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Research Article

Study on the Growth Driving Model of the Enterprise Innovation Community Based on the Lotka–Volterra Model: A Case Study of the Chinese Automobile Manufacturing Enterprise Community

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The goal of this paper is to establish a feasible three-species equilibrium model to analyze the symbiotic relationship of an automobile manufacturing community. In order to extend the Lotka–Volterra model to empirical analysis, this paper proposes an enterprise community symbiosis model based on a three-dimensional Lotka–Volterra model, as the classical two-dimensional Lotka–Volterra model has limited application scenarios. This paper takes the innovation assets of three communities of the Chinese automobile manufacturing industry as samples. The industrial community related to automobile manufacturing consists of the automobile manufacturing population, automobile parts population, and enterprise service industry population. The symbiosis system is empirically analyzed from two aspects: the balanced development of the three populations and the competitive evolution of the three populations. The stability of the model is tested by the data from information technology and the intelligent manufacturing community. In the process of dynamic simulation, the symbiotic relationship between automobile manufacturing-related populations shows a significant "skew symbiotic relationship." This paper reconstructs the "whole population symbiosis" optimization model as skew distribution is difficult to apply to support collaborative development. The symbiosis optimization under the equilibrium state of the three populations shows that the growth of the three automobile manufacturing industry populations has the possibility of equilibrium and reciprocity. The empirical analysis fully demonstrates the feasibility of this research paradigm. The evolution analysis of the symbiotic system shows that cooperative behavior is better than competitive strategy. The research paradigm proposed in this paper can better analyze the symbiosis mechanism of the enterprise community.

1. Introduction

Automobile manufacturing plays an important role in the manufacturing system. The development of automobile manufacturing enterprises is restricted by the market environment and the development of related industries. At the same time, the development of automobile manufacturing enterprises also affects the development and innovation activities of related industries. The automobile manufacturing industry and related industries form a symbiotic industrial and innovation ecological community. In order to promote the coordinated development of the automobile manufacturing industry and related industries, it is first necessary to understand the symbiotic mechanism of the automobile manufacturing industry and related industries. The research object is to use the three-dimensional Lotka–Volterra model to explain the symbiotic mechanism between the automobile manufacturing industry and related industries.

In recent years, with the advent of innovation 2.0 and the Internet + era, increasingly mature information technology, blurring of enterprise boundaries, faster product iteration, and the complex competitive environment make it difficult to guarantee the innovation efficiency of previously closed innovation and cooperative innovation. Therefore, many enterprises have adopted the open innovation mode, changed the innovation mode of enterprises, and deepened the innovation openness of enterprises. The rapidly changing social and economic environment has brought new challenges to global innovation activities. Countries across the world must face these challenges if they want to keep up with the trend of competition and maintain growth. Some developed countries and companies in these countries have begun to respond flexibly to environmental changes. Japan has paid close attention to and closely follows the innovation policies of other countries, such as Germany's industry 4.0 and United States' advanced manufacturing partnership [1]. In Australia, human capital, ICT, and other factors have proved to be of great significance in the process of innovation and creation [2]. International cooperation with partners such as China, India, and Japan is crucial to the successful implementation of innovation and creation activities in Australia [3]. In Canada, it is necessary to establish an innovation policy based on international background and knowledge sharing [4]. Sweden establishes and strengthens its innovation absorption capacity by providing subsidies and supporting R&D investment, especially in mature industries [5].

From the above examples, it is clear that different countries have analyzed the internal and external determinants of innovation in different countries with the support of various innovation theories and ideas. The following theories are actually applied: the national innovation system theory of South Korea [6]; Finland, Germany, Greece, Ireland, Spain, and Britain's innovation environment theory [7]; German innovation network theory [8]; and Swiss open innovation theory [9]. However, in each innovation theory, different understanding of the key structure can be found in the innovation ecosystem and in the role of innovation subjects. From the perspective of innovation systems, two different structures can be considered: the institutional structure required for technological innovation and the innovation structure supporting specific technologies [10]. From the perspective of government policy support, it is necessary to find out appropriate factors that affect the innovation process of enterprises. From the perspective of regional innovation systems, the importance of the fourth spiral is increasing, including the cross-agency network based on university-industry-government cooperation [11].

Building an efficient and flexible innovation ecosystem based on public support, human resources, complex collaboration networks, and various cross-agency associations is of great importance to all countries in order to cope with the rapidly changing environment and effectively use individual participants operating in these ecosystems [12]. The performance of the innovation ecosystem is the key indicator of public policy implementation and decision-making [13].

Previous studies can be divided into two parts. The part one studies the individual determinants of innovation [14], cooperation [15], knowledge creation [16, 17], and public funds [18]. The other part mainly involves the functional effectiveness of the innovation ecosystem [19, 20] and the key factors of the innovation ecosystem, especially the impact at the macroeconomic level [21].

Previous literature studies have the following shortcomings: (1) research on the innovation ecosystem and symbiotic mechanism mainly focuses on the interior of a specific industry. Few studies have focused on the symbiotic mechanism of development and innovation among related industries. (2) There are many research studies on the growth mechanism of enterprises and the enterprise population. There are few symbiotic relationships among enterprise populations. (3) There are few in-depth studies on the industrial development and innovation of Chinese enterprises, and relevant studies need to be carried out.

The existing theoretical research on socio-economic and innovation ecology is difficult to meet the needs of practical guidance. Open innovation emphasizes breaking the traditional closed innovation mode of enterprises, breaking organizational boundaries, and focusing on innovation through external channels as well as exploring innovation from the inside. It is a "one-to-many" mode, and the enterprise itself interacts with multiple external innovation resources. The innovation mode of open innovation can be studied from the perspective of sharing. This paper selects automobile manufacturing enterprises as the research object, introduces the ecological core model into the analysis of the innovation ecosystem interaction mechanism, and constructs an analysis framework of the symbiotic mechanism based on population dynamics. This paper gives the following research framework: (1) research on the growth mechanism of enterprise innovation capability from the perspective of intrapopulation symbiosis, (2) analysis of the symbiotic mechanism of innovative growth among populations in the community, and (3) symbiotic evolution and equilibrium evolution of the innovation community.

2. Materials and Methods

2.1. Ecosystem Structure Theory. Ecology is a science that explores the relationship between individuals and the environment. Since 1970, it has been introduced into the field of economic management research and practice. The concept of the ecosystem has also been introduced into the field of economic management, from which are derived cross-research fields, such as the organizational ecosystem, business ecosystem, and innovation ecosystem. In the 1990s, Moore combined ecological views with competitive strategy theory and built an "enterprise ecosystem" [22]. The "enterprise ecosystem" described by Moore is a dynamic system composed of consumers, suppliers, manufacturers, investors, business partners, government departments, and other stakeholders [23], which gives great inspiration and reference to the study of the "innovation ecosystem." Later, the exploration in the field of the economic management ecosystem was mostly based on Moore's achievements.

