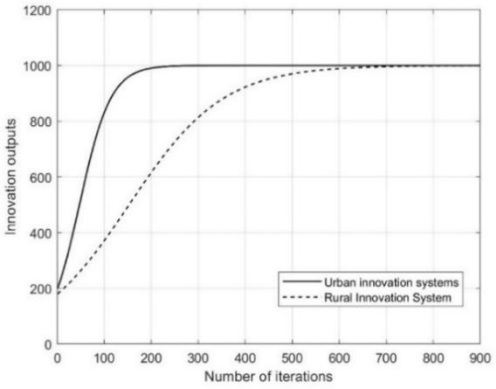

Figure 2. Independent development model

However, in reality, the two will not develop independently, and the integrated development of urban and rural areas has been an important task since the founding of New China, so there is a symbiotic relationship between urban and rural innovation systems.

5.1 Competitive symbiosis model

In the process of urban-rural integration innovation, in the environment of limited innovation resources, when there is the behavior of innovation resource competition between the city and the countryside, the innovation output of the two will be affected to a different degree, which belongs to the biased symbiosis mode. As shown in Figure 3, the value range of the symbiosis coefficient is $0 < \alpha < 1$, $0 < \beta < 1$, set $\alpha = 0.4$, $\beta = 0.5$. At this time, the symbiosis coefficients of the urban innovation system and the rural innovation system are greater than zero. In this case, the urban and rural areas are in a kind of coexisting and competitive relationship in the process of integrating innovations, and their symbiotic relationship will have a certain blocking effect on each other's innovation development. At this time, the innovation outputs of both urban and rural areas are affected by competition, and there is no obvious rising trend, and neither of them reaches the upper limit of their respective scales, and the innovation outputs of both urban and rural areas in the competitive symbiosis mode are lower than those in the independent development mode.

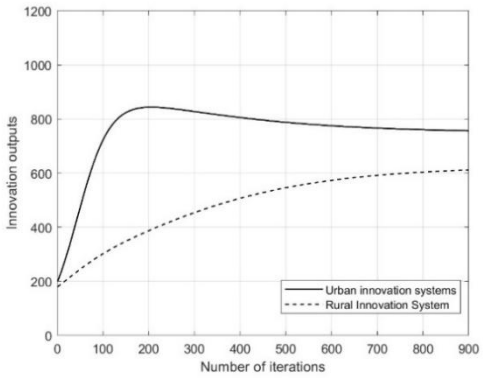

Figure 3. Competitive symbiotic model

5.2 Para-symbiosis model

In the process of urban-rural integration innovation, when the city (rural) has an obvious inhibition effect on the countryside (urban), while the countryside (urban) has no obvious positive or negative effect on the city (rural), it belongs to the biased symbiosis mode. At this time, the value range of the symbiosis coefficient is $0 < \alpha < 1, \beta = 0$, or $0 < \beta < 1, \alpha = 0$. Setting $\alpha = 0.5, \beta = 0$, the symbiosis evolution trend of urban-rural integration innovation is shown in Figure 4. At this time, the symbiosis coefficient of the rural innovation system to the city is 0, indicating that the city does not consume the innovation resources of the countryside, and the symbiosis coefficient of the urban innovation system to the countryside is greater than zero, indicating that the countryside consumes the innovation resources of the city. That is to say, while the countryside obtains the innovation resources it owns from the city, such as capital, talents, and technology, the city does not obtain the production factors, such as land and labor force, owned by the countryside, which indicates that the city and the countryside are in a kind of unequal cooperation in the process of integrating innovation.

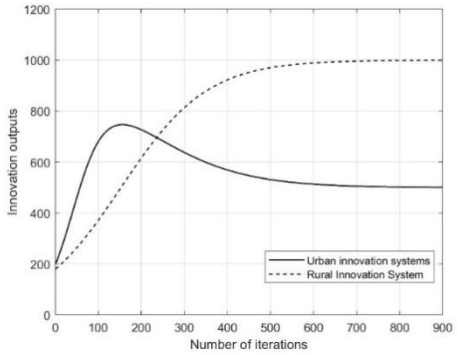

Figure 4. Prejudicial symbiosis model

5.3 Para-symbiotic model

In the process of urban-rural integration and innovation, when the city (rural) has an obvious promotion effect on the countryside (urban), and the countryside (urban) has no obvious positive or negative effect on the city (rural), it belongs to the biased symbiosis mode. At this time, the value range of the symbiosis coefficient is $\alpha = 0, \beta < 0$, or $\beta = 0, \alpha < 0$; set $\alpha = 0, \beta = -0.2$, and the symbiosis evolution trend of urban-rural integration and innovation is shown in Figure 5. At this time, the symbiosis coefficient of countryside to city is zero, which means that the countryside does not consume the innovation resources of the city, while $\beta < 0$ means that the countryside has a positive driving effect on the innovation development of the city. Therefore, in Figure 5, it can be seen that the rural innovation ecosystem is not affected, and the innovation output of the urban innovation system develops well beyond its maximum size in the independent development state. In this case, the countryside unilaterally provides innovation resources such as land and labor to the city, and the city does not reciprocate.

