Article

Symbiotic Evolution Mechanism of the Digital Innovation Ecosystem for the Smart Car Industry

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Abstract: As an essential product in the automotive industry, the smart car industry has attracted widespread attention from scholars. However, there are few studies on the evolution of innovation ecosystems under different modes for the smart car industry. Thus, we construct evolution equations based on the symbiosis theory and Lotka–Volterra. Specifically, MATLAB simulations are utilized to comprehensively analyze the specific conditions for different symbiotic modes. The results indicate that (1) the smart car digital innovation ecosystem includes four symbiotic units. They are vehicle manufacturers, internet enterprises, supporting enterprises, and application groups. The symbiotic relationship among units depends on the symbiosis coefficient. (2) According to the symbiosis coefficient, the system is mainly divided into five symbiotic models: independent symbiosis, competitive symbiosis, parasitic symbiosis, partial symbiosis, and mutually beneficial symbiosis. Moreover, the mutually beneficial symbiosis is the optimal evolution model, and it is also a model that can enable the sustainable development of the smart car industry, which has been verified through case studies.

Keywords: digital innovation ecosystem; smart cars; symbiotic evolution; numerical simulation; case study analysis

1. Introduction

Ecosystems are increasingly being used in management-related fields such as strategy, innovation, and entrepreneurship [1,2]. Innovation and value creation cannot be achieved by any single organization that develops singularly. The value acquisition and creation in an organization depends on the interaction of the rest of the organization and internal and external resources. In this role, the interconnectedness between the participants enables the flow of knowledge, supports the development of technology, and ultimately leads to organizational innovation. This is the formation of an innovation ecosystem. Digital innovation was first proposed by Yoo. He points out that digital innovation is the production of new products through new combinations of digital and physical components [3]. In 2017, based on Yoo, Liu Yang [4] claimed that digital innovation is the process of combining digital or physical components in a new way to produce new products or services. Digital innovation is an innovative activity that applies the new generation of digital technologies to existing industries to form new products or services, thus achieving industrial convergence. In this new activity, a new organizational form will be developed, which is the digital innovation ecosystem [5]. Within the system, participants play different species, which are interrelated and interact with each other to form an ecological community.

In the era of the digital economy, digital ecological empowerment will promote changes in various aspects such as enterprise value, organization, business model, communication cost [6], portfolio efficiency [7], and other aspects. Digital transformation is
gradually promoting the high-quality development of the economy [8]. With the continuous improvement of digital innovation ecology, the automotive industry is also gradually stepping into the era of smart driving. Digital transformation is promoting the upgrade of the automobile from a simple means of transportation to an intelligent mobile terminal. The global automotive industry is in the midst of unprecedented changes, and the collision between mobile technology and the automotive industry will erupt into new opportunities. Currently, there have been several studies examining the impact of digital empowerment on the automotive industry and even on manufacturing as a whole. Chen [9] has established a co-evolution model from the perspective of an innovation ecosystem, which enables sustainable development in advanced manufacturing. Men [10] contends that digital transformation, mediated by digital technological innovation capabilities, positively influences the performance of automotive enterprises. Drawing on fsQCA, Llopis-Albert [11] asserts that enterprises at the forefront of introducing digital technologies will possess a distinct competitive advantage within the automotive industry. This evidence suggests that the empowerment conferred by digital technology plays a catalytic role in the developmental trajectory of the automotive industry. Furthermore, there are studies focusing on the impact of introducing digital technology into the manufacturing process on the automotive industry [12]. We will specifically investigate the outcomes resulting from the integration of digital technology into the automotive industry.

Against this backdrop, new-generation technologies such as big data, the Internet of Things, and artificial intelligence are gradually being applied to the automotive industry, thus giving rise to smart cars. In this process, smart cars are gradually gaining widespread attention and accelerating the formation of a new industrial ecosystem. Smart cars span a wide range of fields, including traditional automobiles, artificial intelligence, and digital communication. The smart car industry not only reshapes the ecological chain but also the ecosphere. The most important feature that distinguishes smart cars from traditional cars is their “self-learning and self-growth” ability, which is inseparable from the support of software and hardware.

The existing research on the smart car innovation ecosystem consists of two main aspects. On the one hand, the concept [13], current development [13,14], and advanced technologies of smart are explored from a technological perspective. Due to the internet connection, smart cars include new technologies such as smart parking [15] and smart seats [16]. In addition, the data from smart cars will be shared with various actors in the industry chain [13]. On the other hand, from the perspective of management, we will explore the consumer service and the current risks faced by the development of smart cars. At present, consumers are most interested in driving assistance, followed by infotainment and IoT platforms. Compared to other smart products, consumers consider smart cars as vehicles that provide utility rather than as devices that provide personal utilities [17]. However, despite the incremental characteristics of digital technologies for the development of smart cars [18], it still faces many risks, such as cyber risk [19] or security risk [20].

In summary, current research has explored the sustainable development of industries from the perspective of co-evolution, including cross-industry collaboration, strategic emerging industries, and manufacturing. However, the focus has primarily been on macro-level industries, lacking specificity for individual sectors. Research on digital innovation ecosystems is still in a dynamic developmental stage, with a notable gap in the study of digital innovation ecosystems specific to intelligent automobiles. Therefore, this study explores the mechanism of evolutionary symbiosis with the help of numerical simulation. Then, the numerical simulation results are verified with a case study.

The contribution of this paper is tripartite. Firstly, this study combines ecosystem theory, symbiosis theory, and evolutionary theory and innovatively analyzes the evolutionary process of the digital innovation ecosystem for smart cars from the perspective of evolutionary symbiosis. Secondly, the evolution of the smart car digital innovation ecosystem is a dynamic and complex process. Therefore, based on the Lotka–Volterra dynamic evolution model, this paper analyzes in depth the evolution law of the smart car
digital innovation ecosystem, the interactions between populations, and the impact on the evolution of the whole system. With the help of MATLAB, five evolutionary models are drawn, which are independent symbiosis, competitive symbiosis, parasitic symbiosis, partial symbiosis, and mutually beneficial model. The third point is the introduction of case studies on the basis of numerical simulation. Case study analysis is an effective research method to provide the numerical simulation. It is highly persuasive to verify the evolution process of the digital innovation ecosystem of smart cars through a case study. This study explores the symbiotic roles and relationships between Chang’an Automobile Company and other groups to validate the numerical simulation results.

The overall structure of the study takes the form of six sections. The Section 2 points out the theory involved in this paper, mainly including the theory of digital innovation and symbiotic evolution theory. Section 3 constructs the symbiotic evolution model and determines the equilibrium points corresponding to each symbiotic model. Section 4 combines previous models and performs numerical simulations for each simulation model. Then, a case study analysis is proposed in Section 5. The Section 6 is included in the final part.

