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Research Article

Symbiosis Evolution of E-commerce Platform Ecosystem with Cooperative and Competitive Effect: An Extended Population Density Logistic Model-Based Simulation

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With the development of the Internet, traditional platforms have been challenged by competition from participants on the platform. However, it is unclear how these two types of population, which are in competition but also mutually dependent, can co-exist in the new platform ecosystem. This paper sheds light on that key phenomenon by extending the population density logistic model of the e-commerce platform ecosystem between participants and platforms based on the symbiosis theory. By solving the logistic equation, we acquire the evolutionary trajectory and final size of populations under different symbiotic patterns. The results reveal that the cooperative and competitive effect determines the equilibrium outcome of the symbiosis evolution of e-commerce platform ecosystem. In the asymmetric symbiosis mode, only one population is influenced by positive synergy that increases population density and promote evolution. The contribution coefficient of subordinate to the dominant is greater than the feedback coefficient from the dominant; the trends of output value are inconsistent. The symmetric symbiosis mode is the optimal model for participants and platforms. The effect "$1 + 1 > 2$" can only be achieved under the symmetric symbiosis mode, and the growth of the participants and the platforms is more stable and sufficient than that in other modes. The findings will provide additional perspectives to promote the sustainable development of e-commerce platform ecosystem considering the cooperative and competitive effect.

1. Introduction

Business models are increasingly platform-based, which allow different parties to participate in order to promote leveraged growth. Their relevance has become more important with the formation of platform ecosystems. A platform ecosystem can be defined as a network where platform owners encourage other participants to develop complementary services, resulting in a network of companies that exhibit significant interdependence [1]. Platform-based businesses, such as social networks, e-commerce marketplaces, and search engines, have become an inaccessible part of modern business. With the popularity of emerging business models, traditional business models are challenged by competition from platforms [2]. Amazon and JD.com have established the platform ecosystems with themselves as the transaction center, attracting participants that include users, suppliers, demand enterprises, financial institutions, and logistics companies [3]. In a platform ecosystem, cooperative ventures can not only overcome resource limitation but also realize business collaboration [4, 5]. However, unlike the traditional business model, platform ecosystems are complex networks of interdependent actors that benefit from network effects based on cooperation and competition between companies [6]. The spontaneous cooperation and competition between platform and participants are the drivers of the evolution of the platform ecosystem; it is impossible to maintain sustainable and stable development only by maximizing the equity of platform owners.

Although there is already research on platform ecosystems in information systems research [7, 8] and strategic management research [9, 10], we lack a clear understanding of different symbiotic models among stakeholders in the population evolution process, which hindered the sustainable and stable development of e-commerce platform ecosystems. This gap due to the current research on economic management mainly adopts the symbiotic theory to study the symbiotic relationship between enterprises and industries. Research involves enterprises' cluster symbiosis [11, 12], symbiotic cooperation between different industries [13], and the symbiotic model of innovative systems [14]. However, there is a lack of literature on the symbiotic relationship of e-commerce platform ecosystem using symbiotic theory. The value sharing and evolution between different populations are similar to symbiosis in biology. Although the symbiotic relationship in the e-commerce platform ecosystems is more complicated, it is mainly characterized by the non-linearity and disorder of the interaction between symbiotic populations [15]. The identification of symbiotic models plays a crucial role if the e-commerce platform ecosystems pursue sustainable development. Although there is much research on platform ecosystems, it is rare to study platform ecosystems by combining symbiosis theory and evolutionary method.

The logistic growth model is widely used to depict the evolutionary trajectory of agents in symbiotic relationships, which has good data fit and prediction performance. Assumma et al. [16] discussed how to use the logistic model to assess the regional economy. Ditzen [17] studied the convergence of the logistic model and described the evolution of the entrepreneurial ecosystem based on the extended logistic model. The symbiotic structure, cooperative effect, and competitive effect of e-commerce platform ecosystems are not considered in the traditional logistic growth model. In this paper, the output value of platforms and participants is used as the index of population density. An adjusted population density logistic model is proposed to compensate for the deficiencies of the existing methods. On one hand, the symbiotic model is divided according to different symbiotic structures, which are reflected in the model. On the other hand, we introduce the influence coefficient and contribution coefficient to represent the cooperative effect and the competitive effect in different stages, analyze the stability conditions of each stage, and demonstrate the evolution path. In the evolution of e-commerce platform ecosystems, we introduce the population density, symbiotic structure, and the size of cooperative and competitive effect under different symbiotic modes.

In sum, there are some studies about the evolution of e-commerce platform ecosystems and the application of the logistic growth model. The literature shows existing research concern on the symbiosis between enterprises or industries. We expect to ensure compatibility between e-commerce platforms and participants in population changes, increasing the vitality of individuals to participate in e-commerce platform ecosystems. From a symbiosis theory of view, platforms and participants are two symbiotic units in the e-commerce platform ecosystems, which forms symbiosis relationship, and the change of the population size of one party will inevitably affect the population size of the other party from the perspective of ecology. In this paper, we discuss the population symbiosis between platforms and participants from an ecological perspective. Additionally, we extend the population density logistic model between e-commerce platforms and participants, and investigate the symbiosis evolution between them considering the cooperative effect and competitive effect, to supplement the research on evolution of e-commerce platform ecosystems for sustainable development.

This paper aims to study the symbiotic relationships, evolutionary modes, and dynamic process to obtain the evolutionary dynamic mechanism of the platform ecosystem and provide corresponding suggestions. We study the platform ecosystems by combining symbiosis theory and evolutionary method. The competition and cooperation between platforms and participants is the driving force of platform ecosystem evolution. An adjusted population density logistic model is proposed to consider the population density, symbiotic structure, cooperative effect, and competitive effect under different symbiotic modes. Stability of symbiotic modes in different stages is analyzed to grasp the features and dynamic changes of the e-commerce platform ecosystem. Finally, we propose the evolutionary dynamic mechanism to present the evolution process. The main contribution is shown as follows:

(i) From the perspective of ecology, this paper creatively uses symbiosis theory to study the constitution and characteristics of e-commerce platform ecosystem and analyzes the symbiosis phases of e-commerce platform ecosystem.

(ii) An extended logistic model combining the new agglomeration of symbiotic effects is proposed. The influence coefficient and contribution coefficient are introduced to reflect the cooperative effect and competitive effect in different stages. The results show that the adjusted model has higher efficiency and stability in identifying the symbiotic mode of e-commerce platform ecosystem.

(iii) A novel evolutionary dynamic mechanism is developed to describe the changes in cooperative and competitive effect over time between participants and platforms during the formation of e-commerce platform ecosystem. The evolutionary dynamic mechanism contributes to intuitively identify the important drivers among stakeholder of the platform ecosystem.

The remainder of this paper is organized as follows. First, we review the literature on the evolution of platform ecosystem based on the symbiotic theory. The extended logistic model and its calculation process are presented in Section 3. Section 4 provides a simulation of the evolution mode of e-commerce platform ecosystem. A discussion of the results and the evolutionary dynamic mechanism is presented in Section 5. Section 6 provides the main conclusion and future research direction.

2. Literature Review

To highlight the correlation between the literature and our study, we briefly review the literature from two perspectives:

academic research associated with symbiosis theory and the application of the population density logistic model in the e-commerce platform ecosystem.

2.1. Scholarly Works on Symbiosis Theory. The symbiosis theory is used mainly to represent the symbiotic relationship between populations and the environment resource in a certain mode [18, 19]. Zhang [20] applied symbiosis theory to the study of small economy in China from the perspective of social economics [21]. The application scope of symbiosis theory continues to expand, which has a significant meaning in the study of industrial convergence methods. Ehrenfeld and Gertler [22] first introduced the symbiosis theory into industrial ecology research. They proposed the concept of industrial symbiosis and analyzed the types of mode. Chopra and Khanna [23] analyzed the elastic characteristics of the industrial symbiotic network by case study and verified the key factors affecting industrial symbiosis. Zhao et al. [24] divided industrial symbiosis modes into autonomous mode, interactive mode, integrated mode, and loose mode on the basis of diversification and close cooperation.

Although some scholars have studied the industrial symbiosis mode, the evolution of industrial symbiosis models has received more and more attention in recent years. Zhang et al. [25] established a symbiosis model for the service industry and the manufacturing industry based on the symbiosis theory and discussed the effect of symbiosis on the environmental capacity. Spina and Compaó [26] used the mobile phone ecosystem in South Korea as an example to reveal the symbiotic evolution between the service and manufacturing industries. Chen [27] fitted the revenue curves of four different types of bio-energy and analyzed the formation rules of the curves based on symbiosis theory. Anvari et al. [28] applied the symbiosis theory and the theory of industrial clusters to construct a knowledge network symbiotic evolution model and analyzed the evolution rules of knowledge networks from low to high level by empirical research. Although symbiosis theory has been used in many fields, its successful application in the evaluation of the e-commerce platform ecosystem is rare. Therefore, different from previous studies, we will introduce the symbiosis theory into the symbiotic relationships of e-commerce platform ecosystems. It is well known that symbiotic relationships are crucial in identifying the evaluation of e-commerce platform ecosystem.