Adner defines an ecosystem as a composite structure of multilateral partners that need to interact to achieve key value propositions [24]. These interactions are based on multilateral interdependence and cannot be simply decomposed into multiple binary relationships [25]. Multilateral dependence and symbiosis cannot be seen as a simple superposition of multiple binary relations. Compared with the economic relations in transaction cost economics, value chain, strategic alliance network, and other theories, this symbiotic relationship makes the ecosystem a new structure of economic relations [26]. Similar to the above point of view, Jacobides et al. defined the ecosystem as a group of participants, who have different degrees of multilateral, nonuniversal complementarity, and are not completely controlled by hierarchy [27]. Almost all ecosystem studies emphasize complementarity, but it is the structural view that clearly links this economic relationship with the value creation structure.

Not all types of complementary innovation activities need to be coordinated by multilateral interdependence. Enterprises, rather than resort to ecosystems, can obtain the support of generic complementary innovation activities through market transactions. Ecosystems cannot function if universal complementarity exists on the consumer or production side. According to the definition of ecosystems, ecosystems only deal with the situation that the complementarity of consumption and production is nonuniversal. When value creation does not require readjustment of multilateral partners, the ecosystem may not necessarily exist. Multilateral interdependence exists at the level of a series of innovation subjects. The modular system and activity system of the ecosystem are both labor division systems [28] or “modular ecosystems” [29]. In order to effectively solve existing problems, this paper proposes an improved population dynamic model to analyze the mechanism of ecosystem operation.

2.2. Population Dynamic Model. The development of any population will be restricted by its own growth capacity and resources and environment. Almost all species follow the law of the life cycle. Similarly, there is an upper limit to the population growth in the socioeconomic system. If a socioeconomic system is regarded as an ecosystem, the species in the socioeconomic system can be regarded as populations in the ecosystem. The population dynamic model mainly focuses on the change of the population number, and its change rule is based on the nonlinear growth law of biological population quantity. Many species in nature grow nonlinearly, which is also very common. The competition and coordination mechanism within the population is also an important factor. This setting is based on the principle of intraspecific competition of biological populations. There is competition among natural biological populations. The larger the number of population, the more intense the competition. Therefore, this mechanism should also become an important part of the population growth model.

The advantage of this model is that there are not too many requirements in normality and homogeneity of variance, and the coefficient can be explained, which makes the logistic regression model widely used in many fields, such as medicine and social investigation.

The logistic regression model has been widely used in the past many years. For example, it has been used to study infectious diseases from the very beginning. As an effective data processing method, logistic regression analysis is widely used in biomedicine, criminology, ecological engineering, health, linguistics, wildlife science, biology, and other fields. The logistic regression model has achieved similar results in statistics.

According to the logistic model, the growth dynamic system within population 1 (P1) is constructed as follows:

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

where $g_1(t)$ is the growth rate of the stage T, $N_1(t)$ is the population size of the T period, K_1 is the largest population size, α_1 is the intrinsic growth rate, and $(1 - N_1/K_1)$ is the growth retardation factor.

The metering model is as follows:

$$\begin{aligned}&\text{because: } dN_1(t) \approx \Delta N_1(t), \Delta N_1(t) = N_1(t) - N_1(t-1), dt \approx \Delta t = t - (t-1) = 1,\\&\text{therefore: } g_1(t) \approx \Delta N(t) = \gamma_1 N_1(t-1) + \gamma_2 N_1^2(t-1).\end{aligned} \tag{2}$$

Among them, we set $\gamma_1 = \alpha_1$. Normally, $\gamma_1 > 0$, which represents the synergy within a group, namely, an internal synergy coefficient. When $\gamma_1 > 1$, there is a significant synergistic effect. We set $\gamma_2 = -\alpha_1/K_1$. Normally, $\gamma_2 < 0$, which represents the competition effect within the population. It is called the internal competition coefficient or population density inhibition coefficient.

Automobile manufacturing enterprises share their own resources with other enterprises and share various resources of other enterprises at the same time. A healthy innovation ecosystem can effectively promote the sharing of various innovation resources among enterprises.

Similarly, the internal relation model of population 2 ($p2$) can be obtained as follows:

$$g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2\left(1 - \frac{N_2}{K_2}\right). \tag{3}$$

The following model explains the effect of population $p2$ on population $p1$:

$$g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1\left(1 - \frac{N_1}{K_1} + \frac{\beta_{12}N_2}{K_2}\right), \tag{4}$$

β_{12} is the effect of population 2 on population 1 ($\beta_{12} > 0$, synergistic effect; $\beta_{12} > 0$, competitive effect).

The following population dynamic system expresses the effect of population $p1$ on population p:

$$g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2\left(1 - \frac{N_2}{K_2} + \frac{\beta_{21}N_1}{K_1}\right), \tag{5}$$

β_{21} is the influence factor of population 1 on population 2. The dynamic system composed of population $p1$ and population $p2$ is

$$g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1\left(1 - \frac{N_1}{K_1} + \frac{\beta_{12}N_2}{K_2}\right),$$
$$g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2\left(1 - \frac{N_2}{K_2} + \frac{\beta_{21}N_1}{K_1}\right). \tag{6}$$

Equation (6) is called the Lotka–Volterra (LV) system. Based on the logical model of a single species, the LV model takes into consideration the dynamic growth of simultaneous competition and symbiosis between two or more entities in the ecosystem [30–32] and can accurately describe the competition and symbiosis among enterprise groups. The LV system can determine the influence of the core population on the evolution of the whole ecosystem [33], so it has better data fitting and prediction expression [34].

The classical Lotka–Volterra model is a differential dynamic system, which is used to simulate the dynamic relationship between populations in ecology. Later, economists introduced it into the fluctuation of macroeconomic growth and the market competition of the medium scale and scope. According to biological principles, there are many functional relationships between biological populations: promotion or inhibition. For their own survival and development, there is also a relationship between market competition subjects: the existence of one subject can promote or inhibit the diffusion process of another subject. The LV model of two or more population growth is a differential dynamic system that simulates the dynamic relationship between populations.

In business activities, competition may occur among people who use public resources. Symbiosis in the industrial ecosystem does not exclude competition. People in the same living space or part of the same living space need to interact with technology, talent, and market in the factor market. Through large-scale reproduction, core competitiveness can be enhanced, and new offspring that adapt to the ecological environment be formed. However, when the population in the ecosystem depends on another core population or dominant population to obtain resources and living space, it will form a parasitic relationship. In the parasitic relationship, the symbiotic subject has a one-way exchange of interests. This asymmetric one-way exchange does not exist widely. Therefore, the system will gradually develop towards a symbiotic direction conducive to interdependence, mutual benefits, and win-win results.

