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Research Article

The Multiagent Evolutionary Game Research of Enterprise Resource Sharing on a Shared Manufacturing Platform

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Shared manufacturing is the application innovation of the digital economy in the field of manufacturing and brings new opportunities for the transformation and upgrading of China and even the global manufacturing industry. In order to explore the strategy selection of enterprises on the shared manufacturing platform, this study constructs a two-party evolutionary game model and analyzes the dynamic relationship between manufacturing enterprise A and manufacturing enterprise B. Furthermore, in order to explore the influence of consumers' strategies of manufacturing enterprises on the platform, the study constructs a tripartite evolutionary game model of manufacturing enterprise A, manufacturing enterprise B, and consumers. Based on the principles of system dynamics, the paper uses Matlab to simulate the evolutionary game process dynamically and discusses the influence of parameter changes on resource-sharing enthusiasm and strategy selection. The research shows that in the two-party game, manufacturing enterprises are more inclined to adopt the strategy of sharing manufacturing resources. In the tripartite game, consumers' decision-making will affect the strategic choice of manufacturing enterprises. Consumers tend to establish strong dependence on shared-manufacturing products in the process of sharing manufacturing resources.

1. Introduction

With the world entering a period of economic development dominated by digital industry, developing the digital economy is a strategic choice to grasp the opportunities of the new round of technological revolution and industrial transformation. The integration of the digital economy and manufacturing has created new production modes, such as industrial Internet and shared manufacturing [1]. Numerous government documents clearly had set out the development plans and objectives of shared manufacturing, for example, the report of the 19th National Congress of the Communist Party of China, "14th Five-Year Plan," and "Made in China 2025." All of them have created a good institutional environment for the development of shared manufacturing. Shared manufacturing is the trend of the new generation of information technology and manufacturing integration, and it is also includes cultivating and developing new kinetic energy. Meanwhile, it is a crucial measure to optimize resource allocation, improve output efficiency, and promote the development of the manufacturing industry [2].

Shared manufacturing is the application innovation of the digital economy in the field of manufacturing [3]. It is based on cloud manufacturing technology and the industrial Internet of Things and is characterized by the sharing of usage rights of idle manufacturing resources and capabilities [4]. Using the concept of sharing to gather scattered and idle production resources [5], it realizes the effective integration and utilization of idle manufacturing capacity through accurate supply-and-demand matching and intelligent production scheduling among multiple manufacturing entities.

At present, it has become a general consensus in academia that shared manufacturing can promote the high-quality development of enterprises. Delavar et al. [6] believed that all links in the manufacturing process are concentrated on the shared platform, which forms the user aggregation effect and reduces the transaction costs between enterprises and links. Enterprises can find efficient resources at low cost in the market, so a shared platform can reduce the total operating costs of enterprises. Li et al. [7] proposed shared manufacturing to transform vertical internal production processes into flat collaboration between enterprise production networks. Through the connection and circulation of data, enterprises have effectively improved production efficiency and product supply level. Lee et al. [8] argued that manufacturing capacity sharing can effectively allocate production resources through big data, calming the peaks and troughs of the manufacturing cycle. Xu [9] proposed that shared manufacturing creates a resource-sharing pool in essence. Users can obtain manufacturing resources anytime and anywhere according to their own needs. This model greatly reduces management workload and supplier interaction costs. Accordingly, as a deep integration of sharing economy and manufacturing, shared manufacturing can cultivate more innovative models and formats and promote the transformation of manufacturing industry from resource-driven to data-driven.

However, shared manufacturing has changed the traditional resource allocation method, which not only brings new opportunities to manufacturing enterprises but also brings many operational and management problems [10]. There are still many urgent problems to be solved in the process of sharing manufacturing resources. For example, the data centralization is obvious, the information symmetry is low, the responsibility mechanism of the sharing process is difficult to divide, and there are information barriers in sharing manufacturing enterprises [11]. Therefore, manufacturing enterprises will determine whether to share resources according to their own benefits. In addition, there are speculative behaviors and self-interested behaviors in resource sharing among shared manufacturing enterprises, which can easily lead to instability and the high failure rates of enterprises [12]. Ma and Xie [13] constructed an evolutionary game theory-based analysis model for failed matching capacity sharing and investigated whether buyers and sellers could benefit from capacity sharing and how different matching success rates affect manufacturers' decision-making for spontaneous matching through platforms. Moufid et al. [14] constructed a production resource-sharing model between two small enterprises and expounded the possible fraud between small enterprises in the case of a noncooperative game. Furthermore, they analyzed the negative impact of fraud on the mutual benefit of resource sharing. Therefore, under the guidance of high-quality development, we should deepen our understanding of the content structure of shared manufacturing, explore more effective shared manufacturing development models for enterprises within the shared manufacturing platform, and accelerate the high-quality development of shared manufacturing.