2.2. The Application of the Population Density Logistic Model. The logistic growth model is used to depict the evolutionary trajectory of the populations over time [29]. The e-commerce platform ecosystem is a complex system composed of different individuals gathered on a certain type of e-commerce platform [30]. The e-commerce platform ecosystems have experienced a continuous evolution process from creation, expansion, and maintenance to decline [31]. The difference between the e-commerce platform ecosystem and the natural ecological ecosystem is reflected in changes of the relationship between dominant and subordinate. The relationship is predation in the natural ecological chain. Energy is a one-way flow from dominant to subordinate [32]. However, there is no traditional predation relationship between platforms and participants in the e-commerce platform ecosystem; the one-way flow has been transformed into a two-way symbiosis relationship between the access of platforms to the network effect and the access of participants to value-added services from platforms.

Some scholars have extended the logistic growth model. The traditional logistic growth model takes the profit index as objective function of the equation. Zhu and Wang [33] regarded value-added as the objective function of the company in the logistic model. In the symbiosis relationship of the logistic growth model, the population density is represented by the characteristics of symbiotic subject [34]. Some scholars [35] took Gross Domestic Product (GDP) as the population density of industry. Ji et al. [36] divided the symbiotic modes of industry-university research into 15 categories based on the extended logistic model. Simultaneously, some scholars have focused on the stable conditions and evolution rules of symbiosis. Liu and Wei [37] described the conditions and stability of symbiosis in satellite mode by extending the logistic model. Zhang et al. [38] established a logistic equation to describe the interaction among companies and obtained the stable conditions of the symbiosis modes. Xie and Zhu [39] analyzed the balance conditions of enterprises from competition to cooperation and then to symbiosis based on the logistic equation. Wang et al. [40] measured the evolution trajectory of the manufacturing enterprise clusters using a logistic symbiotic model and determined the evolution stages of enterprise clusters. Gang et al. [41] studied the multi-agent symbiosis modes of the Swarm platform through the extended logistic model.

As mentioned before, on the one hand, the above literature mainly focused on the symbiosis between enterprises or industries. The application of the symbiosis theory to the evolution of the platform ecosystem is rare. Meanwhile, there is a two-way symbiosis relationship between the platforms and the participants. The two populations of the platform ecosystem have certain competition but also mutual dependence. Therefore, we need to extend the population density logistic model to explore internal mechanisms. Consequently, it is feasible to apply symbiosis theory to the evolutionary mechanism research of platform ecosystems. The adjusted logistic model is used to describe the path diagram that affects the evolution of the platform ecosystem. Based on the competitive effect and cooperative effect at different stages, the stability conditions of the system are analyzed by adjusting the influence coefficient and contribution coefficient of the output value in the model, and the evolutionary dynamic mechanism of the platform ecosystem is proposed. The existing literature that can illustrate the contribution of the article is summarized in Table 1.

3. Research Methodology

In this section, the population density logistic model with competition effect and cooperation effect is developed. In addition, according to the competitive effect and the cooperative effect in different stages, the system stability conditions in each stage are discussed.

Table 1: Summary of the existing literature.

Papers	Methodology	Basic theories	Multiple phases	Cooperative effect	Competitive effect
Wang and Zheng-Xin [42]	Lotka–Volterra competition model	Grey prediction theory		√	
Zhu et al. [43]	Piecewise logistic model	Ecosystem theory	√		
Liu and Yuan [44]	Industrial cluster transfer evolution model	Stakeholder theory	√	√	
Li and Shi [45]	Two-dimensional logistic model	Network structure theory	√		
Our work	The extended population density logistic model	Symbiosis theory	√	√	√

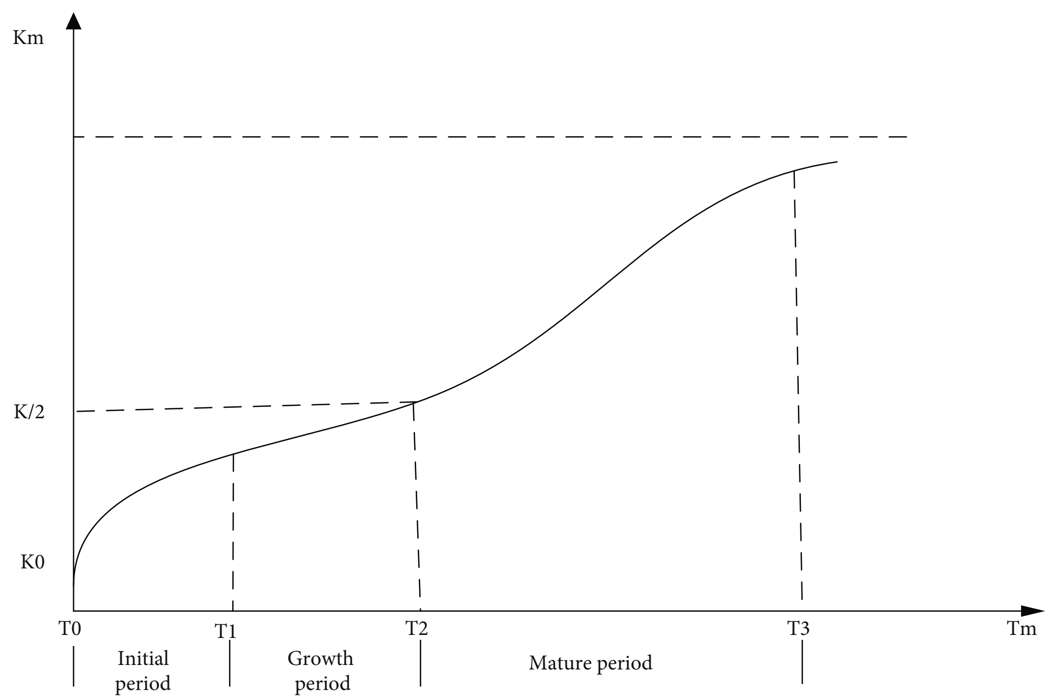

Figure 1: Logistic growth curve and the divisions of each stage.

3.1. Population Density Logistic Model. A logistic model is used to depict the evolutionary trajectory of populations in the symbiotic relationship, which is widely applied in the biological field. Nowadays, it has expanded to other fields, such as industry cluster evolution, enterprise strategic alliances, and so on. It means that the growth of subjects is affected not only by their own rules but also by the external environment and resource capacity [46]. From the perspective of ecology, the growth of populations is as follows: the population size generally follows the growth law of the Malthusian model in a short period and increases exponentially. The effects of population size and density increase over time, which presents the logistic growth curve. Then, the growth rate of population size slows down and gradually reaches saturation. The logistic equation is described as follows.

$$\frac{\mathrm{d}N(t)}{\mathrm{d}t} = rN(t)\left(1 - \frac{N(t)}{K}\right). \tag{1}$$

In equation (1), r is the growth rate of the subject in the natural state, and $N(t)$ is the actual output value of the subject. K represents the maximum output value of the subject under the resource restriction of the market. $1 - N(t)/K$ denotes the retardation effect, and the individual growth rate $\mathrm{d}N(t)/\mathrm{d}t$ increases from small to large, reaches a maximum at $K/2$, and then decreases, showing the general law of cooperation evolution. It can be observed from equation (1), the two equilibrium points are (0, 0), and (k, $+\infty$) can be obtained when $\mathrm{d}N(t)/\mathrm{d}t = 0$. From the perspective of the second derivative of $N(t)$, when $N < K/2$, then $\mathrm{d}^2N(t)/\mathrm{d}t^2 > 0$, the size of population increases rapidly as r increases; conversely, when $N(t) > K/2$, the growth rate of population size slows down. Therefore, logistic model contains three stages: initial stage, growth stage, and maturity stage. The growth curve is shown in Figure 1.

3.2. Model Construction. The symbiosis relationship among platform is similar to the population symbiosis in the

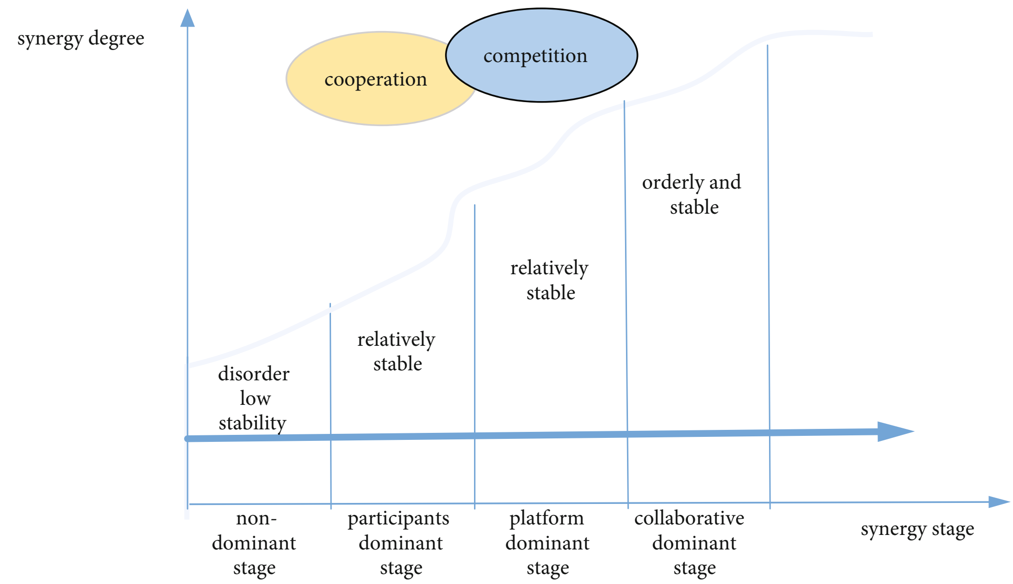

Figure 2: The stages of the platform ecosystem.

ecosystem. The platforms provide the resource to the participants, and the participants create and share the value by implementing various businesses in the platform ecosystem. Competition and cooperation between platforms and other participants are the intrinsic motivation of evolution [47]. According to the different competitive effects and cooperative effects, it can be divided into four stages: non-dominant, participant dominant, platform dominant, and collaborative dominant [48, 49]. As shown in Figure 2.