In the symbiotic system composed of population 1 ($P1$), population 2 ($P2$), and population 3 ($P3$), the mathematical model is

$$\begin{cases} g_1(t) = \dfrac{dN_1(t)}{dt} = \alpha_1 N_1\left(1 - \dfrac{N_1}{K_1} + \dfrac{\beta_{12}N_2}{K_2} + \dfrac{\beta_{13}N_3}{K_3}\right), \\ g_2(t) = \dfrac{dN_2(t)}{dt} = \alpha_2 N_2\left(1 - \dfrac{N_2}{K_2} + \dfrac{\beta_{21}N_1}{K_1} + \dfrac{\beta_{23}N_3}{K_3}\right), \\ g_3(t) = \dfrac{dN_3(t)}{dt} = \alpha_3 N_3\left(1 - \dfrac{N_3}{K_3} + \dfrac{\beta_{31}N_1}{K_1} + \dfrac{\beta_{32}N_2}{K_2}\right), \end{cases} \tag{7}$$

where $\beta_{ij}\,(i = 1,2,3.\, j = 1,2,3)$ is the interaction coefficient between populations.

If $\beta_{ij} > 0$, there is a synergetic relationship among populations. If $\beta_{ij} > 0$, there is a competitive relationship among populations. In the above three-species symbiotic system, if all $\beta_{ij} > 0$, the system is in a comprehensive cooperative state. In this comprehensive cooperative symbiotic system, each population has a positive impact on other populations. Under the interactive symbiosis and comprehensive positive influence of the three types, the system is in the state of collaborative evolution. This comprehensive collaborative evolution state is the most ideal situation of an innovation ecosystem. In the above three-species symbiotic system, if all $\beta_{ij} > 0$, the system is in a state of full competition. In this comprehensive competitive symbiotic system, each population has a negative impact on other populations. The system is in the state of competitive evolution under the interactive symbiosis and comprehensive negative impact of the three types. This comprehensive competitive evolution state is not conducive to the coevolution of populations from the perspective of sharing and symbiosis. In real-world practice, more system states are between the above two special states.

2.3. Lotka–Volterra-MCGP Model. The authors embed the equilibrium condition of the Lotka–Volterra system into the MCGP model to obtain the Lotka–Volterra-MCGP model in this paper [35–41]:

$$
\begin{aligned}
&\textit{objective function}\colon\ \min = \sum_{i=1}^{n}\left(d_i^{+} + d_i^{-}\right) + \sum_{i=1}^{n}\left(e_i^{+} + e_i^{-}\right),\\
&\textit{constraints}\colon\\
&g_i = f_i(x) + d_i^{-} - d_i^{+}, \quad i = 1, 2, \cdots, n,\\
&x \in X, X = \{x_1, x_2, \cdots, x_m\},\\
&X \in F \quad (F \textit{ is the set of feasible solutions}),\\
&g_{i,\max} = g_i + e_i^{-} - e_i^{+}, \quad i = 1, 2, \cdots, n,\\
&g_{i,\min} \le g_i, g_i \le g_{i,\max}, \quad i = 1, 2, \cdots, n,\\
&d_i^{+}, d_i^{-}, e_i^{+}, e_i^{-} \ge 0, \quad i = 1, 2, \cdots, n,\\
&g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1\left(1 - \frac{N_1}{K_1} + \frac{\beta_{12}N_2}{K_2} + \frac{\beta_{13}N_3}{K_3}\right),\\
&g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2\left(1 - \frac{N_2}{K_2} + \frac{\beta_{21}N_1}{K_1} + \frac{\beta_{23}N_3}{K_3}\right),\\
&g_3(t) = \frac{dN_3(t)}{dt} = \alpha_3 N_3\left(1 - \frac{N_3}{K_3} + \frac{\beta_{31}N_1}{K_1} + \frac{\beta_{32}N_2}{K_2}\right),\\
&-1 < \beta_{ij} < 1, i = 1, 2, 3. j = 1, 2, 3,\\
&\sum g_i = K, \ (K \textit{ is the sum of market capacity}).
\end{aligned}
\tag{8}
$$

As a linear form for goal programming, multichoice goal programming embedded with Lotka–Volterra equilibrium (LV-MCGP) can be easily resolved by software.

2.4. Empirical Analysis. Since the 1990s, the pace of global automobile industrial structure adjustment has been significantly accelerated, due to the global automobile overcapacity and increasingly stringent safety, emission, and energy-saving regulations. Many automobile companies in developed countries have strengthened their competitiveness through expansion, integration, and merger. The trend of automobile industry globalization has had a profound impact on the development of the automobile industry and industrial policies in developing countries, including China. As a country with a large population in the world, China's economy is rising. With the continuous improvement of people's income and the upgrading of consumption structure, China has become the most potential emerging market in the world. Therefore, improving the consumption environment will become an important measure to transform the public's potential demand for automobiles into actual demand and promote economic growth. At present, China has initially formed a relatively independent automobile production system as the market advantages, labor quality, cost advantages, and scale advantages of industrial support are gradually emerging. With the entry of global automobile manufacturing multinational companies and the development of domestic automobile enterprises, China has become an important automobile manufacturing base in the world. An analysis of the symbiotic situation and development mechanism of the automobile manufacturing community is helpful to understand the operating mechanism of Chinese automobile enterprise innovation.

This paper selects the data from listed companies in China's automobile manufacturing and related industries as the research sample. When selecting listed companies, the authors mainly selected industry-leading enterprises as the representatives. For example, enterprises with a market value of more than 10 billion yuan in the automobile manufacturing industry have been selected. Data indicators mainly use the intangible asset indicators in the company's financial statements to represent the innovation resources of the enterprise. The observation period is the quarterly data in the company's financial statements from 2015 to 2022 (data source: Securities Star website, https://www.stockstar.com/).

The data in the table shows that the shared driving mode is slightly more than the external competition mode. The shared driven model is not universal among automobile manufacturing enterprises. There is still much room for improvement in the innovation capability growth of automobile manufacturing enterprises from the perspective of sharing.