The research of shared manufacturing has important practical significance. In the past two decades, advanced technologies have developed rapidly, such as cloud computing, cyber-physical systems, and the Internet of Things. Therefore, the idea that "everything can be shared" is realized in manufacturing [15, 16]. The existing shared manufacturing has begun to take shape, mainly in the following three modes. First, large-scale manufacturing enterprises build resource development platforms, such as the Aerospace Cloud Network of the Aerospace Science and Industry Group, Haichuanghui of the Haier Group, and i5 intelligent shared machine tools, launched by the Shenyang Machine Tool Group [17]. Second, third-party organizations build resource allocation platforms, such as Alibaba's Tao Factory platform and Ningbo's Yilianhuishang Business Alliance. The third model is the collaborative sharing platform for small and medium enterprises. Shared manufacturing has achieved some achievements, but production capacity sharing is still in its infancy. Compared with other fields, the growth rate of China's shared manufacturing is slow. The existing problems mainly include a lack of sharing willingness, unsound development ecology, and weak digital infrastructure. Therefore, studying the resource sharing of enterprises on the shared manufacturing platform and analyzing the strategies of sharing resources can effectively promote win-win cooperation and promote the high-quality development of shared manufacturing.

Domestic and foreign scholars have done much research on shared manufacturing. Liu et al. [18] compared the capacity and service sharing between the traditional mode and platform-based mode. They analyzed the characteristics and advantages of the platform-based mode and put forward the current difficulties and corresponding solutions. Argoneto and Renna [19] proposed a framework for capacity sharing in cloud manufacturing. It supported the capacity-sharing issue among independent firms. On the basis of in-depth analysis of the shared manufacturing process and the allocation process of manufacturing resources, Liu et al. [20] established a bilevel programming model for the optimal allocation of manufacturing resources considering the benefits of the shared manufacturing platform and the rights of consumers. Archimede et al. [21] established an incentive mechanism for resource sharing in a distributed environment and explored the promotion mode of manufacturing resource sharing. Yin et al. [22] believed that resource-sharing needs digital and green transformation by constructing a pressure-state-response system framework. Rožman et al. [23] proposed that in shared manufacturing, blockchain can provide a technical solution to the trust problem between manufacturing service providers and demanders. Wang et al. [24] constructed a digital twin-driven service model to seamlessly monitor shared manufacturing resources.

At the same time, with the development of consumer sovereignty theory, consumers have become an important resource for enterprises to obtain advantages in the fierce market competition environment. Consumers have gradually become the cocreators and leaders of market value [25]. Shared manufacturing can mobilize consumers' initiative to participate in manufacturing by accurately positioning consumer demand. Tao et al. [26] believed that small batches and personalized production can be better achieved when consumers are involved in manufacturing. Enterprises can improve the degree of personalization of products, thereby increasing consumer satisfaction. Mamun et al. [25] believed that customers can participate in enterprise value-creation activities through information exchange and interference behavior. Schuler and Cording [27] found that consumer preferences affect enterprises' behavior. He et al. [28] used game theory to study the dynamic channel selection and pricing strategy based on customer strategic behavior. Lin et al. [29] divided consumers into two types: strategic consumers and myopic consumers. Strategic consumers mainly consider future choices, while myopic consumers only focus on current choices. Through comparison, this study found that the behavior of strategic consumers has a positive impact on shared manufacturing enterprises. Consumers' feedback on shared-manufacturing products can not only form certain innovation incentives for shared manufacturing enterprises but also restrict their behavior. Although scholars have studied the relationship between consumers and manufacturing, few scholars link consumers with shared manufacturing. Few scholars have studied the role of consumers in the shared manufacturing platform and whether consumers affect the behavior of manufacturing enterprises on the platform. Therefore, under this research background, this paper focuses on the evolutionary game between shared manufacturing enterprises and consumers, which is of great significance to the stable operation of enterprises and the healthy development of industry on the shared manufacturing platform.

To summarize, the research on shared manufacturing is relatively deep, but most of the research methods are empirical, and the research objects are usually isolated. In reality, enterprises are faced with incomplete information and incomplete rationality in the decision-making process. Research has widely used evolutionary game theory in incomplete rationality and long-term dynamic evolution because of its strong description ability. In recent years, evolutionary game theory has been widely used in the fields of economy, management, and so on. In this context, evolutionary game theory is very suitable for modeling the manufacturing resource-sharing problem. Liu and Wei [30] constructed a three-party evolutionary game model of shared manufacturing under the leadership of core manufacturing company. Wang et al. [31] constructed a tripartite evolutionary model to analyze the benefits to the government, innovation-supplying enterprises, and potential demand-oriented enterprises based on the rational use of environmental regulation to promote the diffusion of green technology innovation in Chinese manufacturing enterprises. Yin and Li [32] established the stochastic differential game of low-carbon technology sharing in the collaborative innovation system of superior enterprises and inferior enterprises.