To establish a population density logistic model of the e-commerce platform ecosystem, the related assumptions are given as follows.

Hypothesis 1. The e-commerce platforms and participants coexist in the e-commerce platform ecosystem. The population of e-commerce platforms and participants are competitive and dependent on the ecosystem.

Hypothesis 2. Changes in the size of e-commerce platforms and participants of the ecosystem represent their growth. The positive change in the population size indicates the size of the output value in the e-commerce platform ecosystem. The higher the value output, the greater the benefits in the symbiotic evolution process. When the growth rate is 0, it means the population is extinct.

Hypothesis 3. The evolution of the e-commerce platforms and participants follows the law of logistic growth. Limited by environmental resources, the population growth rate will gradually decrease with increasing of population density when each participant grows separately.

Hypothesis 4. When the marginal output of the e-commerce platforms and participants is equal to the marginal input, the scale of population reaches its maximum size.

Based on the above assumptions and equation (1), we select two key populations, e-commerce platforms and participants, to construct the symbiotic model. We assume that the output value is a function of time t. $N_e(t)$ represents the output value of the platform participant cluster, and $N_p(t)$ represents the output value of the e-commerce platform. In the process, the influence of competition on output value is called the competitive effect, where A_1 is the influence coefficient of the platform on the output value of the platform participants and A_2 is the influence coefficient of the platform participants on the output value of the platform. The contribution of output value is cooperative effect, where B_1 represents the contribution coefficient of the platform to the output value of platform participants, and B_2 represents the contribution coefficient of platform participants to the output value of the platform. r_e and r_p are the natural growth rates of the platform participants and platforms, respectively. They are set as constants because of their industry characteristics. K represents the optimal output that the subject can achieve in an optimal state. It is assumed that the maximum output value of platform participants is K_e and the maximum output value of the platform is K_p. The influence and contribution coefficient of the value output are introduced based on the characteristics of the symbiotic phases. The extended logistic model is shown as follows.

$$\begin{cases} \dfrac{dN_e(t)}{dt} = r_e N_e(t)\left(\pm 1 - \dfrac{N_e(t)}{K_e} - A_1 \dfrac{N_p(t)}{K_e} + B_1 \dfrac{N_p(t)}{K_p}\right) \\ \dfrac{dN_p(t)}{dt} = r_p N_p(t)\left(\pm 1 - \dfrac{N_p(t)}{K_p} - A_2 \dfrac{N_e(t)}{K_p} + B_2 \dfrac{N_e(t)}{K_e}\right) \end{cases}. \tag{2}$$

In equation (2), it can be seen that the influence coefficient and the contribution coefficient are introduced to

Table 2: Classification of symbiosis modes among the e-commerce platform ecosystem.

Phase	Symbiotic coefficient	Symbiosis model	Characteristics
1	(1, 1), $A_1 = A_2 = 0$, $B_1 > 0$, $B_2 > 0$	Independent symbiosis	There is no symbiotic relationship between platforms and participants. They develop independently.
2	(1, −1), $A_1 = A_2 = 0$, $B_1 > 0$, $B_2 > 0$	Asymmetric reciprocal symbiosis (platform participants dominant)	The growth of the platform drives the growth of participants, and platform participants are dominant.
3	(−1, 1), $A_1 = A_2 = 0$, $B_1 > 0$, $B_2 > 0$	Asymmetric reciprocal symbiosis (platform dominant)	The growth of the participants drives the growth of platform, and the platforms are dominant.
4	(1, 1), $A_1 > 0, A_2 > 0$ $B_1 > 0$, $B_2 > 0$	Symmetric reciprocal symbiosis	The growth of one side drives the growth of the other side, and the driving effect is symmetric.

reflect the competitive effect and the cooperative effect, which affect the population growth rate. Based on the value of the influence coefficient and the contribution coefficient, we divided the evolution of the platform ecosystem into four modes based on the Li Hongbo's classification method [45]. The corresponding value of the different modes of symbiosis is listed in Table 2.

In phase 1, when (1, 1) and $A = 0, B > 0$, the e-commerce platforms and participants develop independently. In management practice, it is rare for e-commerce platforms and participants to develop independently. There is less cooperation between the platform and the participants, which can be described by equation (3):

$$\begin{cases} \phi_1(N_e(t), t) = \dfrac{dN_e(t)}{dt} = r_e N_e(t)\left(1 - \dfrac{N_e(t)}{K_e} + B_1 \dfrac{N_p(t)}{K_p}\right) \\ \phi_2(N_p(t), t) = \dfrac{dN_p(t)}{dt} = r_p N_p(t)\left(1 - \dfrac{N_p(t)}{K_p} + B_2 \dfrac{N_e(t)}{K_e}\right) \end{cases}, \quad (3)$$

In phase 2, when (1, −1) and $A = 0, B > 0$, the e-commerce platforms and participants are in an asymmetric symbiosis model. The platform participants are dominant and benefit from the symbiosis. Since the coordinated distribution of the output value is the basis for cooperation between different groups in the ecosystem, the population who cannot benefit from the symbiosis relationship will not allow this model to exist for a long time. This mode can be described by equation (4):

$$\begin{cases} \phi_1(N_e(t), t) = \dfrac{dN_e(t)}{dt} = r_e N_e(t)\left(1 - \dfrac{N_e(t)}{K_e} + B_1 \dfrac{N_p(t)}{K_p}\right) \\ \phi_2(N_p(t), t) = \dfrac{dN_p(t)}{dt} = r_p N_p(t)\left(-1 - \dfrac{N_p(t)}{K_p} + B_2 \dfrac{N_e(t)}{K_e}\right) \end{cases}. \quad (4)$$

In phase 3, when (−1, 1) and $A = 0, B > 0$, the e-commerce platforms and participants are in an asymmetric reciprocal symbiosis model. Platforms are in a dominant position and benefit from symbiotic relationships, the distribution of output value is asymmetrical, that is the platform receives more value than the participants. The unilateral governance model of e-commerce platforms ignores the significance of participants, which resulted in the inconsistent evolution of the e-commerce platform ecosystem. This mode can be described by equation (5):

$$\begin{cases} \phi_1(N_e(t), t) = \dfrac{dN_e(t)}{dt} = r_e N_e(t)\left(-1 - \dfrac{N_e(t)}{K_e} + B_1 \dfrac{N_p(t)}{K_p}\right) \\ \phi_2(N_p(t), t) = \dfrac{dN_p(t)}{dt} = r_p N_p(t)\left(1 - \dfrac{N_p(t)}{K_p} + B_2 \dfrac{N_e(t)}{K_e}\right) \end{cases}. \quad (5)$$

In phase 4, when (1, 1) and $A > 0, B > 0$, the e-commerce platforms and participants are in a symmetric reciprocal symbiosis model. The e-commerce platforms and participants benefit from each other, and the distribution of value is symmetric. The platforms and participants will join in the governance of the ecosystem. This makes cooperation more stable and improves the efficiency of the ecosystem, to achieve the sustainable development for the e-commerce platform ecosystem. This mode can be described by equation (6):

$$\begin{cases} \phi_1(N_e(t), t) = \dfrac{dN_e(t)}{dt} \\ \qquad = r_e N_e(t)\left(1 - \dfrac{N_e(t)}{K_e} - A_1 \dfrac{N_p(t)}{K_e} + B_1 \dfrac{N_p(t)}{K_p}\right) \\ \phi_2(N_p(t), t) = \dfrac{dN_p(t)}{dt} \\ \qquad = r_p N_p(t)\left(1 - \dfrac{N_p(t)}{K_p} - A_2 \dfrac{N_e(t)}{K_p} + B_2 \dfrac{N_e(t)}{K_e}\right) \end{cases}. \quad (6)$$

3.3. Model Analysis. Due to the non-linear characteristics of the population density logistic model, we judge the stability of local equilibrium points according to the Jacobian matrix [50], which is

$$J = \begin{bmatrix} \dfrac{\partial \phi_1}{\partial N_e} & \dfrac{\partial \phi_1}{\partial N_p} \\ \dfrac{\partial \phi_2}{\partial N_e} & \dfrac{\partial \phi_2}{\partial N_p} \end{bmatrix}. \quad (7)$$

Table 3: Analysis of the equilibrium point in the independent stage.