According to the data in the table, half of the enterprises can obtain the driving force of shared innovation from the population innovation pool. From the perspective of sharing, enterprise innovation-driven models can be divided into two categories: one is a significantly shared driven model and the other is an external competition model. From the perspective of intrinsic growth, the innovation-driven modes of enterprises can also be divided into two categories: one is the mode with significant intrinsic growth and the other is the mode of intrinsic competition. From the results of empirical analysis, the intrinsic growth coefficient of most enterprises is positive, which shows that the internal growth power of automobile manufacturing enterprises is abundant. From the perspective of sharing, half of the enterprises have obvious sharing driven modes, which basically conform to the population dynamic law of the natural ecosystem. Not all enterprises can obtain shared driving power from the innovation ecosystem. Enterprises that obtain driving resources from shared driving can better obtain and maintain their own core competitiveness.

There is a symbiotic relationship between enterprise innovation communities, which is similar to that in a natural ecosystem. The relevant populations gather to form a community. The populations in the community may be mutually beneficial and cooperative, or there may be competition or even vicious competition, or there may be predatory or parasitic relationships among populations. In this section, intangible assets are used to represent the innovation resources of different innovation populations, and the growth mode of innovation capability from the perspective of sharing is analyzed based on the population dynamic model.

The data in Table 1 are the moving averages of the observed data. Based on the data in Table 1, the population growth mechanism shown in Table 2 can be obtained by using the regression operation of the population dynamics model. Based on the discreteness of financial data, the original model is equivalently transformed, and the following model can be obtained:

$$\begin{cases} \Delta N_1(t) = \alpha_1 N_1(t-1)\left(1 - \dfrac{N_1(t-1)}{K_1} + \dfrac{\beta_{12}N_2(t-1)}{K_2} + \dfrac{\beta_{13}N_3(t-1)}{K_3}\right), \\ \Delta N_2(t) = \alpha_2 N_2(t-1)\left(1 - \dfrac{N_2(t-1)}{K_2} + \dfrac{\beta_{21}N_1(t-1)}{K_1} + \dfrac{\beta_{23}N_3(t-1)}{K_3}\right), \\ \Delta N_3(t) = \alpha_3 N_3(t-1)\left(1 - \dfrac{N_3(t-1)}{K_3} + \dfrac{\beta_{31}N_1(t-1)}{K_1} + \dfrac{\beta_{32}N_2(t-1)}{K_2}\right), \end{cases}$$

$$\begin{cases} \Delta N_1(t) + N_1(t-1) = (\alpha_1+1)N_1(t-1) + \gamma_{12}N_1^2(t-1) + \gamma_{13}N_1(t-1)N_2(t-1) + \gamma_{14}N_1(t-1)N_3(t-1), \\ \Delta N_2(t) + N_2(t-1) = (\alpha_2+1)N_2(t-1) + \gamma_{22}N_2^2(t-1) + \gamma_{23}N_2(t-1)N_1(t-1) + \gamma_{24}N_2(t-1)N_3(t-1), \\ \Delta N_3(t) + N_3(t-1) = (\alpha_3+1)N_3(t-1) + \gamma_{32}N_3^2(t-1) + \gamma_{33}N_3(t-1)N_1(t-1) + \gamma_{34}N_3(t-1)N_2(t-1), \end{cases} \tag{9}$$

$$\begin{cases} N_1(t) = \gamma_{11}N_1(t-1) + \gamma_{12}N_1^2(t-1) + \gamma_{13}N_1(t-1)N_2(t-1) + \gamma_{14}N_1(t-1)N_3(t-1), \\ N_2(t) = \gamma_{21}N_2(t-1) + \gamma_{22}N_2^2(t-1) + \gamma_{23}N_2(t-1)N_1(t-1) + \gamma_{24}N_2(t-1)N_3(t-1), \\ N_3(t) = \gamma_{31}N_3(t-1) + \gamma_{32}N_3^2(t-1) + \gamma_{33}N_3(t-1)N_1(t-1) + \gamma_{34}N_3(t-1)N_2(t-1). \end{cases}$$

The regression results are as follows.

As shown in Table 3, regression effects are uneven. The p values of some regression coefficients are high and fail to pass the test. Among them, α_1 = -0.037, K_1 = 855; α_2 = -0.198, K_2 = 124; and α_3 = 0.158, K_3 = 875. The theoretical symbiotic network model can be obtained as follows:

$$\begin{cases} N_1(t) = (1-0.037)N_1(t-1) + \dfrac{0.037}{855}N_1^2(t-1) + \dfrac{-0.037\beta_{12}}{124}N_1(t-1)N_2(t-1) + \dfrac{-0.037\beta_{13}}{875}N_1(t-1)N_3(t-1), \\ N_2(t) = (1-0.198)N_2(t-1) + \dfrac{0.198}{124}N_2^2(t-1) + \dfrac{-0.198\beta_{21}}{855}N_2(t-1)N_1(t-1) + \dfrac{-0.198\beta_{23}}{875}N_2(t-1)N_3(t-1), \\ N_3(t) = (1+0.158)N_3(t-1) + \dfrac{-0.158}{875}N_3^2(t-1) + \dfrac{0.158\beta_{31}}{855}N_3(t-1)N_1(t-1) + \dfrac{0.158\beta_{32}}{124}N_3(t-1)N_2(t-1). \end{cases} \tag{10}$$

Table 1: Smooth data of innovation resources (unit: 100 million yuan).

Year/month/day	Automobile manufacturing	Auto parts	Automobile service industry
2022/3/31	633	371	144
2021/12/31	625	370	146
2021/9/30	603	373	149
2021/6/30	591	374	151
2021/3/31	580	378	152
2020/12/31	565	380	154
2020/9/30	554	378	155
2020/6/30	539	373	156
2020/3/31	518	366	158
2019/12/31	497	358	158
2019/9/30	480	354	159
2019/6/30	459	352	160
2019/3/31	441	349	163
2018/12/31	425	348	162
2018/9/30	410	344	160
2018/6/30	397	341	157
2018/3/31	388	342	153
2017/12/31	372	341	154
2017/9/30	359	341	155
2017/6/30	345	310	156
2017/3/31	331	278	155
2016/12/31	325	244	147
2016/9/30	314	209	138
2016/6/30	308	205	130
2016/3/31	302	199	120
2015/12/31	290	191	116

Table 2: Innovation symbiotic mechanism of the automobile manufacturing community.