2. Theoretical Foundation

2.1. Digital Innovation Ecosystem of the Smart Car

Management research introduced the concept of ecosystems decades ago [21] and has continued to deepen the understanding of this concept since then [22]. The innovation ecosystem is an interesting development, built on ecological theory [9,23,24] and biomimetic thinking [25]. An innovation ecosystem is a system of resource circulation and value flow in each space and time, consisting of an organization and its environment [1]. The system demonstrates a more complex relationship composed of multiple subjects or populations. The goal of these subjects or populations is to be able to achieve the development and creation of technology [26,27]. Phillips et al. [25] claim that there are seven types of innovation ecosystems, and values are passed between the groups in the ecosystem according to the stakes. The main players within the innovation ecosystem are similar to the species in the natural environment. The relationships between these species form different communities. In the process of rapid digitization, the introduction of digital technologies into industrial development has resulted in a new type of innovation, namely digital innovation. Digital innovation is an innovation process that combines information, computing, communication, and connectivity to form new products [3,28]. The introduction of digital technology in the digital innovation process makes the product innovation process more sensible and searchable and reduces the cost of the company [29]. The ecosystem that emerged in this context is the digital innovation ecosystem. Digital innovation ecosystems are value-creating networks. Core companies build with other organizations that use digital technologies to produce complementary products and services in order to increase the value of the innovation [4]. Phillips et al. [25] point out that digital innovation ecosystems can be applications, platforms, and distributors that make the technology visible. The digital innovation ecosystem is dynamic, diverse, and borderless. Dynamic means that it is a constantly changing system. The system responds quickly to changes in the environment, resources flow, and other factors. This also lays the foundation for subsequent research proposing the ecosystem evolution. Diversity refers to the fact that the identities of participants within the system present diversity. In a complete ecosystem, it includes not only core enterprises but also users, governments, universities, and third-party organizations. The diversity of participants allows different resources to circulate within the ecosystem. This also leads to the redistribution and reuse of resources among different participants. Borderless means that digital technology breaks down the barriers between industries, allowing participants from all walks of life to participate in the ecosystem. This nature facilitates value exchange and increases the efficiency of resource utilization [30].
Driven by the internet, artificial intelligence, and other new technologies, a new round of technological revolution and industrial change is flourishing. The global landscape of the automotive industry is constantly being reshaped. This has also given rise to the birth of smart cars. In the internet era, whether the internet intervenes in the automotive field or automotive companies expand into the internet and artificial intelligence, the essence of both parties is to build an open and inclusive digital innovation ecosystem through a vehicle networking platform. The platform ultimately integrates the internet, artificial intelligence concepts, and automotive production experience in a new way. The system responds to the rapidly changing market demand through dynamic changes. With the addition of internet companies, the system is gradually becoming richer and more diverse in terms of participating parties. Automotive companies are also increasingly cooperating and innovating with stakeholders involved in the system [31]. The auto industry has a long industrial chain, and the new demand for AI algorithms, software, chips, networks, and intelligent hardware platforms has broken the boundaries of the traditional auto industry. The resources of each industry are fully allocated and reorganized within the system. Smart cars will also face numerous challenges in the development process. In order to overcome the risks and challenges, the ecosystem should evolve and develop continuously to maintain a stable state among the participants.

2.2. Symbiotic Evolution Mechanism

2.2.1. Symbiosis Theory

Symbiosis theory originates in biology and is proposed by the biologist DeBerry. It is widely used in biology to explore the relationship between different populations. DeBerry [32] points out that symbiosis is the linkage of different populations based on different beneficial relationships, and Caullery [29] deepened the concept of symbiosis and further proposed the concepts of parasitism, symbiosis, and reciprocal symbiosis for the relationship between populations. Scott [33] believes that the equilibrium relationship between two or more interdependent populations is symbiosis. In the mid-20th century, symbiosis theory was gradually introduced into other research fields, such as management, sociology, and economics. According to the symbiosis theory, this study considers that a symbiotic system composed of populations consists of five elements: symbiotic unit, symbiotic substrate, symbiotic interface, symbiotic environment, and symbiotic pattern. In the smart car digital innovation ecosystem, a cohesive integration of various elements rooted in the symbiosis theory will achieve not only technological advancement but also sustainable development. It is shown in Figure 1.

The symbiotic unit [34] is the basis of symbiosis theory. It is a symbiotic subject involved in energy production and exchange. The smart car digital innovation ecosystem includes four symbiotic units. They are vehicle manufacturers, internet enterprises (e.g., enterprises engaged in digital technologies such as big data, artificial intelligence, and cloud computing), supporting enterprises (e.g., government, universities, banks, investment institutions, and component manufacturers), and application groups (e.g., user groups).

The symbiotic substrate is necessary for symbiosis theory, such as the physical, the information, and the energy in an ecosystem. In the smart car digital innovation ecosystem, there is a resource flow and complementary relationship between clusters. The vehicle manufacturers have the key resources and technologies, such as manufacturing knowledge, instruments and equipment, management experience, etc. This cluster is the basis for the development of smart cars. The key resources of internet enterprises are big data, artificial intelligence, 5G, and other advanced digital technologies. Through these digital technologies, internet companies create advanced resources such as smart driving, auto-parking, smart cockpit, 3D gesture system, car integration with smartwatch, integration with various apps, etc., which are compatible with the development of smart cars.
The key resources for supporting organizations are human resources, funding, consulting services, policies, etc. The application group is the audience group of smart cars.

![Diagram of the digital innovation ecosystem for smart cars from a symbiotic perspective.](image)

**Figure 1.** The model of the digital innovation ecosystem for smart cars from a symbiotic perspective.

The symbiotic interface is a vehicle for information sharing as well as resource flow between various clusters, such as innovation platforms, system alliances, etc. Through the symbiotic interface, various clusters break the ecological barriers and achieve resource complementation and redistribution. This continuous circulation of resources will promote the continuous synergistic development of the whole ecosystem.

The symbiotic environment is the factor in the symbiotic system that is outside the symbiotic unit and the environment on which the symbiotic unit depends. It mainly includes the international environment, socio-economy, capital, etc.