Equilibrium point	Det(J)	Tr(J)	Stability condition
E_1	$-r_e r_p(1+B_2)$	$-r_e + r_p(1+B_2)$	Unstable
E_2	$-r_e r_p(1+B_1)$	$-r_p + r_e(1+B_1)$	Unstable
E_3	$r_e r_p\left(\frac{B_1+1}{1-B_1B_2}\right)(B_2+1)$	$-r_e\left(\frac{B_1+1}{1-B_1B_2}\right) - r_p\left(\frac{B_2+1}{1-B_1B_2}\right)$	$B_1B_2<1$
E_4	$r_e r_p$	$r_e + r_p$	Unstable

If equilibrium points satisfy the condition of $\mathrm{Det}(J) > 0$ and $\mathrm{Tr}(J) < 0$, the equilibrium point is stable. As shown in equations (8) and (9). Therefore, the conditions for the evolution of symbiosis between the e-commerce platforms and the participants are $\mathrm{Det}(J) > 0$ and $\mathrm{Tr}(J) < 0$.

$$\mathrm{Det}(J) = \frac{\partial\phi_1}{\partial N_e} \times \frac{\partial\phi_2}{\partial N_p} - \frac{\partial\phi_1}{\partial N_p} \times \frac{\partial\phi_2}{\partial N_e}, \quad (8)$$

$$\mathrm{Tr}(J) = \frac{\partial\phi_1}{\partial N_e} + \frac{\partial\phi_2}{\partial N_p}. \quad (9)$$

3.3.1. Independent Phase. In the early stage of the e-commerce ecosystem, cooperation between enterprises is mainly based on geographical location. At this stage, the habit of online trading is not fully formed, and the functionality of the platform is not implemented. The e-commerce platforms and participants perform separately. With the increase of e-commerce transactions, there is cooperation between platform participants and platforms, which makes certain contributions to each other's value output, as described by equation (3). Let $\phi_1(N_e(t), t) = 0$ and $\phi_2(N_p(t), t) = 0$, and the equilibrium points of e-commerce platforms and participants are $E_1(K_e, 0)$, $E_2(0, K_p)$, $E_3((K_e(B_1+1)/1-B_1B_2), (K_P(1+B_2)/1-B_1B_2))$, and $E_4(0,0)$. The Jacobian matrix is obtained as follows:

$$J = \begin{bmatrix} \frac{\partial\phi_1}{\partial N_e} & \frac{\partial\phi_1}{\partial N_p} \\ \frac{\partial\phi_2}{\partial N_e} & \frac{\partial\phi_2}{\partial N_p} \end{bmatrix} = \begin{bmatrix} r_e - 2\frac{r_e}{k_e}N_e + B_1\frac{r_e}{k_p}N_P & B_1\frac{r_e}{k_p}N_e \\ B_2\frac{r_P}{k_e}N_p & r_p - 2\frac{r_P}{k_p}N_P + B_2\frac{r_P}{k_e}N_e \end{bmatrix}. \quad (10)$$

According to the method by Friedman and Fung [51], the Det(J) and Tr(J) of the equilibrium point (E_1, E_2, E_3, and E_4) are obtained in Table 3.

At this stage, platform participants are incapable of choosing e-commerce platforms according to their own needs and market trends, and some platform participants hesitate to enter the platforms. At present, the scale of e-commerce platform is small, and the service is not perfect. They do not know exactly what they want from each other, so the partnership is unstable. The disorder leads to the disintegration of the relationship. Many participants flocked to the e-commerce platform to make more money. $B_1B_2 < 1$ indicates that the contribution coefficient to the value output is low between the e-commerce platforms and participants. Partnerships are easily swayed by interests.

3.3.2. Participants' Dominant Phase. With the development of e-commerce, the number of e-commerce platforms is increasing, and the competition is becoming more and fiercer. The platforms attract participants with low entry fees to expand their user base. At this stage, participants have greater autonomy in the choice of platforms [52]. An asymmetric relationship is formed with platform participants dominating. The analysis of the equilibrium point is based on equation (4). Let $\phi_1(N_e(t), t) = 0$ and $\phi_2(N_p(t), t) = 0$, the equilibrium points of e-commerce platforms and participants are $E_1(K_e, 0)$, $E_2(0, -K_p)$, $E_3((K_e(1-B_1)/1-B_1B_2), (K_P(B_2-1)/1-B_1B_2))$, and $E_4(0,0)$. The Jacobian matrix is obtained as follows:

$$J = \begin{bmatrix} \frac{\partial\phi_1}{\partial N_e} & \frac{\partial\phi_1}{\partial N_p} \\ \frac{\partial\phi_2}{\partial N_e} & \frac{\partial\phi_2}{\partial N_p} \end{bmatrix} = \begin{bmatrix} r_e - 2\frac{r_e}{k_e}N_e + B_1\frac{r_e}{k_p}N_P & B_1\frac{r_e}{k_p}N_e \\ B_2\frac{r_P}{k_e}N_P & -r_p - 2\frac{r_P}{k_p}N_P + B_2\frac{r_P}{k_e}N_e \end{bmatrix}. \quad (11)$$

The Det(J) and Tr(J) of the equilibrium point (E_1, E_2, E_3, and E_4) are obtained in Table 4.

In this stage, platforms reduce the entry cost to improve the network effect and occupy market share. However, due to the lower entry barrier, the homogenization of product is serious, and $B_1 > 1$ indicates that the contribution of platforms to the output value of participants is greater. $B_1 > 1$, $B_2 < 1$, $B_1B_2 < 1$ reveals that B_1 is required to be relatively large to achieve the equilibrium state between e-commerce platforms and participants. This means that the platforms depend on the participants at this stage, and the platforms contribute more to the output value of the participants.

3.3.3. Platform Dominant Phase. With the improvement of e-commerce environment, the platforms integrate payment,

Table 4: Analysis of the equilibrium point in the dominant stage of platform participants.

Equilibrium point	Det(J)	Tr(J)	Stability condition
E_1	$r_e r_p(1-B_2)$	$-r_p(1-B_2)-r_e$	$B_2<1$
E_2	$r_e r_p(1-B_1)$	$r_e(1-B_1)+r_p$	Unstable
E_3	$2r_e r_p \frac{(1-B_1B_2)(B_2-1)^2(1-B_1)^2}{(1-B_1B_2)^2}$	$r_e\left(\frac{1-B_1}{1-B_1B_2}\right)+r_p\left(\frac{B_2-1}{1-B_1B_2}\right)$	$B_1>1, B_2<1, B_1B_2<1$
E_4	$-r_e r_p$	r_e-r_p	Unstable

logistics, big data marketing, and consulting service to obtain value-added fees. The platforms have expanded the user scale in the early stages, and users can complete transactions through the platforms skillfully. At this stage, participants' dependence on e-commerce platforms has increased, and the output value of participants will be greatly affected if they leave the e-commerce platform. An asymmetric relationship is formed with e-commerce platforms dominating. Meanwhile, the participants maximize their interests through the services provided by the platforms. Participants have become a major source of revenue for platforms. The stability points are analyzed based on equation (5). Let $\phi_1(N_e(t),t)=0$ and $\phi_2(N_p(t),t)=0$, and the equilibrium points of e-commerce platforms and participants are $E_1(-K_e,0)$, $E_2(0,K_p)$, $E_3((K_e(B_1-1)/1-B_1B_2),(K_P(1-B_2)/1-B_1B_2))$, and $E_4(0,0)$. The Jacobian matrix is obtained as follows:

$$J=\begin{bmatrix}\frac{\partial\phi_1}{\partial N_e} & \frac{\partial\phi_1}{\partial N_p}\\ \frac{\partial\phi_2}{\partial N_e} & \frac{\partial\phi_2}{\partial N_p}\end{bmatrix} = \begin{bmatrix}-r_e-2\frac{r_e}{k_e}N_e+B_1\frac{r_e}{k_p}N_P & B_1\frac{r_e}{k_p}N_e\\ B_2\frac{r_p}{k_e}N_P & r_p-2\frac{r_p}{k_p}N_P+B_2\frac{r_p}{k_e}N_e\end{bmatrix}. \quad (12)$$

The $\mathrm{Det}(J)$ and $\mathrm{Tr}(J)$ of the equilibrium point (E_1, E_2, E_3, and E_4) can be obtained in Table 5.

At this time, the reputation and user base of e-commerce platforms have formed. They want to increase revenue through the network effect. $B_1<1$, $B_2>1$, $B_1B_2<1$ indicates that when the contribution of e-commerce participants to the value output of the platform is greater, participants and e-commerce platforms reach the equilibrium state. Alliances between companies are formed through the accumulation of resources that play an important role in the improvement of the scale and quality of platform. At this stage, participants are more dependent on e-commerce platforms.