Population	Enterprise	γ_1	γ_{11}	γ_{12}	Symbiotic mechanism
Automobile manufacturing	BYD	0.014 (0.364)	$-9.179E-12$ (−0.887)	$2.503E-12$ (1.264)	Share driven
	Great Wall	−0.057 (−3.902)***	$-3.489E-12$ (−0.400)	$2.345E-12$ (2.771)***	Share driven
	SAIC	0.102 (6.661)***	$-1.337E-12$ (−0.287)	$-1.204E-12$ (−1.025)	External competition
	GAC	−0.188 (−1.935)*	$-4.400E-11$ (−3.450)***	$1.424E-11$ (3.061)***	Share driven
	Changan	0.112 (3.798)***	$1.351E-11$ (1.275)	$-3.452E-12$ (−4.684)***	External competition
	FAW	−0.392 (−2.766)***	$-2.389E-10$ (−4.110)***	$1.796E-11$ (4.019)***	Share driven
	JAC	0.197 (4.312)***	$-3.452E-11$ (−2.040)**	$-2.124E-12$ (−4.601)***	External competition
Auto parts	Weichai Power	0.292 (3.943)***	$-2.273E-12$ (−0.306)	$-6.692E-12$ (−1.452)	External competition
	Huayu automobile	0.120 (3.030)***	$-3.789E-11$ (−2.333)**	$1.156E-12$ (0.509)	Share driven
	Desaisi	0.334 (1.464)	$-4.066E-10$ (−1.259)	$-5.413E-12$ (−0.676)	External competition
	Xingyu Co., Ltd	−0.267 (−1.753)*	−1.311E-09 (−4.265)***	$2.129E-11$ (3.326)***	Share driven
	Top group	0.373 (0.034)***	$1.447E-10$ (0.972)*	$-1.173E-11$ (−0.606)***	External competition
	Chang'anB	0.139 (3.183)***	$-1.105E-11$ (−0.640)	$-2.343E-12$ (−0.983)	External competition
	Fuyao Glass	0.097 (1.612)	$-7.141E-11$ (−1.177)	$-1.731E-13$ (−0.233)	External competition
	Ningde Era	0.293 (1.578)*	$6.827E-11$ (3.417)***	$-9.552E-12$ (−1.635)*	External competition

Table 2: Continued.

Population	Enterprise	γ_1	γ_{11}	γ_{12}	Symbiotic mechanism
Automobile service industry	Guanghui	0.163 (1.029)	$-5.259E-11$ $(-3.943)^{***}$	$2.157E-11$ (1.263)	Share driven
	CARI	-0.216 $(-2.163)^{**}$	$1.222E-11$ (1.31)	$1.581E-11$ $(2.453)^{**}$	Share driven
	Huge Group	-0.058 (-1.521)	$2.027E-12$ (0.578)	$1.893E-12$ (1.130)	Share driven
	Guoji automobile	$1.011(2.970)^{***}$	$-5.471E-10$ $(-3.093)^{***}$	$-3.921E-11$ $(-2.696)^{***}$	External competition
	Oriental Fashion	-0.231 $(-1.597)^{*}$	$-6.826E-10$ $(-8.736)^{***}$	$5.001E-11$ $(4.141)^{***}$	Share driven

() t value, $^{*}p$ value < 0.1, $^{**}p$ value < 0.05, $^{***}p$ value < 0.01.

The actual symbiotic network model can be obtained after removing insignificant regression items:

$$\begin{cases} N_1(t) = (1-0.037)N_1(t-1) + \dfrac{-0.037\beta_{13}}{875}N_1(t-1)N_3(t-1), \\ N_2(t) = (1-0.198)N_2(t-1) + \dfrac{0.198}{124}N_2^2(t-1) + \dfrac{-0.198\beta_{21}}{855}N_2(t-1)N_1(t-1) + \dfrac{-0.198\beta_{23}}{875}N_2(t-1)N_3(t-1), \\ N_3(t) = (1+0.158)N_3(t-1) + \dfrac{0.158\beta_{32}}{124}N_3(t-1)N_2(t-1), \end{cases} \tag{11}$$

$$\begin{cases} N_1(t) = 0.963N_1(t-1) - 0.000042\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 0.802N_2(t-1) + 0.001596N_2^2(t-1) - 0.000231\beta_{21}N_2(t-1)N_1(t-1) - 0.000226\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 1.158N_3(t-1) + 0.001274\beta_{32}N_3(t-1)N_2(t-1). \end{cases} \tag{12}$$

By substituting the above symbiotic relationship into the MCGP model, a multidimensional Lotka–Volterra-MCCGP model is obtained as follows:

$$\begin{cases} objective\ function,\ \min \sum_{i=1}^{n}(d_i^+ + d_i^-) + \sum_{i=1}^{n}(e_i^+ + e_i^-), \\ constraints, \\ g_i = f_i(x) + d_i^- - d_i^+, \quad i = 1,2,\cdots,n, \\ x \in X, X = \{x_1, x_2, \cdots, x_m\}, \\ X \in F, \quad (F\ is\ the\ set\ of\ feasible\ solutions), \\ g_{i,\max} = g_i + e_i^- - e_i^+, \quad i = 1,2,\cdots,n, \\ g_{i,\min} \le g_i, g_i \le g_{i,\max}, \quad i = 1,2,\cdots,n, \\ e_i^+, e_i^-, d_i^+, d_i^- \ge 0, \quad i = 1,2,\cdots,n, \\ N_1(t) = 0.963N_1(t-1) - 0.000042\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 0.802N_2(t-1) + 0.001596N_2^2(t-1) - 0.000231\beta_{21}N_2(t-1)N_1(t-1) - 0.000226\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 1.158N_3(t-1) + 0.001274\beta_{32}N_3(t-1)N_2(t-1), \\ -1 < \beta_{ij} < 1, i = 1,2,3. j = 1,2,3, \\ \sum g_i = K, (K\ is\ the\ sum\ of\ market\ capacity). \end{cases} \tag{13}$$

LINGO software is used to solve the above optimization problem. The optimization results of β_{ij} value are shown in the table.

By observing Table 4, it can be seen that the symbiotic relationship between automobile manufacturing-related populations shows a significant "skew symbiotic relationship." In the dynamic simulation process, with the expansion of the scale of the innovation sharing pool, the value of the interaction influence coefficient is constantly changing. However, the changing symbiotic coefficient is always concentrated on a few relationships, which indicates that there is a key symbiotic feedback path in the system. These main feedback paths control the development direction of the whole system. However, the resources in the innovation ecosystem in real society may not be able to support the population development on the main feedback loop. The skew distribution is difficult to support collaborative development. The optimization model returns to the "whole population symbiotic relationship model," and the full state model is as follows:

$$\begin{cases} N_1(t) = 0.963N_1(t-1) + 0.000043N_1^2(t-1) - 0.000298\beta_{12}N_1(t-1)N_2(t-1) - 0.000042\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 0.802N_2(t-1) + 0.001596N_2^2(t-1) - 0.000231\beta_{21}N_2(t-1)N_1(t-1) - 0.000226\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 1.158N_3(t-1) - 0.000180N_3^2(t-1) + 0.000184\beta_{31}N_3(t-1)N_1(t-1) + 0.001274\beta_{32}N_3(t-1)N_2(t-1). \end{cases} \tag{14}$$