The symbiotic pattern refers to the way and intensity of interaction between symbiotic units. Different symbiotic patterns are classified to reflect different symbiotic relationships and behaviors. According to the degree of material and energy interactions between symbiotic units, four symbiotic modes can be classified. They are competitive symbiosis, parasitic symbiosis, partial symbiosis, and mutually beneficial. Competitive symbiosis includes equal competition and vicious competition. Equal competition means that the redistribution of resources among groups is reduced by competition. Specifically, the value creation of the four groups is reduced in the digital innovation ecology of smart cars. Vicious competition means that some populations will die out with the competition process. The value of the species that benefits from the competition process will increase. In the smart car digital innovation ecosystem, the value of each one, two, or three actors increases, while the other three, two, or one will gradually die out. Parasitic symbiosis is a one-way flow of resources and a transfer from the host to the parasite. There is no new energy generated in the process. If the value of each one, two, or three actors increases or decreases, the value of the other three, two, or one actors will decrease or increase. The partial symbiosis will generate new energy. However, this energy is gained by the benefiting population and has no effect on the others. In a smart car innovation ecosystem, one,
two, or three populations gain while the other three, two, or one remain unaffected. The mutually beneficial symbiotic process generates new energy. Energy is distributed among symbiotic units. Value co-creation is achieved among vehicle manufacturers, internet companies, supporting organizations, and application groups. The value of the four populations is increased. The mutually beneficial symbiosis model is the optimal solution for the development of digital innovation ecosystems for smart cars.

2.2.2. The Evolution of the Symbiotic Process

Ecosystem change is a dynamic process. Symbiotic units, patterns, and interactions change over time with the external environment. This reflects the evolutionary nature of ecosystems. With the gradual evolution of symbiotic units, the innovation ecosystem exhibits the qualities of symbiotic evolution. Symbiotic evolution could keep system diversity in a prolonged evolution [35]. Through symbiotic evolution between various groups, the ecosystem could develop and evolve sustainably. In natural ecosystems, the number of species, the relationships between species, and the components of the ecosystem change over time. Ecosystems are dynamic when species interact with the external environment to make the ecosystem sustainable. Symbiotic evolution also exists in the development of smart cars. The smart car digital innovation ecosystem is a complex, dynamic evolutionary system composed of multiple elements and subjects. The populations within the ecosystem interact with the environment and dynamically influence each other. The growth pattern of the population is divided into Malthus and logistic [36]. Malthus shows a J-shaped growth. It is essentially exponential growth based on the idea of the function being proportional to the speed at which the function grows. Logistic shows an S-shaped growth. It points out that the initial stage of growth is approximately exponential (geometric); then, as saturation begins, the growth slows to linear (arithmetic), and at maturity, growth stops. Since the populations in the smart car digital innovation ecosystem will be influenced by economic, political, and technological aspects, this study considers that the populations follow the logistic pattern. The life cycle will go through four periods: the start-up period, the growth period, the maturity period, and the saturation period. This is shown in Figure 2.

![Figure 2. The logistic curve of the symbiosis evolution. a is lag phase, b is exponential growth phase, c is inflection point, d is deceleration phase, e is saturation phase.](Image)

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3. Methodology and Assumptions

3.1. Lotka–Volterra Model

The Lotka–Volterra model was originally used to simulate the predator–prey relationship between populations in the ecosystem, and it was later applied in various fields. The model describes an ecosystem in which two or more participating agents exist simultaneously and maintain dynamic competition and cohabitation growth. The Lotka–Volterra model is an extension of the logistic model. This model also lays the theoretical foundation of interspecies competition. For smart car digital innovation, this model could accurately explain the competitive symbiosis among vehicle manufacturers, internet enterprises, supporting enterprises, and application groups in the system.

The following four assumptions are proposed.

**Assumption 1.** The smart car digital innovation ecosystem is composed of four types of symbiotic species, which are the vehicle manufacturer $A_i(i = 1, 2, 3 \ldots m)$, internet enterprises $B_j(j = 1, 2, 3 \ldots n)$, supporting enterprises $C_k(k = 1, 2, 3 \ldots a)$ and application groups $D_r(r = 1, 2, 3 \ldots s)$. The species size of the vehicle manufacturer, internet enterprises, supporting enterprises, and application groups are all limited and affected by the external environment, such as resources and environment. The smart car innovation ecosystem is similar to the natural ecosystem evolution, which will experience the law of survival from birth to extinction.

**Assumption 2.** There are interactions among the species in the smart car digital innovation ecosystem. Various species influence each other, and there is a certain directionality in this influence. The positive and negative of the symbiosis degree reflect the symbiotic relationship among the species. When the degree is less than 0, it means that the actor has a positive effect on the growth of the audience. Conversely, when the degree is greater than 0, it means that the actor has a negative effect on the growth of those acted upon.

**Assumption 3.** The growth process of vehicle manufacturers, internet enterprises, supporting enterprises, and application groups follows the logistic growth. Since four species are constrained by resources and environment, the growth rate decreases when the population grows to a certain level. When the marginal output of a species (vehicle manufacturer $A_i$, internet enterprises $B_j$, supporting enterprises $C_k$ or application groups $D_r$) is equal to the marginal input, the growth rate of the population is 0. At this point, the scale of the population reaches its maximum.

**Assumption 4.** The natural growth rate of each population in the smart car digital innovation ecosystem is determined by the inherent properties of its own population under ideal conditions. Therefore, this study ignores the influence of population evolution, and the natural growth rate is kept constant.

Based on the above assumptions, this paper constructs the Lotka–Volterra dynamics model for the symbiotic evolution of four populations in the smart car innovation ecosystem as follows.

$$\frac{dy_1(t)}{dt} = r_1 y_1 \left(1 - \frac{y_1}{N_1} - \frac{\varphi_{12} y_2}{N_2} - \frac{\varphi_{13} y_3}{N_3} - \frac{\varphi_{14} y_4}{N_4}\right), y_1(0) = y_{10} \quad (1)$$

$$\frac{dy_2(t)}{dt} = r_2 y_2 \left(1 - \frac{y_2}{N_2} - \frac{\varphi_{21} y_1}{N_1} - \frac{\varphi_{23} y_3}{N_3} - \frac{\varphi_{24} y_4}{N_4}\right), y_2(0) = y_{20} \quad (2)$$

$$\frac{dy_3(t)}{dt} = r_3 y_3 \left(1 - \frac{y_3}{N_3} - \frac{\varphi_{31} y_1}{N_1} - \frac{\varphi_{32} y_2}{N_2} - \frac{\varphi_{34} y_4}{N_4}\right), y_3(0) = y_{30} \quad (3)$$

$$\frac{dy_4(t)}{dt} = r_4 y_4 \left(1 - \frac{y_4}{N_4} - \frac{\varphi_{41} y_1}{N_1} - \frac{\varphi_{42} y_2}{N_2} - \frac{\varphi_{43} y_3}{N_3}\right), y_4(0) = y_{40} \quad (4)$$
where \( y_1(t), y_2(t), y_3(t) \) and \( y_4(t) \) are the population size of the vehicle manufacturer, internet enterprises, supporting enterprises, and application groups, respectively. \( r_1, r_2, r_3 \) and \( r_4 \) are the natural growth rates of the four populations, respectively. \( N_1, N_2, N_3 \) and \( N_4 \) denote the maximum size of the four populations under the condition of limited resources for the innovation ecosystem, respectively. \( 1 - \frac{y_1}{N_1}, 1 - \frac{y_2}{N_2}, 1 - \frac{y_3}{N_3} \) and \( 1 - \frac{y_4}{N_4} \) are logistic coefficients that indicate the hindrance of the consumption of limited resources by vehicle manufacturers, internet enterprises, supporting enterprises, and application groups to the growth of their own population size, respectively.