3.3.4. Symmetric Reciprocal Symbiosis Phase. With the maturity of e-commerce, the homogenization and credit problem of participants have improved, and their competitiveness has strengthened. The negotiating positions of the participants in the transactions have increased. Platform participants have more options, such as enterprise alliances and self-built platforms, which produce the competitive effect on e-commerce platforms. At this time, the service quality of e-commerce platforms continues to improve, and the impact on the value output of the participants gradually stabilizes. They form a beneficial and symbiotic relationship. The influence of the competition effect A on value output is introduced to the model. The stability points are analyzed based on equation (6). Let $\phi_1(N_e(t),t)=0$ and $\phi_2(N_p(t),t)=0$, and the equilibrium points of symbiosis and evolution of e-commerce platforms and participants are as follows: $E_1(K_e,0)$, $E_2(0,K_p)$, $E_3((K_eK_P(A_1K_p-B_1K_e-K_e)/(A_1K_p-B_1K_e)(A_2K_e-B_2K_p)-K_eK_P), (K_eK_p(A_2K_e-B_2K_p-K_p)/(A_1K_p-B_1K_e)(A_2K_e-B_2K_p)-K_eK_P))$, and $E_4(0,0)$. The Jacobian matrix is obtained as follows:

$$J=\begin{bmatrix}\frac{\partial\phi_1}{\partial N_e} & \frac{\partial\phi_1}{\partial N_p}\\ \frac{\partial\phi_2}{\partial N_e} & \frac{\partial\phi_2}{\partial N_p}\end{bmatrix} = \begin{bmatrix}r_e-2\frac{r_e}{k_e}N_e-\frac{r_e}{k_e}A_1N_P+B_1\frac{r_e}{k_p}N_P & -\frac{r_e}{k_e}A_1N_e+B_1\frac{r_e}{k_p}N_e\\ -\frac{r_p}{k_p}A_2N_P+B_2\frac{r_p}{k_e}N_P & r_p-2\frac{r_p}{k_p}N_P-\frac{r_p}{k_p}A_2N_e+B_2\frac{r_p}{k_e}N_e\end{bmatrix}. \quad (13)$$

The $\mathrm{Det}(J)$ and $\mathrm{Tr}(J)$ of the equilibrium point (E_1, E_2, E_3, and E_4) can be obtained in Table 6.

The group of participants and e-commerce platforms reach the equilibrium state under the condition of $B_2>(K_e/K_p)A_2-1$, $B_1>(K_P/K_e)A_1-1$ and $A_1A_2+B_1B_2<1$. With the convergence of participants, e-commerce platforms strive to occupy more market, information, and other resources. The situation of competition and cooperation is severe. Due to the high cost of self-built logistics and platform operation, many participants still need to rely on e-commerce platforms for transactions. Competition between enterprise clusters and platforms still exists, but cooperation

Table 5: Analysis of the equilibrium point in the platform dominant stage.

Equilibrium point	Det(J)	Tr(J)	Stability condition
E_1	$r_e r_p (1 - B_2)$	$r_p (1 - B_2) + r_e$	Unstable
E_2	$r_e r_p (1 - B_1)$	$-r_e (1 - B_1) - r_p$	$B_1 < 1$
E_3	$2 r_e r_p \frac{(1 - B_1 B_2)(B_2 - 1)^2 (B_1 - 1)^2}{(1 - B_1 B_2)^2}$	$-r_e \left(\frac{1 - B_1}{1 - B_1 B_2} \right) - r_p \left(\frac{B_2 - 1}{1 - B_1 B_2} \right)$	$B_1 < 1,\ B_2 > 1,\ B_1 B_2 < 1$
E_4	$-r_e r_p$	$r_p - r_e$	Unstable

Table 6: Analysis of the equilibrium point in the cooperative dominant stages.

Equilibrium point	Det(J)	Tr(J)	Stability condition
E_1	$-r_e r_p \left(1 - \frac{K_e}{K_p} A_2 + B_2 \right)$	$-r_e + r_p \left(1 - \frac{K_e}{K_p} A_2 + B_2 \right)$	$B_2 < \frac{K_e}{K_p} A_2 - 1$
E_2	$-r_e r_p \left(1 - \frac{K_p}{K_e} A_1 + B_1 \right)$	$-r_p + r_e \left(1 - \frac{K_p}{K_e} A_1 + B_1 \right)$	$B_1 < \frac{K_p}{K_e} A_1 - 1$
E_3	$r_e r_p \frac{\left[(1 - A_1 A_2 - B_1 B_2) K_e K_p + A_1 B_2 K_p{}^2 + A_2 B_1 K_e{}^2 \right]}{\left[\left(A_1 K_p - B_1 K_e \right) \left(A_2 K_e - B_2 K_p \right) - K_e K_p \right]}$ $\frac{\left(B_1 K_e + K_e - A_1 K_p \right) \left(B_2 K_p + K_p - A_2 K_e \right)}{\left[\left(A_1 K_p - B_1 K_e \right) \left(A_2 K_e - B_2 K_p \right) - K_e K_p \right]}$	$-r_e K_p \left(B_1 K_e + K_e - A_1 K_p \right)$ $-r_p K_e \left(B_2 K_p + K_p - A_2 K_e \right)$	$B_2 > \frac{K_e}{K_p} A_2 - 1$ $B_1 > \frac{K_p}{K_e} A_1 - 1$ $A_1 A_2 + B_1 B_2 < 1$
E_4	$r_e r_p$	$r_p + r_e$	Unstable

is strengthened through profit sharing, information sharing, and co-construction of logistics. When the cooperation effect that contributed to the output value exceeds the negative influence caused by the competition effect, a stable state is formed, which helps to maintain the long-term symbiotic relationship.

4. Simulation of the Symbiotic Modes of the Platform Ecosystem

As can be seen from the above analysis, the evolution of the platform ecosystem is a process from disordered to ordered structure. This process is the spontaneous behavior of the system. The original system is in a disorder state. The evolution path is selected to realize the evolution of the platform ecosystem through the competition and cooperation between the participants and the platforms. MATLAB2019a is used to simulate the model results. According to the stability condition, the parameters are initially assigned as $K_p = 9$, $K_e = 7$, $N_e = 1$, $N_p = 3$, and $r_p = r_e = 0.02$, and the simulation results of the participants and the e-commerce platforms in different phases are shown in Figures 3, 4, 5, and 6.

4.1. Independent Symbiotic Mode. The independent symbiotic mode is the initial stage of the platform ecosystem. In this model, the e-commerce platforms and the participants are independent. The cooperative effect is not obvious in the non-dominant stage. When the conditions are met as $B_1 B_2 < 1$, which are proved in the previous section, the two groups are in equilibrium. We assume that $B_1 = B_2 = 0.2$, and the evolution of the independent symbiotic mode is shown in Figure 3. The output value of both sides shows a slow upward trend, and they have the same upward trend when the contribution rate of value output is low. Through the above mathematical analysis, it can be seen that the evolution speed of the system constantly increases in the initial stage. The platform ecosystem relies on resource, technology, and government policy to accumulate user scales. Although the number of participants is gradually increasing, the platform ecosystem is still in the initial stage. There is a low population density in the system, and the structure of the system is not perfect, so there is less competition and cooperation among the platform ecosystem. In the non-dominant stage, the cooperative relationship is unstable due to the lack of trust. At this stage, e-commerce platforms should improve the level of construction to promote the stability of cooperation.

4.2. Asymmetric Symbiosis Mode. In the participants' dominant stage, when the conditions are met $B_1 > 1$, $B_2 < 1$, $B_1 B_2 < 1$, which are proved in the previous section, the two groups are in equilibrium. We assume that $B_1 = 1.2, B_2 = 0.25$, and the evolution of the participants' dominant mode is shown in Figure 4. The output value of the participants increased rapidly, but the trend is inconsistent. Due to the greater contribution of the platform to the participants, the participants developed more rapidly. At this time, the e-