By substituting the above symbiotic relationship into the MCGP model, the following results are obtained:

$$\begin{cases} objective\ function,\ \min \sum_{i=1}^{n}(d_i^{+} + d_i^{-}) + \sum_{i=1}^{n}(e_i^{+} + e_i^{-}), \\ constraints, \\ g_i = f_i(x) + d_i^{-} - d_i^{+}, \quad i = 1, 2, \cdots, n, \\ x \in X, X = \{x_1, x_2, \cdots, x_m\}, \\ X \in F, \quad (F\ is\ the\ set\ of\ feasible\ solutions), \\ g_{i,\max} = g_i + e_i^{-} - e_i^{+}, \quad i = 1, 2, \cdots, n, \\ g_{i,\min} \le g_i, g_i \le g_{i,\max}, \quad i = 1, 2, \cdots, n, \\ e_i^{+}, e_i^{-}, d_i^{+}, d_i^{-} \ge 0, \quad i = 1, 2, \cdots, n \\ N_1(t) = 0.963N_1(t-1) + 0.000043N_1^2(t-1) - 0.000298\beta_{12}N_1(t-1)N_2(t-1) - 0.000042\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 0.802N_2(t-1) + 0.001596N_2^2(t-1) - 0.000231\beta_{21}N_2(t-1)N_1(t-1) - 0.000226\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 1.158N_3(t-1) - 0.000180N_3^2(t-1) + 0.000184\beta_{31}N_3(t-1)N_1(t-1) + 0.001274\beta_{32}N_3(t-1)N_2(t-1), \\ -1 < \beta_{ij} < 1, i = 1, 2, 3. j = 1, 2, 3, \\ \sum g_i = K, \ (K\ is\ the\ sum\ of\ market\ capacity). \end{cases} \tag{15}$$

As shown in Table 5, the system optimization path, the biggest feature of the current system, is that the intrinsic growth rate of population 1 and population 2 is a negative value. In the optimization path simulation, it can be set that population 1 and population 2 can reach a small positive intrinsic growth rate, and the system can evolve into the following new system:

$$\begin{cases} N_1(t) = 1.037N_1(t-1) - 0.000043N_1^2(t-1) + 0.000298\beta_{12}N_1(t-1)N_2(t-1) + 0.000042\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 1.198N_2(t-1) - 0.001596N_2^2(t-1) + 0.000231\beta_{21}N_2(t-1)N_1(t-1) + 0.000226\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 1.158N_3(t-1) - 0.000180N_3^2(t-1) + 0.000184\beta_{31}N_3(t-1)N_1(t-1) + 0.001274\beta_{32}N_3(t-1)N_2(t-1). \end{cases} \tag{16}$$

Table 3: Regression results of the Lotka–Volterra model of three populations.

N_i (t)	γ_{i1} (intrinsic growth)	γ_{i2} (internal inhibition coefficient)	γ_{i3} (population symbiosis)	γ_{i4} (population symbiosis)
N_1 (t)	0.963 (22.554)***	-4.325×10^{-5} (−0.954)	-3.038×10^{-5} (−0.238)	6.427×10^{-4} (1.564)*
N_2 (t)	0.802 (6.846)***	−0.0016 (−4.939)***	3.037×10^{-4} (2.684)***	4.061×10^{-3} (3.725)***
N_3 (t)	1.158 (18.310)***	-1.806×10^{-4} (−0.301)	-1.012×10^{-5} (−0.151)	-3.651×10^{-4} (−2.039)**

() t value, $^{*}p$ value < 0.1, $^{**}p$ value < 0.05, $^{***}p$ value < 0.01.

Table 4: Simulation of the symbiotic relationship of the automobile manufacturing community.

Parameter simulation	Total innovation resources (100 million yuan)										
	600	700	800	900	1000	1200	1400	1600	1800	2000	2200
G1	290	290	330	330	480	600	600	600	600	600	600
G2	190	190	280	280	350	370	370	370	370	370	370
G3	120	220	190	290	170	230	430	630	830	1030	1230
β13	0	0	0	0	0	0.024	0	0	0	0	0
β21	0	0	0	0	0	0.024	0	0	0	0	0
β23	0	0	0	0	0	0.020	0	0	0	0	0
β32	1	1	1	1	1	0.858	1	1	1	1	1

Table 5: Simulation of the symbiotic relationship of balanced growth of three populations.

Parameter simulation	Total innovation resources (100 million yuan)										
	600	700	800	900	1000	1200	1400	1600	1800	2000	2200
G1	290	290	333	330	480	600	600	600	600	600	600
G2	190	190	280	280	350	370	370	370	370	660	822
G3	120	220	187	290	170	230	430	630	830	740	778
β12	0	0	0.038	0	0	0	0.087	0	0	0	0
β13	0	0	0.039	0	0	0	0.089	0	0	0	0
β21	0	0	0.038	0	0.083	0	0.086	0	0	0	0
β23	0	0	0.036	0	0.080	0	0.076	0	0	0	0
β31	0.271	0.302	0.307	0.437	0.305	0.893	0.349	1	1	1	1
β32	0.275	0.616	0.573	1	0.349	1	0.388	1	1	1	1

In this virtual system, the intrinsic growth rate is adjusted from −0.037 and −0.198 to positive, and other correlation coefficients are also adjusted from the perspective of comprehensive cooperation.

As shown in Table 6, with the expansion of the market scale, more population cooperation behaviors are required. The cooperation behavior is comprehensive, and the cooperation intensity is similar. The greater the cooperation, the better. The cooperation intensity among enterprise communities is close to equilibrium.

This section takes the automobile manufacturing enterprise community composed of three automobile manufacturing-related industrial groups as the research sample and performs an empirical analysis on the symbiotic system from two aspects: the balanced development of the three communities and the competitive evolution of the three communities. The optimization under the symbiotic equilibrium state of the three populations shows that there is a possibility of equilibrium and reciprocity in the growth of the three automobile-related industrial populations. The empirical analysis fully demonstrates the feasibility of this research paradigm. The evolutionary analysis shows that the cooperative behavior is better than the competitive strategy, and comprehensive cooperation is the ideal state of the three-species symbiotic system.

2.5. Model Robustness Test. This section uses the data from information technology and the intelligent equipment manufacturing community to analyze the growth mode of innovation ability of the innovation community from the perspective of sharing based on the population dynamic model. The movement smoothing data of the observed values are shown in the following table.

By substituting the data in Table 7 into the econometric model and performing regression analysis, the data in Table 8 can be obtained.