The symbiosis degree \( \varphi_{ab}(a, b \in [1, 2, 3, 4], a \neq b) \) indicates the symbiotic effect of population \( b \) on population \( a \). The magnitude of the value indicates the intensity of symbiosis. The symbiosis model is the form of mutual combination for symbiotic units, which mainly includes five symbiosis models: independent symbiosis, competitive symbiosis, parasitic symbiosis, partial symbiosis, and mutually beneficial symbiosis. The basic conditions of symbiosis models are shown in Table 1.

### Table 1. The conditions of different symbiosis models.

<table>
<thead>
<tr>
<th>Relevant Values of ( \varphi_{ab} )</th>
<th>Symbiotic Model</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varphi_{ab} = \varphi_{ba} = 0 )( \ (a, b \in [1, 2, 3, 4], a \neq b )</td>
<td>Independent symbiosis model</td>
<td>The various species develop independently and do not affect each other.</td>
</tr>
<tr>
<td>( \varphi_{ab} &gt; 0, \varphi_{ba} &gt; 0 )( \ (a, b \in [1, 2, 3, 4], a \neq b )</td>
<td>Competitive symbiosis model</td>
<td>There are mutually beneficial relationships among the four species. The symbiotic coefficient is positive.</td>
</tr>
<tr>
<td>( \varphi_{ab} &gt; 0, \varphi_{ba} &lt; 0 )( \ (a, b \in [1, 2, 3, 4], a \neq b )</td>
<td>Parasitic symbiosis model</td>
<td>One kind of population is damaged (the symbiotic coefficient is positive), and the other benefits (the symbiotic coefficient is negative).</td>
</tr>
<tr>
<td>( \varphi_{ab} &lt; 0, \varphi_{ba} = 0 )( \ (a, b \in [1, 2, 3, 4], a \neq b )</td>
<td>Partial symbiosis model</td>
<td>One kind of population benefits (the symbiotic coefficient is negative), and the other has no impact (the symbiotic coefficient is equal to zero).</td>
</tr>
<tr>
<td>( \varphi_{ab} &lt; 0, \varphi_{ba} &lt; 0 )( \ (a, b \in [1, 2, 3, 4], a \neq b )</td>
<td>Mutually beneficial model</td>
<td>There are mutually beneficial relationships among the four species. The symbiotic coefficient is negative.</td>
</tr>
</tbody>
</table>

### 3.2. Analysis of the Symbiotic Evolution

The symbiotic evolution of the four populations for the smart car innovation ecosystem is a dynamic game process. In order to explore the results of symbiotic evolution among the four populations in depth, we will analyze the equilibrium point of Equations (1)–(4) for stability. In this study, we make Equations (1)–(4) equal to 0. Equations (5)–(8) are then obtained as follows.

\[
\begin{align*}
\text{Equation 5:} & \quad r_1 y_1 \left(1 - \frac{y_1}{N_1} - \varphi_{12} \frac{y_2}{N_2} - \varphi_{13} \frac{y_3}{N_3} - \varphi_{14} \frac{y_4}{N_4}\right) = 0 \\
\text{Equation 6:} & \quad r_2 y_2 \left(1 - \frac{y_2}{N_2} - \varphi_{21} \frac{y_1}{N_1} - \varphi_{23} \frac{y_3}{N_3} - \varphi_{24} \frac{y_4}{N_4}\right) = 0 \\
\text{Equation 7:} & \quad r_3 y_3 \left(1 - \frac{y_3}{N_3} - \varphi_{31} \frac{y_1}{N_1} - \varphi_{32} \frac{y_2}{N_2} - \varphi_{34} \frac{y_4}{N_4}\right) = 0 \\
\text{Equation 8:} & \quad r_4 y_4 \left(1 - \frac{y_4}{N_4} - \varphi_{41} \frac{y_1}{N_1} - \varphi_{42} \frac{y_2}{N_2} - \varphi_{43} \frac{y_3}{N_3}\right) = 0
\end{align*}
\]

Solving Equations (5)–(8), we obtain 16 equilibria, as shown in Table 2. The Jacobian matrix of the coefficients is shown below, where \( A = r_1 \left(1 - \frac{y_1}{N_1} - \frac{\varphi_{12} y_2}{N_2} - \frac{\varphi_{13} y_3}{N_3} - \frac{\varphi_{14} y_4}{N_4}\right) \), \( B = r_2 \left(1 - \frac{y_2}{N_2} - \frac{\varphi_{21} y_1}{N_1} - \frac{\varphi_{23} y_3}{N_3} - \frac{\varphi_{24} y_4}{N_4}\right) \), \( C = r_3 \left(1 - \frac{y_3}{N_3} - \frac{\varphi_{31} y_1}{N_1} - \frac{\varphi_{32} y_2}{N_2} - \frac{\varphi_{34} y_4}{N_4}\right) \) and \( D = r_4 \left(1 - \frac{y_4}{N_4} - \frac{\varphi_{41} y_1}{N_1} - \frac{\varphi_{42} y_2}{N_2} - \frac{\varphi_{43} y_3}{N_3}\right) \).
When the innovation ecosystem is stable, there are different equilibrium points in the system. Among the five symbiotic models, different models have different equilibrium points. By calculating eigenvalues for these 16 equilibrium points, we qualitatively analyzed the local stability and stability conditions for the innovation ecosystem. The system reaches evolutionary stability when all the eigenvalues are negative [37]. Finally, we obtain nine stable points. These stable points constitute the boundary of the four populations’ symbiotic evolutionary ecosystem. The results are shown in Table 2. Due to limited space and too many data items, we present equilibrium points $Q_{12}$ to $Q_{16}$ in Appendix A.