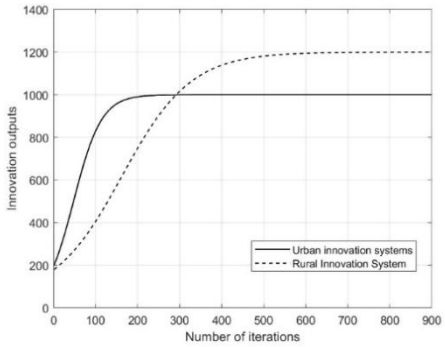

Figure 5. Partial Beneficial Symbiosis Model

5.4 Parasitic symbiosis model

In the process of urban-rural integration innovation, when the city (countryside) occupies the innovation resources of the countryside (city) without compensation, there will be a situation in which the city (countryside) benefits while the countryside (city) suffers, which belongs to the parasitic symbiosis mode. At this time, the value range of the symbiosis coefficient is $0 < \alpha < 1, \beta < 0$, or $0 < \beta < 1, \alpha < 0$, set $\alpha = 0.6, \beta = -0.5$. The symbiosis evolution trend of urban-rural integration innovation is shown in Fig. 6. At this time, the symbiosis coefficient of the countryside to the city is greater than zero, indicating that the countryside consumes the innovation resources of the city, and the symbiosis coefficient of the city to the countryside is less than zero, indicating that the city has a positive effect on the countryside in the process of integration innovation. As can be seen in Figure 6, the innovation output of the city shows a trend of growth and then decline, and the innovation output of the countryside shows a trend of growth and exceeds the maximum output under its independent development mode.

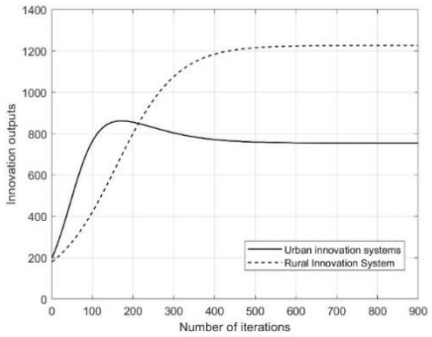

Fig. 6. Parasitic symbiosis model

5.5 Reciprocal symbiosis model

Under the background of urban-rural integration and urban-rural integration development, the urban-rural integration innovation model takes the sharing of innovation resources as a bridge, promotes the exchange of innovation talents, innovation technology, and infrastructure, realizes the rational allocation of innovation resources between urban and rural areas, and shares the benefits of innovation, which belongs to the reciprocal symbiosis model. At this time, the value range of the symbiosis coefficient is $\alpha < 0, \beta < 0$, α、β are assigned as $(-0.3, -0.4)$ and $(-0.1, -0.1)$, respectively, and the symbiosis evolution trend of urban-rural integration innovation is shown in Figure 7. At this time, the symbiosis coefficient of city to countryside and the symbiosis coefficient of countryside to city are both greater than zero, indicating that both urban and rural areas benefit from each other in the process of integrating innovation, and the greater the absolute value of the symbiosis coefficient, the greater the growth of innovation output. When $\alpha = -0.3, \beta = -0.4$, the innovation output of the city and the innovation output of the countryside exceed the maximum scale of independent development, although the innovation output of the city is higher than the innovation output of the countryside in the figure. But comparing the increase in innovation output of the two innovation outputs compared to the maximum scale of the independent development state, it is found that the countryside benefits more than the city, and the pattern of this kind of urban and rural benefit but the degree of benefit is unequal belongs to the asymmetric mutual benefit Symbiosis model. When $\alpha = -0.1, \beta = -0.1$, the innovation output of the city and the innovation output of the countryside still exceed the maximum scale of independent development, and at this time, the two benefit to the same extent, which is a symmetric reciprocal symbiosis mode, and this mode is the most desirable symbiosis mode in the innovation model of urban-rural integration.

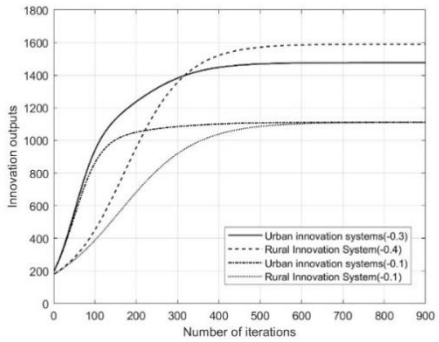

Figure 7. Reciprocal symbiosis model

6 Conclusions

Based on the symbiosis theory, this paper analyzes the symbiosis mechanism of urban-rural integration innovation mode, constructs the symbiosis evolution model of urban-rural integration innovation mode by using the logistic growth model, simulates it using Matlab software, and conducts an in-depth study on the symbiosis evolution law of urban-rural integration innovation mode by combining theory and empirical evidence. The main conclusions are as follows:

(1) The symbiosis system of urban-rural integration innovation model is a system in which the two symbiotic units, urban innovation system and rural innovation system, carry out integration innovation and generate value gain through certain symbiosis modes in the symbiosis environment, and the evolution and development of symbiosis is promoted by the complementarity of each other's strengths and the rational allocation of innovation resources between the urban and rural areas.

(2) The symbiosis coefficient determines the magnitude of the symbiosis effect between urban and rural innovation systems in the urban-rural integration innovation mode. When the symbiosis coefficient is positive, it indicates the degree of competition between the two, with the existence of one party consuming the resources of the other; when the symbiosis coefficient is zero, it indicates that urban and rural areas have no influence on each other; and when the symbiosis coefficient is negative, it indicates the intensity of the symbiosis, with the existence of one party promoting the innovation output of the other party.

(3) The symbiotic relationship of the urban-rural integration system presents five symbiotic modes: competitive symbiosis, harmful symbiosis, beneficial symbiosis, parasitic symbiosis, and reciprocal symbiosis, among which the reciprocal symbiosis mode can benefit both cities and villages and the innovation outputs can exceed their respective maximum sizes, which is the most desirable symbiosis mode in the urban-rural integration model.

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