As shown in Table 8, the regression effect is very good: the p value is low, and the value of the correlation coefficient meets the requirements of theoretical assumptions. Of which, $\alpha_1 = 0.179$, $K_1 = 103$; $\alpha_2 = -0.815$, $K_2 = 128$; and $\alpha_3 = 1.066$, $K_3 = 2173$. Based on previous research, the theoretical symbiotic network model between the innovation population of information technology and the intelligent equipment manufacturing community is obtained as follows:

Table 6: Simulation of the symbiotic relationship of balanced growth of three populations.

Parameter simulation	Total innovation resources (100 million yuan)										
	600	700	800	900	1000	1200	1400	1600	1800	2000	2200
G1	290	290	360	460	471	690	890	600	1290	1490	1562
G2	200	190	280	280	280	370	370	370	370	370	370
G3	110	220	160	160	249	140	140	630	140	140	268
$\beta 12$	0.973	1	0	0	0.149	0	0	0	0	0	0
$\beta 13$	1	1	0	0	1	0	0	0	0	0	0
$\beta 21$	0.014	1	1	1	1	1	1	1	1	1	1
$\beta 23$	1	1	1	1	1	1	1	1	1	1	1
$\beta 31$	0.011	0.254	0	0	0	0	0	0	0	0	0
$\beta 32$	0.011	0	0	0	0	0	0	0	0	0	0

Table 7: Information technology and the intelligent equipment manufacturing community from innovation resource movement smoothing data (unit: 100 million yuan).

Year/month/day	Special equipment	General intelligent equipment	New generation information technology
2022/3/31	127	26	402
2021/12/31	120	26	398
2021/9/30	114	26	392
2021/6/30	111	27	365
2021/3/31	108	28	337
2020/12/31	106	28	307
2020/9/30	105	29	277
2020/6/30	106	28	270
2020/3/31	106	27	268
2019/12/31	108	26	266
2019/9/30	108	25	264
2019/6/30	108	24	256
2019/3/31	108	22	242
2018/12/31	108	21	229
2018/9/30	108	20	213
2018/6/30	107	20	205
2018/3/31	107	19	196
2017/12/31	109	19	185
2017/9/30	110	17	180
2017/6/30	113	15	169
2017/3/31	115	13	160
2016/12/31	115	10	144
2016/9/30	114	9	128
2016/6/30	114	8	111
2016/3/31	114	8	91
2015/12/31	115	8	80

Table 8: Regression optimization results of the three-species Lotka–Volterra model.

N_i (t)	γ_{i1} (intrinsic growth)	γ_{i2} (internal inhibition coefficient)	γ_{i3} (population symbiosis)	γ_{i4} (population symbiosis)
N_1 (t)	1.179 $(8.181)^{***}$	-1.737×10^{-3} $(-3.344)^{*}$	-5.519×10^{-3} $(-3.344)^{***}$	5.567×10^{-4} $(3.052)^{***}$
N_2 (t)	0.185 (0.411)	6.366×10^{-3} $(3.584)^{***}$	0.010 $(39.828)^{***}$	-9.638×10^{-4} $(-7.314)^{***}$
N_3 (t)	2.066 $(4.440)^{***}$	4.905×10^{-4} $(1.429)^{*}$	-0.008 $(-2.081)^{**}$	-0.009 $(-1.899)^{*}$

() t value, $^{*}p$ value < 0.1, $^{**}p$ value < 0.05, $^{***}p$ value < 0.01.

Table 9: Simulation of the symbiotic relationship among three populations of information technology and the automobile manufacturing community.

Parameter simulation	Total innovation resources (100 million yuan)										
	200	250	300	350	400	450	500	550	600	700	800
G1	100	100	113	113	113	113	113	113	113	196	208
G2	8	8	15	15	16	15	15	15	15	15	15
G3	92	142	172	222	270	322	372	422	472	489	576
$\beta 12$	0.468	0.467	0.529	0.527	0.957	0.724	0.880	1	1	0.415	0.388
$\beta 13$	0.490	0.611	0.741	0.881	0.862	0.641	0.837	1	1	0.302	0.301
$\beta 21$	0	0	0	0	0.701	0	0	0	0	0	0
$\beta 23$	1	1	1	1	1	1	1	1	1	1	1
$\beta 31$	0	0	0	0	0.212	0	0	0	1	1	1
$\beta 32$	0.064	0.052	0	0	0.232	0	0	0	1	1	1

$$\begin{cases} N_1(t) = (1+0.179)N_1(t-1) + \frac{-0.179}{103}N_1^2(t-1) + \frac{0.179\beta_{12}}{128}N_1(t-1)N_2(t-1) + \frac{0.179\beta_{13}}{2173}N_1(t-1)N_3(t-1), \\ N_2(t) = (1-0.815)N_2(t-1) + \frac{0.815}{128}N_2^2(t-1) + \frac{-0.815\beta_{21}}{103}N_2(t-1)N_1(t-1) + \frac{-0.815\beta_{23}}{2173}N_2(t-1)N_3(t-1), \\ N_3(t) = (1+1.066)N_3(t-1) + \frac{-1.066}{2173}N_3^2(t-1) + \frac{1.066\beta_{31}}{103}N_3(t-1)N_1(t-1) + \frac{1.066\beta_{32}}{128}N_3(t-1)N_2(t-1). \end{cases} \tag{17}$$

Based on the regression results, this paper optimizes the model, removes insignificant regression terms, and obtains the actual symbiotic network as follows:

$$\begin{cases} N_1(t) = (1+0.179)N_1(t-1) + \frac{-0.179}{103}N_1^2(t-1) + \frac{0.179\beta_{12}}{128}N_1(t-1)N_2(t-1) + \frac{0.179\beta_{13}}{2173}N_1(t-1)N_3(t-1), \\ N_2(t) = \frac{0.815}{128}N_2^2(t-1) + \frac{-0.815\beta_{21}}{103}N_2(t-1)N_1(t-1) + \frac{-0.815\beta_{23}}{2173}N_2(t-1)N_3(t-1), \\ N_3(t) = (1+1.066)N_3(t-1) + \frac{-1.066}{2173}N_3^2(t-1) + \frac{1.066\beta_{31}}{103}N_3(t-1)N_1(t-1) + \frac{1.066\beta_{32}}{128}N_3(t-1)N_2(t-1), \end{cases} \tag{18}$$

$$\begin{cases} N_1(t) = 1.179N_1(t-1) - 0.001737N_1^2(t-1) + 0.001398\beta_{12}N_1(t-1)N_2(t-1) + 0.000082\beta_{13}N_1(t-1)N_3(t-1), \\ N_2(t) = 0.006367N_2^2(t-1) - 0.007912\beta_{21}N_2(t-1)N_1(t-1) - 0.000375\beta_{23}N_2(t-1)N_3(t-1), \\ N_3(t) = 2.066N_3(t-1) - 0.000491N_3^2(t-1) + 0.010349\beta_{31}N_3(t-1)N_1(t-1) + 0.008328\beta_{32}N_3(t-1)N_2(t-1). \end{cases}$$

As shown in Table 9, with the expansion of the market scale, more population cooperation behaviors are required, and the intensity of population cooperation is gradually increasing. The actual symbiotic model of information technology and the automobile manufacturing community is very close to the whole population symbiotic model in the ideal state, and the symbiotic relationship coefficient of its evolution simulation is relatively comprehensive. The relationship between populations has developed in a balanced way. Compared with the automobile manufacturing community, information technology and the automobile manufacturing community can promote the development of innovation resources by sharing.