### Table 2. The stable points and conditions of the symbiotic evolution.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>Stability Conditions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_1(0,0,0,0)$</td>
<td>Not a stable point</td>
<td>Positive</td>
</tr>
<tr>
<td>$Q_2(N_1,0,0,0)$</td>
<td>(1 - $\varphi_{13}$)(1 - $\varphi_{31}$)(1 - $\varphi_{41}$) &lt; 0</td>
<td>Negative</td>
</tr>
<tr>
<td>$Q_3(N_2,0,0,0)$</td>
<td>(1 - $\varphi_{13}$)(1 - $\varphi_{32}$)(1 - $\varphi_{42}$) &lt; 0</td>
<td>Negative</td>
</tr>
<tr>
<td>$Q_4(N_3,0,0,0)$</td>
<td>(1 - $\varphi_{13}$)(1 - $\varphi_{33}$)(1 - $\varphi_{43}$) &lt; 0</td>
<td>Negative</td>
</tr>
<tr>
<td>$Q_5(N_4,0,0,0)$</td>
<td>(1 - $\varphi_{14}$)(1 - $\varphi_{23}$)(1 - $\varphi_{34}$) &lt; 0</td>
<td>Negative</td>
</tr>
</tbody>
</table>

\[
\begin{pmatrix}
A & -r_2\varphi_{12}y_1 & -r_1\varphi_{13}y_1 & -r_1\varphi_{14}y_1 \\
N_2 & B & -r_2\varphi_{23}y_2 & -r_2\varphi_{24}y_2 \\
N_1 & -r_3\varphi_{31}y_3 & C & -r_3\varphi_{34}y_3 \\
N_1 & -r_4\varphi_{41}y_4 & -r_4\varphi_{42}y_4 & D
\end{pmatrix}
\] (9)
4. Results and Discussion

Based on the mobility of resources, each innovation population in the digital innovation ecosystem of smart cars generates greater value through the division of labor and cooperation to achieve industrial integration. These new values are circulated, distributed, and reused among the various populations to realize symbiosis. The degree of symbiosis will determine the different symbiosis models and the equilibrium state of the whole ecosystem.

In the absence of a large amount of empirical research data, numerical and image simulations are the most effective methods to visualize the symbiotic evolution models and trajectories of ecosystems. Based on the above analysis, we use MATLAB 2020b to simulate the five symbiotic models separately.

It is assumed that the natural growth rates of automobile manufacturers, internet enterprises, supporting enterprises, and application groups are 0.2, 0.15, 0.1, and 0.05, respectively [17]. The initial size of all four populations is 100. Under the condition of limited resources, the maximum size that can be reached by the independent development of vehicle manufacturers, internet enterprises, supporting enterprises, and application groups is 1000. The evolutionary cycle is 500. The symbiosis degree is mainly set according to the model conditions and the equilibrium point shown in Table 2.

(1) Independent symbiosis. The symbiosis degree of four subjects—vehicle manufacturers, internet enterprises, supporting enterprises, and application groups—is 0. Four populations develop independently without influencing each other. The development rate of each population is only related to its own natural growth rate. When the four populations reach the equilibrium state, the scale of each population reaches the maximum. The independent symbiosis model is an ideal model that does not exist in reality. The symbiosis degree and simulation results are shown in Table 3 and Figure 3, respectively.

(2) Competitive symbiosis. Competitive symbiosis includes equal competition and vicious competition. The results of the two symbiosis models are opposite.

When the symbiosis degree \( \varphi \) satisfies \( 0 < \varphi < 1 \), it is equal competition (Table 4). The equal competition model means that the development of a population is influenced not only by its own growth rate but also by other populations. Since there is resource competition among populations, the development of each population does not reach the maximum size. Among them, the growth of the vehicle manufacturer and the internet enterprise has experienced the process from rising to falling and finally not reaching the upper limit of scale. It is shown in Figure 4.

Table 3. The symbiosis degree of the independent symbiosis model.

<table>
<thead>
<tr>
<th>Symbiosis Model</th>
<th>Symbiosis Degree ( \varphi_{ab} ) ((a, b \in {1, 2, 3, 4}, a \neq b))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent symbiosis model</td>
<td>( \varphi_{12} = 0; \varphi_{13} = 0; \varphi_{14} = 0; )</td>
</tr>
<tr>
<td></td>
<td>( \varphi_{21} = 0; \varphi_{23} = 0; \varphi_{24} = 0; )</td>
</tr>
<tr>
<td></td>
<td>( \varphi_{31} = 0; \varphi_{32} = 0; \varphi_{34} = 0; )</td>
</tr>
<tr>
<td></td>
<td>( \varphi_{41} = 0; \varphi_{42} = 0; \varphi_{43} = 0; )</td>
</tr>
</tbody>
</table>
Figure 3. Evolution process of independent symbiosis model.

Table 4. The symbiosis degree of the equal competition symbiosis model.

<table>
<thead>
<tr>
<th>Competitive Symbiosis Model</th>
<th>Symbiosis Degree $\varphi_{ab}$ ($a, b \in {1, 2, 3, 4}, a \neq b$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal competition symbiosis model</td>
<td>$\varphi_{12} = 0.25; \varphi_{13} = 0.1; \varphi_{14} = 0.2$; $\varphi_{21} = 0.1; \varphi_{23} = 0.2; \varphi_{24} = 0.1$; $\varphi_{31} = 0.05; \varphi_{32} = 0.1; \varphi_{34} = 0.05$; $\varphi_{41} = 0.05; \varphi_{42} = 0.1; \varphi_{43} = 0.1$;</td>
</tr>
</tbody>
</table>

Figure 4. Evolution process of equal competition symbiosis.
The vicious competition is required to satisfy the symbiosis degree $\phi > 1$ (Table 5). It includes three types. One is that the supporting enterprise is consumed by the other three populations with a large number of innovative resources. Moreover, it declines and eventually tends to disappear after a short upward development. In contrast, the remaining three populations survive in the competition. The final scale is close to the upper limit of independent development, as shown in Figure 5a. The second type is that the supporting enterprise and the vehicle manufacturer are consumed by the resources of the remaining two populations. Eventually, the supporting enterprise and the internet enterprise tend to die out. The other two populations survive in the competition and eventually approach the size with a maximum of 1000. The evolutionary scale is shown in Figure 5b. The third type is that only the application group survives in the competition. The last three populations grow briefly in competition, then decline and eventually die out. At this time, the application group will eventually reach the upper limit of the population size (see Figure 5c).

Table 5. The symbiosis degree of the vicious competition symbiosis model.