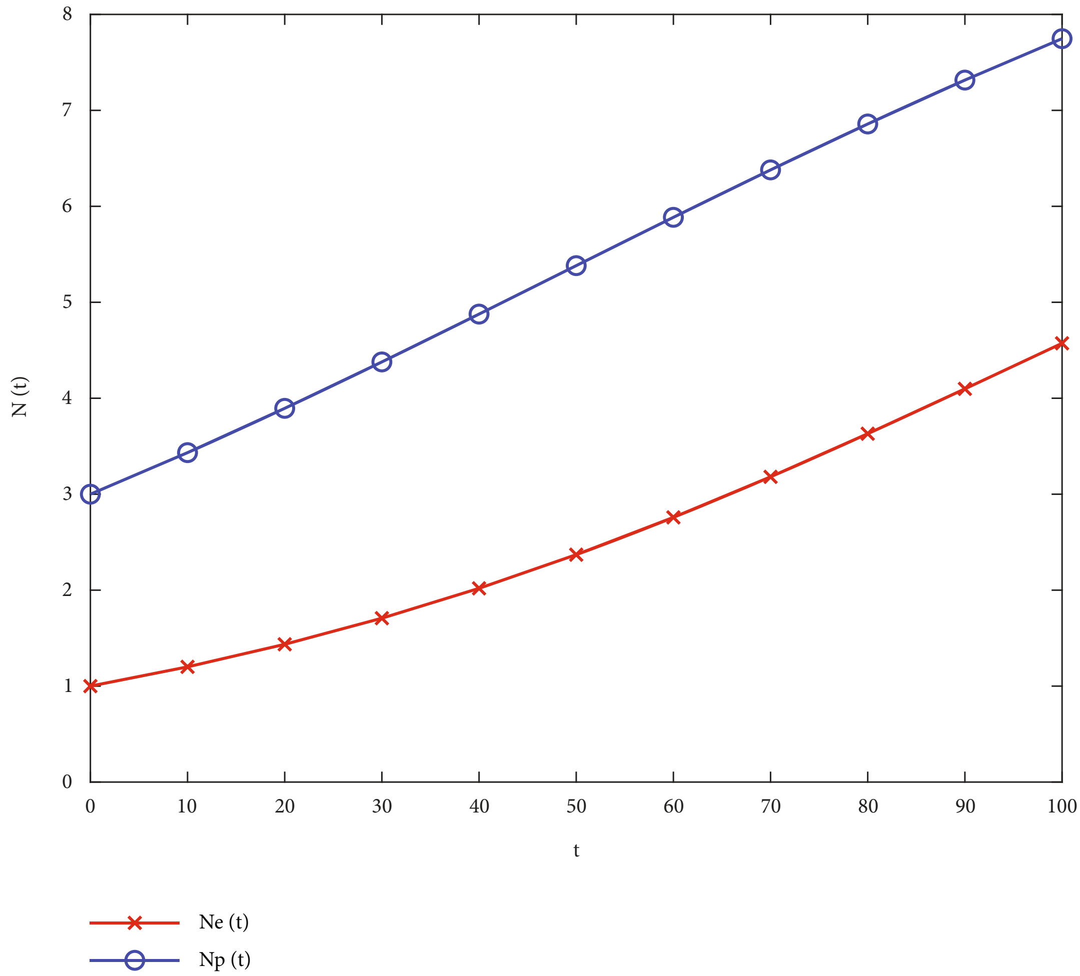

FIGURE 3: The evolution of the independent symbiosis model. The figure shows changes in the output value of the platforms and participants over time ($B_1 = B_2 = 0.2$).

commerce platforms need to expand the scale of users and improve the network effect, so that participants dominate. To gain market share, the platforms are busy expanding and ignoring the real needs of participants. Therefore, the output value of the platform decreases. The cooperation is unstable due to the blindness of participants to enter the platform. After the accumulation of the user scale, the population density of the participants increases.

In the platform-dominant stage, when the conditions are met $B_1 < 1$, $B_2 > 1$, $B_1 B_2 < 1$, which are proved in the previous section, the two groups are in equilibrium. We assume that $B_1 = 0.25$, $B_2 = 1.2$, and the evolution of the participants' dominant mode is shown in Figure 5. At this time, the trends of output value are inconsistent. Due to the increase in the number of participants, the contribution coefficient of participants to the e-commerce platform is greater than the feedback coefficient from the e-commerce platform, which shows an asymmetric symbiosis mode. The user scale of the e-commerce platform has formed. The network effect of the e-commerce platforms makes it pay more attention to the value-added fees through the user scale. System stability is maintained by the e-commerce platform in this phase.

4.3. Symmetric Symbiosis Mode. In the symmetric symbiosis mode, the mutual dependence between participants and the platforms increases, and the influence coefficient and the contribution coefficient are greater than 0. When the conditions $B_2 > (K_e/K_p) A_2 - 1$, $B_1 > (K_p/K_e) A_1 - 1$ and $A_1 A_2 + B_1 B_2 < 1$ are met, which are proved in the previous section, the two groups are in equilibrium. We assume that $B_1 = B_2 = 0.7$ and $A_1 = A_2 = 0.1$. The evolution of the symmetric symbiosis mode is shown in Figure 6. The trend of the output value changes quickly. E-commerce participants rely on the accumulated resources to form clusters. The competitive effect on the value output of e-commerce platforms is formed through alliance logistics and self-built platforms. After the rapid expansion in the previous stage, the system is stable, and the population density of the system continues to increase. New members joined to expand the boundary of the ecosystem, so that the scale of the system continued to expand. However, the interests of the members are complex, and the development of platform ecosystem faces bottleneck. In response to this phenomenon, a complex symbiotic relationship has been developed between the e-commerce platforms and the participants.

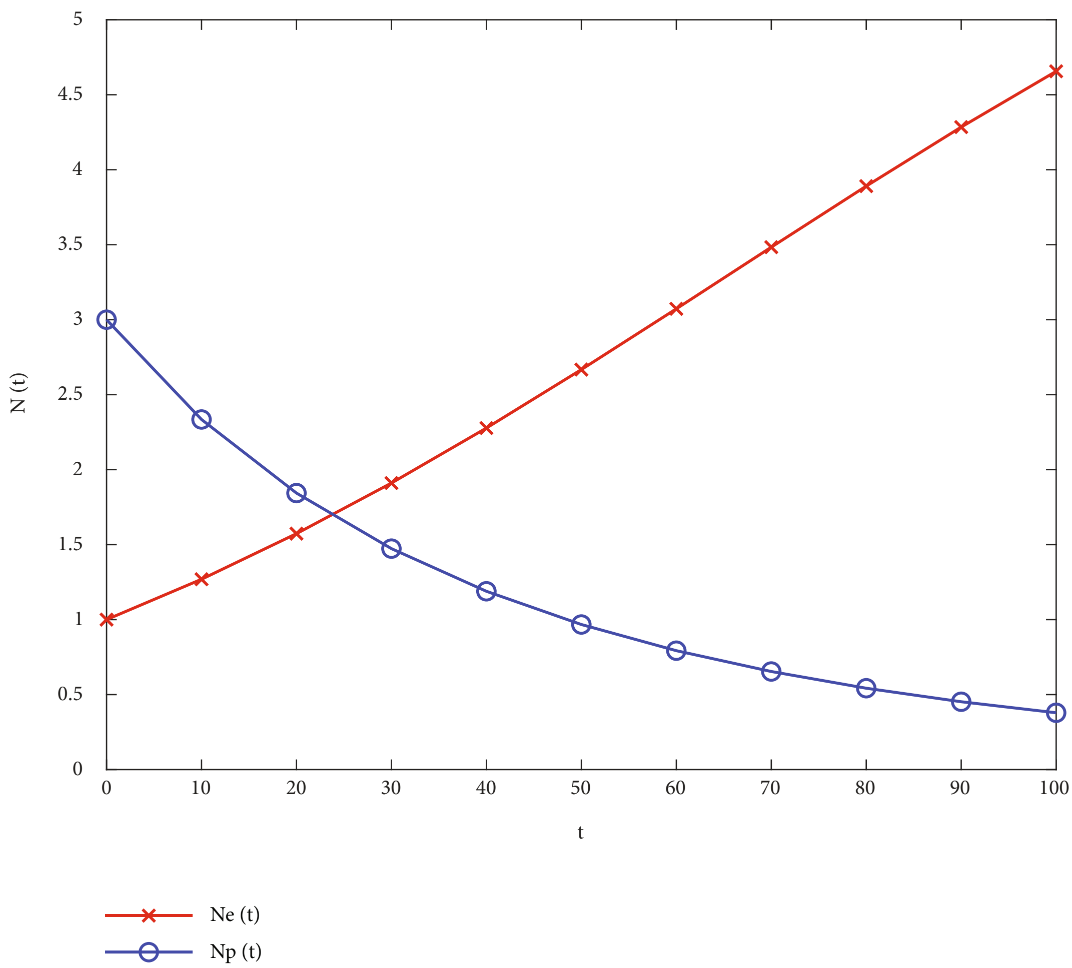

Figure 4: The evolution of the platform participants' dominant model. The figure shows changes in the output value of the platforms and participants over time ($B_1 = 1.2, B_2 = 0.25$).

5. Discussion

In this paper, we discuss the symbiosis mode of e-commerce platform ecosystem based on the extended population density logistic model. We accurately describe the symbiosis relationship between e-commerce platforms and participants, and we determine the influence of two core populations in the evolution of ecosystem. The model performs well in data fitting and prediction. The dynamic evolution process of e-commerce platform ecosystem is presented in Figure 7. Some meaningful results and new contributions are presented as follows.

First, the existing studies are more oriented to the platform leader from the technical or economic perspective, and they seldom pay attention to the perspectives of other participants in the platform [53], who represent the majority of companies in the platform ecosystem that are critical to value creation. However, there is not enough information about the participants in the literature [54]. In the paper, we discuss the symbiosis relationship between e-commerce platforms and participants in the platform ecosystem. This paper creatively introduces the symbiosis theory to describe the symbiosis modes of platform ecosystem. There are four modes: independent symbiotic mode, two types of asymmetric symbiosis mode (participants dominant and platform dominant), and symmetric symbiosis mode, which represent the symbiotic characteristics of platform ecosystems. By the numerical simulation of the two core populations of the platform ecosystem, we acquire the evolutionary trajectories and the final scales of the population (output value) in different symbiosis modes. The results reveal that the symmetric symbiosis mode is the optimal model with respect to the output value. The mode can well reflect the compatibility between e-commerce platforms and participants on population changes.