3. Results and Discussion

The development of any natural, social, and economic ecosystem will be restricted by its own growth capacity, resources, and environment, so the evolution process of the ecosystem is limited and regular. Almost all industries will follow the cycle law and experience the process from birth to growth to maturity and then to recession. Similarly, the development of the population should not be unlimited. Due to the limitations of the population itself and external conditions, there is a problem of limited growth. The population dynamic model of innovative enterprises mainly focuses on the population change mechanism, and its change rule is based on the nonlinear growth law of biological population. In nature, many species grow nonlinearly, and the phenomenon of nonlinear population growth is also very common. Under the influence of the market environment, innovation policies, and development resources in a certain region, the enterprise population and community may change rapidly.

From the perspective of the enterprise innovation subject, this paper uses logistic and Lotka–Volterra models to empirically test the intrinsic driving mechanism, market sharing driving mechanism, and enterprise innovation ability growth mechanism of enterprise growth. It is found that the growth mode of automobile manufacturing enterprises' innovation ability is rich and colorful, and the market sharing driven enterprise growth is the leading mode. The development of automobile manufacturing enterprises mainly depends on the expansion of the market scale, which benefits from the continuous growth of China's economy and the expansion of market demands. Some automobile manufacturing enterprises have performed well in innovation capability development, innovation-driven modes, and shared innovation-driven modes. These enterprises play a leading role in the industry. Some enterprises are facing external competitive pressure from the enterprise population. These enterprises need to strengthen their internal skills, maintain their internal growth capacity, and actively use external innovation and market resources to change their growth mode.

This paper analyzes the mode of shared innovation and development of automobile manufacturing enterprises from the perspective of symbiosis among populations within the community. The study sample was divided into two communities: automobile manufacturing and information technology and automobile manufacturing. Each community has three closely related species. Among them, the automobile manufacturing community shows the characteristics of skew distribution, and the relationship between populations is asymmetric. The innovation-driven ecosystem of information technology and the automobile manufacturing community is a symbiotic system with relatively balanced development. The Lotka–Volterra-MCGP optimization model is used to simulate system evolution, optimization path, and system characteristics. The simulation results show that the balanced system is better than the biased system in the shared development model. The robustness of the multidimensional population dynamic model and its derivative models proposed in this chapter will be verified by the empirical case analysis in the next chapter.

Existing studies usually use a single-MCGP model to analyze the symbiotic relationship of innovation population [38] and pay more attention to the optimization of the scale of innovation population [41]. In this paper, Lotka–Volterra and MCGP are combined to build a multiselection model. Based on the optimization results, community synergy was evaluated. This method integrates and extends the application fields of the two models and is more suitable for solving practical problems. The symbiosis of the enterprise population is a hot topic in the research of innovation ecosystems [42, 43]. The research on innovation ecosystems mainly focuses on resource constraints [44] and ecological institutions [45]. Compared with these studies, this paper studies not only population symbiosis but also community symbiosis. This paper expands the theoretical and practical research field of social economic ecosystems.

Among the existing studies, there is a kind of interesting research mainly focusing on the grey logistic model [46], grey two-dimensional Lotka–Volterra model, and grey three-dimensional Lotka–Volterra model [40, 47–50]. The main feature of this kind of research is that grey system theory is applied to the model construction of population dynamics. The model of grey system theory is good at preprocessing the observation data when the amount of data is small and the data are missing. The Lotka–Volterra model used in this study is characterized by using correlation regression results to construct a multipopulation symbiotic ecosystem and does not focus on data processing. Of course, in some other research situations, the grey Lotka–Volterra model can also be used to explain the similar research contents in this paper.

4. Conclusion

This research has well realized the goal to establish a feasible three-species equilibrium model to analyze the symbiotic relationship of the enterprise community. A practical three-dimensional Lotka–Volterra model has been used to analyze the symbiotic relationship of Chinese automobile manufacturing communities. This paper studies the symbiotic mechanism and symbiotic evolution law among the populations in the automobile manufacturing enterprise community. The classical Lotka–Volterra model is mainly a two-dimensional configuration, which limits the application scenarios of the Lotka–Volterra model. The research goal of this paper is to establish a feasible three-species equilibrium model to analyze the symbiotic mechanism among the populations in the automobile manufacturing enterprise community. In order to extend the Lotka–Volterra model to empirical analysis, this paper proposes a symbiotic model of the automobile manufacturing enterprise community based on the three-dimensional Lotka–Volterra model. In the process of dynamic simulation of the model, the symbiotic relationship between automobile manufacturing-related populations shows a significant "skew symbiotic relationship." Skew distribution is difficult to use to support collaborative development. Instead, the "whole population symbiotic" optimization model has been reconstructed. The symbiotic optimization under the equilibrium state of the three populations shows that the growth of the three automobile manufacturing industry populations has the possibility of equilibrium and reciprocity. The empirical analysis fully demonstrates the feasibility of this research paradigm. The evolution analysis of the symbiotic system shows that cooperative behavior is better than the competitive strategy. The research paradigm proposed in this paper can better analyze the symbiotic mechanism of the enterprise community.

The evolution of the innovation ecosystem of the automobile manufacturing community is a complex process. Data, models, methods, and research samples are relatively simple. In this paper, there are some limitations in the following aspects: (1) first, the research elements considered in the model are limited. The evolution of industrial innovation ecosystems is complex in science and technology, economy, culture, and policy. A more in-depth research process needs to consider the impact of the above complex factors. (2) This study did not explore the life cycle characteristics of communities and populations. According to ecosystem life cycle theory, follow-up research needs to deeply explore the evolution process of the industrial innovation ecosystem. (3) Risk is not considered in this paper. In future research, researchers should strengthen the management of the operation and evolution process of the industrial innovation ecosystem to reduce the risk.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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