<table>
<thead>
<tr>
<th>Vicious Competition Symbiosis Model</th>
<th>Symbiosis Degree $\phi_{ab} \ (a, b \in {1, 2, 3, 4}, a \neq b)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>The supporting enterprise is consumed by the other three populations with a large number of innovative resources.</td>
<td>$\phi_{12} = 0.25; \phi_{13} = 0.1; \phi_{14} = 0.2; \phi_{21} = 0.1; \phi_{23} = 0.2; \phi_{24} = 0.1; \phi_{31} = 1.25; \phi_{32} = 1.1; \phi_{34} = 1.2; \phi_{41} = 0.05; \phi_{42} = 0.1; \phi_{43} = 0.1;$</td>
</tr>
<tr>
<td>The supporting enterprise and the Internet enterprise are consumed by the resources of the other two populations.</td>
<td>$\phi_{12} = 0.25; \phi_{13} = 0.1; \phi_{14} = 0.2; \phi_{21} = 1.1; \phi_{23} = 0.2; \phi_{24} = 1.05; \phi_{31} = 1.2; \phi_{32} = 0.1; \phi_{34} = 1.25; \phi_{41} = 0.05; \phi_{42} = 0.1; \phi_{43} = 1.01;$</td>
</tr>
<tr>
<td>Only the application group survives in the competition.</td>
<td>$\phi_{12} = 0.25; \phi_{13} = 0.1; \phi_{14} = 1.2; \phi_{21} = 0.1; \phi_{23} = 0.2; \phi_{24} = 1.1; \phi_{31} = 0.05; \phi_{32} = 0.1; \phi_{34} = 1.05; \phi_{41} = 0.05; \phi_{42} = 0.1; \phi_{43} = 0.1;$</td>
</tr>
</tbody>
</table>
Figure 5. Evolution process of vicious competition symbiosis model. (a) The supporting enterprise dies out, and the remaining three survive. (b) The supporting enterprise and the internet enterprise tend to die out. The other two populations survive. (c) The application group survives, and the last three populations die out.

(3) Parasitic symbiosis. Parasitic symbiosis includes three types, and the symbiosis degrees are shown in Table 6. One is that the vehicle manufacturer is parasitic to the internet enterprise, the supporting enterprise, and the application group. It is shown in Figure 6a. At this time, the internet enterprise, the supporting enterprise, and the application group are parasitized by the vehicle manufacturer, and the resources are consumed. The final size of the three parasitized populations does not reach the maximum. Moreover, the
vehicle manufacturer gains due to parasitism. The second type is that the vehicle manufacturer and the internet enterprise are parasitic on the other two populations. This is shown in Figure 6b. In this type, the two parasitic populations do not reach their maximum size because their resources are consumed. The vehicle manufacturer and the internet enterprise gain from parasitism, and eventually, their scale exceeds the scale of independent development. The third type is that the supporting enterprise is parasitized by three other populations. In this case, the growth ceiling of the supporting enterprise decreases and is lower than the maximum size of the independent development. As the beneficiaries of the parasitic relationship, the other three populations break through the upper limit of their own size when they develop independently (see Figure 6c).

**Table 6.** The symbiosis degree of the parasitic symbiosis model.

<table>
<thead>
<tr>
<th>Parasitic Symbiosis Model</th>
<th>Symbiosis Degree $\varphi_{ab} (a, b \in [1, 2, 3, 4], a \neq b)$</th>
</tr>
</thead>
</table>
| The vehicle manufacturer is parasitic to the internet enterprise, the supporting enterprise, and the application group. | $\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2; $  
$\varphi_{21} = 0.1; \varphi_{23} = 0.2; \varphi_{24} = 0.1; $  
$\varphi_{31} = 0.05; \varphi_{32} = 0.1; \varphi_{34} = 0.05; $  
$\varphi_{41} = 0.05; \varphi_{42} = 0.1; \varphi_{43} = 0.1; $ |
| The vehicle manufacturer and the internet enterprise are parasitic on the other two populations. | $\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2; $  
$\varphi_{21} = 0.1; \varphi_{23} = -0.2; \varphi_{24} = -0.1; $  
$\varphi_{31} = 0.05; \varphi_{32} = 0.1; \varphi_{34} = 0.05; $  
$\varphi_{41} = 0.05; \varphi_{42} = 0.1; \varphi_{43} = 0.1; $ |
| The supporting enterprise is parasitized by three other populations. | $\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2; $  
$\varphi_{21} = -0.1; \varphi_{23} = -0.2; \varphi_{24} = -0.1; $  
$\varphi_{31} = 0.05; \varphi_{32} = 0.1; \varphi_{34} = 0.05; $  
$\varphi_{41} = -0.05; \varphi_{42} = -0.1; \varphi_{43} = -0.1; $ |
Figure 6. Evolution process of parasitic symbiosis model. (a) The vehicle manufacturer is parasitic to the internet enterprise, the supporting enterprise, and the application group. (b) The vehicle manufacturer and the internet enterprise are parasitic on the other two populations. (c) The supporting enterprise is parasitized by three other populations.

(4) Partial symbiosis. The specific performance of partial symbiosis mainly includes the following three situations, and the symbiosis degrees are shown in Table 7. One is that the vehicle manufacturer is the beneficiary party in the symbiosis relationship. With the development of the industry, due to the increase in resources, the growth limit of this population breaks through the upper limit of 1000 at the time of independent development. It reaches close to 1600. The other three populations, as unaffected populations, develop normally, and the maximum size does not change. This is shown in Figure 7a. The
second type is that the vehicle manufacturer and the internet enterprise are the beneficiaries of a symbiotic relationship. As the two populations develop, their maximum size exceeds the upper limit of their independent development. The sizes reach to 1700 and 1450, respectively. However, the internet enterprise is still slightly lower than the vehicle manufacturer. The other two populations are not affected. Each of them still develops normally, and the maximum size does not change. The specific evolutionary law is shown in Figure 7b. The third type is that there are three beneficiaries in the smart car digital innovation ecosystem, which are the vehicle manufacturer, the internet enterprise, and the application group. These three populations break the original maximum size of 1000 with their own development, reaching 1750, 1500, and 1300, respectively. Moreover, the supporting enterprises are not affected. It is shown in Figure 7c.

**Table 7.** The symbiosis degree of the partial symbiosis model.

<table>
<thead>
<tr>
<th>Partial Symbiosis Model</th>
<th>Symbiosis Degree $\varphi_{ab} (a, b \in {1, 2, 3, 4}, a \neq b)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>The vehicle manufacturer is the beneficiary.</td>
<td>$\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2;$ $\varphi_{21} = 0; \varphi_{23} = 0; \varphi_{24} = 0;$ $\varphi_{31} = 0; \varphi_{32} = 0; \varphi_{34} = 0;$ $\varphi_{41} = 0; \varphi_{42} = 0; \varphi_{43} = 0;$</td>
</tr>
<tr>
<td>The vehicle manufacturer and the internet enterprise are the beneficiaries.</td>
<td>$\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2;$ $\varphi_{21} = -0.1; \varphi_{23} = -0.2; \varphi_{24} = -0.1;$ $\varphi_{31} = 0; \varphi_{32} = 0; \varphi_{34} = 0;$ $\varphi_{41} = 0; \varphi_{42} = 0; \varphi_{43} = 0;$</td>
</tr>
<tr>
<td>The vehicle manufacturer, the internet enterprise, and the application group are the beneficiaries.</td>
<td>$\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2;$ $\varphi_{21} = -0.1; \varphi_{23} = -0.2; \varphi_{24} = -0.1;$ $\varphi_{31} = 0; \varphi_{32} = 0; \varphi_{34} = 0;$ $\varphi_{41} = -0.05; \varphi_{42} = -0.1; \varphi_{43} = -0.1;$</td>
</tr>
</tbody>
</table>
Figure 7. Evolution process of partial symbiosis model. (a) The vehicle manufacturer is the beneficiary party, and the other three populations are not affected. (b) The vehicle manufacturer and the internet enterprise are the beneficiaries. The other two populations are not affected. (c) The supporting enterprises are not affected, and the other three populations are beneficiaries.