Second, a central thesis of the literature on the platform ecosystem is that technology stimulates competition and cooperation in the context of interdependence [55, 56] and that platform owners need to balance their output value rather than resist complementors [57, 58]. However, the symbiotic structure, and cooperative and competitive effects of the e-commerce platform ecosystem are not considered in the traditional logistic growth model. In this study, we proposed an adjusted logistic model with the competitive effect and the cooperative effect to address the problem. The results show that the adjusted model has higher efficiency and stability in identifying the symbiotic mode of platform ecosystems. Through simulation analysis, it is found that

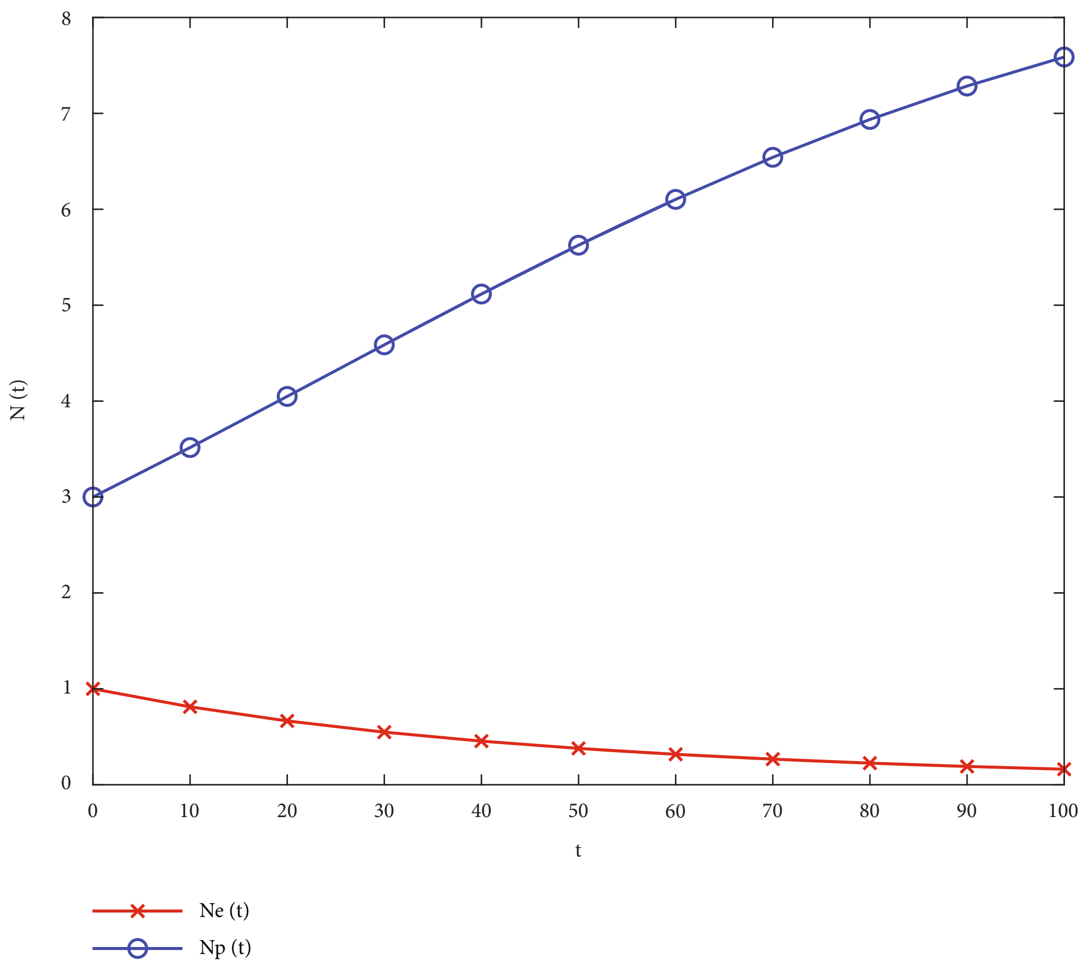

Figure 5: The evolution of the platform dominant model. The figure shows changes in the output value of the platforms and participants over time ($B_1 = 0.25$, $B_2 = 1.2$).

the platform ecosystem is a self-organizing system formed by the interaction between platforms and participants. The size of the cooperative and competitive effect determines the equilibrium result of platform ecosystem. In the asymmetric symbiosis mode, one of the populations is affected by positive synergies that increase population density and promote evolution. In the symmetric symbiosis mode, the output value is greater than that in the asymmetric symbiosis mode and ultimately achieves "1 + 1 > 2" economic benefits.

Furthermore, we expand the platform ecosystem literature, which has traditionally concerned on the changes in the evolution process. Although that literature is helpful in explaining reaction strategies [59] and incumbent-entrant dynamics [60]. These findings need to be integrated when considering the dynamic evolution process of platform ecosystems. In this study, we propose a novel evolutionary dynamic mechanism that depicts the changes in cooperative and competitive effect over time. It is shown in Figure 7. The dynamic process mechanism is used to describe the evolution of the e-commerce platform ecosystem, which could help to intuitively identify the important drivers among populations in the platform ecosystem. The study could further simulate and predict the trend of the e-commerce platform ecosystem in different phases.

(i) Traditional platform ecosystem period: When the structure is (1, 1), $A_1 = A_2 = 0$ and $B_1 B_2 < 1$. The platform and the participants develop independently. The two groups passively maintain ordinary transactions on the platform.

(ii) Platform ecosystem 1.0 period: When the structure is (1, −1) and $B_1 > 1$, $B_2 < 1$, $B_1 B_2 < 1$, the platform ecosystem achieves the equilibrium state. In the process of symbiotic evolution between platforms and participants, the platform is attached to the participants and constantly obtains energy from the participants to maintain the parasitic mode. The development of platform economy reduces transaction costs, bringing more participants indirectly into the platform.

(iii) Platform ecosystem 2.0 period: When the structure is (−1, 1) and $B_1 < 1$, $B_2 > 1$, $B_1 B_2 < 1$, the platform ecosystem achieves the equilibrium state. In the evolution process, the platforms and participants obtain high-quality resources, the participants are attached to the platform and constantly obtains

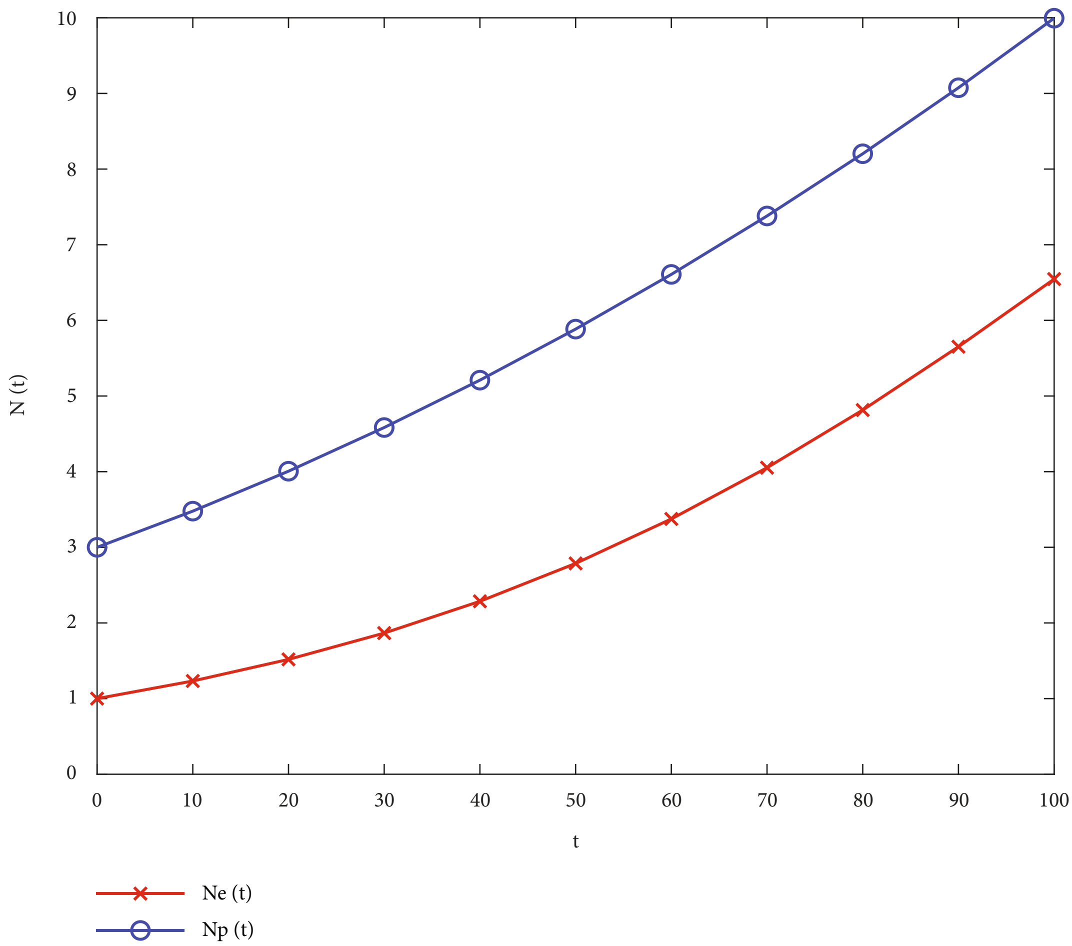

FIGURE 6: The evolution of the symmetric symbiosis mode. The figure shows changes in the output value of the platforms and participants over time ($B_1 = B_2 = 0.7$, $A_1 = A_2 = 0.1$).

energy from the platform to maintain the parasitic mode. They are in a profit-biased symbiosis mode. With the transformation and upgrading of traditional industries, global value chains have been reshaped, and stakeholders in the platform ecosystem interact frequently.