(5) Mutually beneficial symbiosis. Mutually beneficial symbiosis is an optimal evolutionary model for an innovation ecosystem. Various populations interact with each other to achieve mutual benefits and a win-win, thus promoting the system to a higher level of development. Mutually beneficial symbiosis breaks the boundaries of resources and facilitates the flow of resources among different industries to achieve value co-creation. The degree of symbiosis directly influences the extent to which the upper limit of scale can
expand. As the symbiosis degree increases, so does the magnitude of growth in the upper limit of scale. In this model, the degree of symbiosis among various populations is less than 0. It also makes the scale of the final steady state exceed the scale of the population when it develops independently, and finally, the various populations tend to different upper scale limits. The simulation degree and results are shown in Table 8 and Figure 8.

Table 8. The symbiosis degree of the mutually beneficial symbiosis model.

<table>
<thead>
<tr>
<th>Symbiosis Model</th>
<th>Symbiosis Degree $\varphi_{ab}$ ($a, b \in {1, 2, 3, 4}, a \neq b$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutually beneficial symbiosis model</td>
<td>$\varphi_{12} = -0.25; \varphi_{13} = -0.1; \varphi_{14} = -0.2; \varphi_{21} = -0.1; \varphi_{23} = -0.2; \varphi_{24} = -0.1; \varphi_{31} = -0.05; \varphi_{32} = -0.1; \varphi_{34} = -0.05; \varphi_{41} = -0.05; \varphi_{42} = -0.1; \varphi_{43} = -0.1; $</td>
</tr>
</tbody>
</table>

Figure 8. Evolution process of mutually beneficial symbiosis model.

In summary, the smart car digital innovation ecosystem is an adaptive system consisting of dynamic symbiotic evolution between different species. The evolution law and trajectory mainly depend on the symbiosis degree among the population, that is, the symbiotic relationship. Different symbiotic relationships form different evolutionary models. Mutually beneficial symbiosis is the optimal evolution direction of the digital innovation ecosystem for smart cars.

5. Case Study Analysis

Case study analysis can sufficiently supply the results of the computer simulation and make the research more practical. In this study, a company named Chang’an Automobile Company (Chang’an) which is located in Beijing, is taken as a typical case for explanatory analysis. An intelligent car includes multiple aspects, such as intelligent driving, intelligent network connection, and intelligent interaction. Chang’an has mastered a large number of intelligent technologies in the above three aspects. In the field of intelligent driving, the company has created several industries ‘firsts’: the first Chinese company to achieve a long-distance test of 2000 km driverless; the first Chinese company to achieve APA6.0 high-level automatic parking function; the first Chinese company to achieve mass production of IACC, the core technology of automatic driving; the first Chinese company...
to have both Chinese and American licenses to test intelligent vehicles on the road. Chang’an is the undisputed pioneer and leader in several segments of intelligent driving. Therefore, this study is representative and convincing in using this company to verify the symbiotic evolution of the smart car digital innovation ecosystem.

1. The symbiotic role of the smart car digital innovation ecosystem of the company

The essence of the smart car digital innovation ecosystem is to introduce internet enterprises based on the development of traditional automobiles and optimize the application clusters to realize the mutual coupling of populations. The development of the ecosystem depends on the symbiotic relationship between populations. Chang’an is committed to creating a “new car, new ecology” to satisfy the needs of the market and customers. The company is building a new platform-based industrial model to achieve co-creation and win-win with users and partners. The company not only focuses on innovative applications and digital connectivity in all scenes but also creates a unique digital ecology. The ecology mainly includes Chang’an, internet enterprises, supporting enterprises, and application groups. First, internet companies such as Huawei and Contemporary Amperex Technology Company (CATL) provide cutting-edge information and communication technology and new energy advanced control technology. Chang’an provides advanced technology application scenarios and carriers. The product of the company provides users with a more intelligent way of travel, which is supported by three areas of technology (intelligent driving, intelligent network connection, and intelligent interaction). Second, the company builds a user-centered manufacturing system that is intelligent, agile, and collaborative. This also realizes the interaction and integration between Chang’an and the application groups. Finally, the government or financial institutions provide services. The government helps the development of the smart car industry through various resources such as policies, talent, and markets. China has been issuing relevant policies on smart cars since 2020, such as the “Smart Networked Vehicle Technology Roadmap 2.0” in 2020 and the “Opinions on Strengthening the Management of Smart Networked Vehicle Manufacturing Enterprises and Product Access” in 2021. These policies also provide an excellent symbiotic environment for the development of populations within the ecosystem. Financial institutions provide financial services through financing and other means.

2. Mutual symbiotic evolution model of smart cars digital innovation ecosystem

Various clusters in this ecosystem realize the iterative innovation of smart cars through resource integration and allocation. Moreover, the value is shared and distributed among various clusters. This reflects a mutually beneficial symbiotic evolution model. In 2019, Chang’an signed a cooperation agreement with Huawei. In the same year, Chang’an launched a new model. The model enables drivers to control the vehicle remotely from inside the car through the one-touch parking system. The drivers could also access five core functions from outside the car via a mobile app: automatic entry, automatic route planning, automatic space search, automatic parking, and automatic exit from the parking. During the whole process, the driver is not involved in the operation of the real L5 level for a fully automatic parking function. In 2022, Chang’an, Huawei, and CATL, the three companies as the industry leaders, are at the head of the industry chain. They use their complementary strengths to achieve the effect of 1 + 1 + 1 > 3. Chang’an provides the advanced mechanical architecture of the vehicle. Huawei provides a thermal management system, electric drive, charging, etc. Moreover, CATL provides the battery pack. The Intelligent Guidance System created by Huawei stands as one of the foremost products in China’s current lineup of intelligent cockpits and advanced driving technologies. Chang’an is also working with its partners to develop new concept cars. In addition, Chang’an and Huawei established an innovation center. This center conducts in-depth research around advanced technology application scenarios and carriers provided by Chang’an based on Huawei’s advanced information and communication technology and new energy advanced control technology. They cooperate to create an intelligent, networked, electric, and shared innovation R&D platform. The platform provides
opportunities for symbiotic populations to exchange and learn information and enhances trust between populations. As we can see above, the smart cars of Chang’an continue to be introduced without the various populations in the ecosystem, including technical support from internet companies, timely feedback from application groups, and policy support from the government. In fact, not only the three populations, such as internet enterprises, application groups, and supporting populations, promote the development of Chang’an, but also the development of Chang’an promotes the development of these three populations in turn. Internet companies could land technology and resources to specific cars in order to achieve continuous optimization of technology. For example, through the collection of data, Huawei could constantly improve the core algorithm and accurately identify user needs. This also drives the continuous development of Huawei’s R&D technology and the improvement of its own value. Due to the emergence of smart cars, it has brought more convenience to the application group. The government and other supporting enterprises will also realize the continuous creation of their own economy and value with the continuous development of Chang’an intelligent vehicles. This is a mutually beneficial symbiotic process. It will eventually evolve into a sustainable digital ecosystem.

6. Conclusions

Based on the ecosystem theory and symbiosis theory, this study explores the evolutionary symbiosis model of smart car digital innovation. Since the digital innovation ecosystem is dynamic, this study proposes a dynamic symbiotic evolution model for the smart car digital innovation ecosystem based on the Lotka–Volterra model. By solving the quadratic symbiotic evolution equation, the equilibrium and balance points of the system evolution are determined, simulated, and analyzed using MATLAB.

According to the research results, the following conclusion can be given.

(1) In the digital innovation ecosystem of smart cars, there are primarily four populations, namely vehicle manufacturers, internet enterprises, supporting enterprises, and application groups. The symbiosis evolutionary outcomes of these populations depend on the symbiotic relationships, quantified as symbiotic coefficients, among them.

(2) The symbiosis of the digital innovation ecosystem in intelligent automobiles exhibits complex behaviors and trajectories. Under the influence of different symbiotic coefficients, the maximum population size and growth rate of each population continuously change. Based on varying symbiotic coefficients, we categorize the system into five symbiosis models, namely independent symbiosis, competitive symbiosis, parasitic symbiosis, partial symbiosis, and mutually beneficial symbiosis. Among them, the mutually beneficial symbiosis model represents the optimal evolutionary choice for the system. This model embodies the most efficient allocation of resources. In this symbiosis mode, populations interact and promote each other, and their development scale exceeds the maximum scale that can be achieved by independent growth. The digital innovation ecosystem of smart cars is an adaptive system that includes not only populations but also an external environment. Within the entire system, the benefit of a single population is detrimental to the sustainable development of the industry. Chen [9] and Zhang Xiaonan [38] have indicated that in advanced manufacturing and strategic emerging industries, the mutually beneficial symbiosis model represents the optimal symbiosis model of the innovation ecosystem. By specifically selecting the industry of smart cars, we have affirmed that the mutually beneficial symbiosis is the premier choice for the innovation ecosystem. Under this mode, various populations leverage their own strengths. This not only reduces the internal technological barriers of the system but also ensures the continuous flow of resources within the system. The effective integration of the knowledge chain and the industry chain will facilitate value co-creation and sustainable development.
(3) Based on the case study analysis of Chang’an Automobile Company in China, we summarize the evolutionary symbiosis model of the digital innovation ecosystem for smart cars. First, vehicle manufacturers are the main populations within the system. With the vehicle manufacturer as the core, other populations are attracted to join the ecosystem. Secondly, unlike traditional automobiles, the species of the smart car digital innovation ecosystem includes not only supporting enterprises but also internet enterprises and application groups. Internet companies accelerate the development of smart cars by introducing digital technologies. The addition of application groups can even give feedback to various clusters at the end of the industry chain. This will accelerate the redistribution of resources. Ultimately, the mutually beneficial symbiosis is the optimal evolutionary model for this system. The interactions between populations and the mutual promotion of each other will enable the groups to gain more value within the ecosystem. This will also enable smart cars to be sustainable by constantly pushing the boundaries.

Based on the above findings, this study considers that the following aspects can also be investigated: first, this study is a validation analysis of the digital simulation in conjunction with a case study. When data are available, it is recommended to conduct empirical research on simulations with the help of a large amount of data. Secondly, the internal relationship between various species should be explored. Showing the evolutionary trend of the system more graphically by mapping the network is the next step of the research that should be carried out. Third, the development of the smart car digital innovation ecosystem will also encounter many risks, such as the international situation, economic development, and policy making. The smart car will also suffer from occasional system failures or government prohibitions against autonomous driving, etc. Therefore, it is worthwhile to analyze the risks of smart car digital innovation and how to deal with them in the next step.

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Appendix A

Since the value of the equilibrium point is long, Equilibrium points $Q_{12}$ to $Q_{16}$ are shown as below.

Table A1. The Equilibrium Points from $Q_{12}$ to $Q_{16}$

<table>
<thead>
<tr>
<th>$Q_i (i = 12, 13, 14, 15, 16)$</th>
<th>Equilibrium Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{12}(0, E, F, G)$</td>
<td>$E = \frac{N_2(\varphi_{23} + \varphi_{24} - \varphi_{23}\varphi_{34} - \varphi_{24}\varphi_{43} + \varphi_{34}\varphi_{43} - 1)}{\varphi_{23}\varphi_{32} + \varphi_{24}\varphi_{42} + \varphi_{34}\varphi_{43} - \varphi_{23}\varphi_{34}\varphi_{42} - \varphi_{24}\varphi_{32}\varphi_{43} - 1}$</td>
</tr>
<tr>
<td>$F = \frac{N_3(\varphi_{32} + \varphi_{34} - \varphi_{24}\varphi_{32} + \varphi_{24}\varphi_{42} - \varphi_{34}\varphi_{42} - 1)}{\varphi_{23}\varphi_{32} + \varphi_{24}\varphi_{42} + \varphi_{34}\varphi_{43} - \varphi_{23}\varphi_{34}\varphi_{42} - \varphi_{24}\varphi_{32}\varphi_{43} - 1}$</td>
<td></td>
</tr>
<tr>
<td>$G = \frac{N_4(\varphi_{42} + \varphi_{43} - \varphi_{24}\varphi_{32} - \varphi_{23}\varphi_{32} - \varphi_{23}\varphi_{43} - 1)}{\varphi_{23}\varphi_{32} + \varphi_{24}\varphi_{42} + \varphi_{34}\varphi_{43} - \varphi_{23}\varphi_{34}\varphi_{42} - \varphi_{24}\varphi_{32}\varphi_{43} - 1}$</td>
<td></td>
</tr>
</tbody>
</table>
References


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