(iv) Platform ecosystem 3.0 period: When the structure is (1, 1), $B_2 > (K_e/K_p)A_2 - 1$, $B_1 > (K_P/K_e)A_1 - 1$, and $A_1A_2 + B_1B_2 < 1$, the platform ecosystem achieves the equilibrium state. In the process of symbiosis evolution, the platforms and participants receive balanced benefits, and the energy is exchanged equally. They are in a symmetric symbiosis mode. With the change of consumption patterns, new technologies and industries are constantly integrated, forming a platform ecosystem without boundaries.

6. Conclusion

This paper integrates the symbiosis theory into the research of platform ecosystem and constructs a symbiosis evolution model. An adjusted population density logistic model is proposed to describe the growth of species in biology, and the corresponding dynamic mechanism is developed. The evolution process of the model under different symbiotic modes is studied by numerical simulation. Comparing the symbiosis evolution modes under different coefficients, the implications, key lessons learned, and limitations can be summarized as follows.

6.1. Theoretical and Practical Implications. Our work has several important implications for research. First, previous studies have focused on platform-leader oriented, ignoring other platform participants. This paper creatively introduces the symbiosis theory to describe the symbiosis modes of e-commerce platform ecosystem, which can well reflect the compatibility between platforms and participants on population changes. Second, we propose a new population density logistic model, which extends the literature related to the platform ecosystems. Compared with the existing research, we consider the symbiotic structure, and cooperative and competitive effects in the traditional logistic growth model. The results show that the adjusted model has higher efficiency and stability in identifying the evolution modes of platform ecosystems. Third, research has shown that cooperation and competition are key aspects of platform

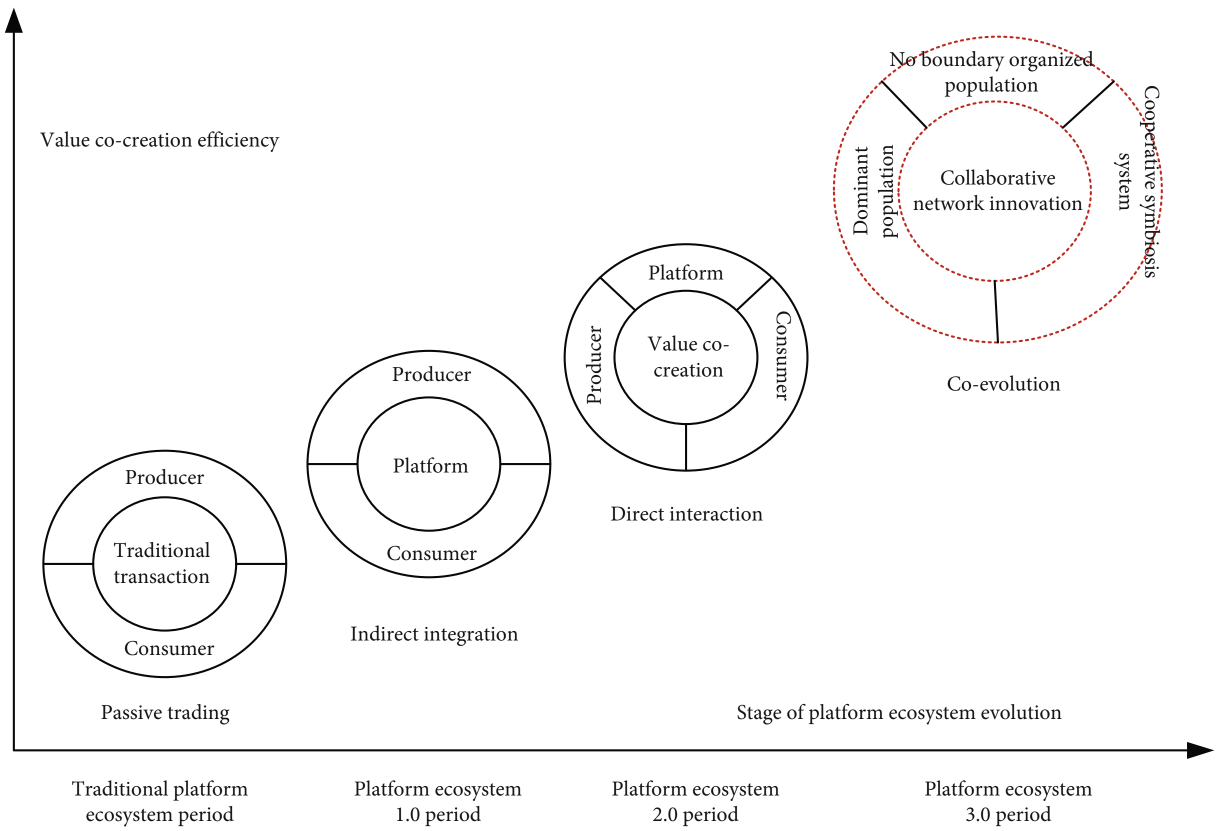

Figure 7: The dynamic evolution process of the platform ecosystem.

ecosystems. The contribution of this study is to propose a new dynamic process mechanism that describes changes in the cooperative and competitive effect over time. They are divided into four periods: traditional platform ecosystem period, platform ecosystem 1.0 period, platform ecosystem 2.0 period, and platform ecosystem 3.0 period. The ultimate result of evolution is to form a platform ecosystem without boundaries. The dynamic process mechanism contributes to the literature on platform ecosystems [61] and related studies on competition and cooperation.

In addition, the research has practical significance for platform ecosystems in maintaining symbiosis relationships. For platform ecosystems, the main contribution is to present the dynamic process mechanism, which increases the understanding of different symbiotic models among stakeholders in the population evolution process. The results reveal that the symmetric symbiosis mode is the optimal model. In the management practice, the company can adjust the symbiosis mode according to the actual symbiosis coefficient and make the symbiosis mode to the direction of mutually beneficial. Moreover, it is clear from this study that platform is only one of the many components in the process of building an ecosystem. It is found that the platform ecosystem is a self-organizing system formed by the interaction between platforms and participants. In addition to clarifying evolution of platform ecosystems, these insights help the organization to better understand the different actor roles (dominant and main participants). Finally, firms can also benefit from insights on the competitive effect and cooperative effect, and the strategies outlined for managing platform actors. The competitive effect and cooperative effect determine the equilibrium result of the evolution. Only in symmetric symbiosis, the benefits of "$1 + 1 > 2$" can be achieved between the two populations.

6.2. Key Lessons Learned. In this paper, we have shown an extended population density logistic model of the symbiosis evolution in e-commerce platform ecosystem under different phases. We use the symbiosis theory and the degree of population density to identify the symbiosis modes. According to the logistic growth equation, we get the cooperative effect, competitive effect, and final scales of the population (output value) of optimal symbiosis mode. By comparing the equilibrium results, we show that the output value of two populations has a slow upward trend when the cooperative effect on output value is low in the independent symbiotic mode. In the asymmetric symbiosis mode, only one population is influenced by positive synergies that increase population density and promote evolution. The contribution coefficient of subordinate to the dominant is greater than the feedback coefficient from the dominant; the trends of output value are inconsistent. In the symbiosis mode, the trend of the output value changes quickly and more than that in the asymmetric symbiosis mode. New members join to expand the boundary of the ecosystem, so the scale of the system continues to expand. Moreover, we have shown that cooperative and competitive effects in e-commerce platform ecosystem can make the degree of population density higher. By analyzing these models, we have also provided a dynamic process mechanism that describes the changes in cooperative and competitive effects over time.

6.3. Limitations and Future Research. The limitations of our work also provide opportunities for future research. First, the proposed model in the paper is a sustainable development model. It requires data over a long period of time to validate the model. At present, the model can only be verified by numerical simulation. Moreover, different roles in the ecosystem can be assumed, such as keystone, dominant, and ordinary subscribers [62], which will have a related impact on the cooperative and competitive dynamics ecosystem. Future research could further focus on this important issue. Finally, the results can be tested in an environment where changes in the cooperative and competitive effects may be caused by the major exogenous shocks such as network externality.

Notations

- $N_e(t)$: The output value of the cluster of participants on the platform
- $N_p(t)$: The output value of the e-commerce platform
- A_1: The influence coefficient of the platform on the output value of platform participants
- A_2: The influence coefficient of the platform participants on the output value of the platform
- B_1: The contribution coefficient of the platform to the output value of platform participants
- B_2: The contribution coefficient of platform participants to the output value of the platform.
- r_e: The natural growth rates of platform participants
- r_p: The natural growth rates of platforms
- K_e: The output value of the platform participants in the optimal state
- K_p: The output value of the platform in the optimal state.

Data Availability

Data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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