Current research has conducted in-depth research on shared manufacturing among manufacturing companies and analyzed the advantages and disadvantages of shared manufacturing. However, there are still some contents worthy of further study. First of all, most of the existing literature is about the mechanism design of shared manufacturing and the optimization of capacity allocation. There are relatively few studies on manufacturing enterprise resource sharing from the strategic level. Second, although it has been confirmed that consumers have a certain influence on the choice of manufacturing enterprises' shared strategies, there is a lack of research on the role of consumers in enterprises' shared manufacturing from the perspective of multi-agent games. Therefore, in order to explore the strategy selection of enterprises on the shared manufacturing platform, this study constructs a two-party evolutionary game model and analyzes the dynamic relationship between manufacturing enterprise A and manufacturing enterprise B. Furthermore, in order to explore the influence of consumers' strategies of manufacturing enterprises on the platform, the study constructs a tripartite evolutionary game model of manufacturing enterprise A, manufacturing enterprise B, and consumers. Based on the principles of system dynamics, the paper uses Matlab to simulate the evolutionary game process dynamically and discusses the influence of parameter changes on resource-sharing enthusiasm and strategy selection. This paper focuses on the new perspective of shared manufacturing and explores how to use new technologies and concepts to share manufacturing resources among manufacturing enterprises. Exploring the influence mechanism of consumers in manufacturing enterprise decision-making, this study provides new ideas for enterprises in sharing manufacturing.

2. Basic Assumptions

Based on the existing theory, this paper constructs a two-party evolutionary game model. Firstly, this paper discusses the two-party game model of manufacturing enterprise A and manufacturing enterprise B on the shared manufacturing platform and analyzes the factors affecting enterprise strategy selection. Secondly, the paper constructs a game model including manufacturing enterprise A, manufacturing enterprise B, and consumers to analyze how consumers' behavior affects the decision-making of manufacturing enterprises. Finally, the study uses Matlab to simulate the evolutionary game process dynamically and discusses the influence of parameter changes on resource-sharing enthusiasm and strategy selection.

According to the above discussion, this paper believes that enterprises on the shared manufacturing platform can adopt two strategies: sharing manufacturing resources and not sharing manufacturing resources. Each member on the platform plays the dual role of data resource provider and receiver. To some extent, the manufacturing resource-sharing behavior of a member will be restricted by the sharing strategy behavior of other members, which in turn will affect the manufacturing resource-sharing behavior of other members. In addition, there is a phenomenon of mutual imitation and learning among manufacturing enterprises. This means that when a manufacturing enterprise adopts a strategy and obtains better returns, other enterprises will have the tendency to copy the strategy. In addition to considering the interaction between manufacturing enterprises, the role of consumers in the sharing manufacturing process is increasingly prominent. Consumers' preference for shared-manufacturing products or nonshared manufacturing products has an important impact on the decision-making of enterprises. Based on the above description, the following assumptions are made in conjunction with the actual situation to make the study more targeted:

Hypothesis 1. In order to simplify the analysis process, it is assumed that manufacturing enterprise A and manufacturing enterprise B exist on a shared manufacturing platform. In the process of shared manufacturing, there are three main participants: manufacturing enterprise A, manufacturing enterprise B, and consumer C. The three parties are independent individuals with bounded rationality. They follow industry guidelines and adjust their strategies when they do not fully understand each other's information based on the principle of maximizing interests.

Hypothesis 2. Each manufacturing enterprise has two strategies to choose from: sharing manufacturing resources and not sharing manufacturing resources. The probability of manufacturing enterprise A adopting the strategy of sharing manufacturing resources is x, and the probability of adopting nonsharing manufacturing resources is $1 - x$. The probability of manufacturing enterprise B adopting the strategy of sharing manufacturing resources is y, and the probability of not sharing manufacturing resources is $1 - y$. When consumers participate in the shared manufacturing process, they have two strategic choices for shared-manufacturing products. They are "building strong dependencies" and "building weak dependencies" on shared-manufacturing products. The probabilities are z and $1 - z$, respectively, and $x, y, z \in [0, 1]$.

Hypothesis 3. If both manufacturing enterprise A and manufacturing enterprise B do not share the enterprise's resources, both parties produce and operate independently, and the income earned by manufacturing enterprise A is W_a and that of manufacturing enterprise B is W_b.

Hypothesis 4. If only unilateral enterprises choose shared manufacturing on the shared manufacturing platform, when manufacturing enterprise A chooses to share manufacturing resources, enterprise A needs to invest many fixed costs to purchase or upgrade existing material-sensing devices, denoted as C_a. At this point, although there is no collaborative relationship between enterprises, the production and information level of group A has been improved, and the proceeds will also change accordingly, from the extra income brought by the upgrade is recorded as Q_a, while that of the manufacturing enterprise B is still W_b. When manufacturing enterprise B chooses the strategy of sharing manufacturing resources, enterprise B also needs to invest in transformation cost, denoted as C_b. The extra income of enterprise B upgrading is recorded as Q_b. The income of manufacturing enterprise A is still W_a.

Hypothesis 5. If both manufacturing enterprise A and B share enterprise resources, both types of enterprises will obtain excess returns, namely, P_a and P_b.

Hypothesis 6. The two parties of the shared manufacturing enterprise establish a cooperative relationship with each other by signing a contract or agreement. Enterprises that do not perform the sharing contract will take appropriate punishment measures. Therefore, a penalty cost is generated, and the penalty costs of enterprise A and enterprise B are denoted as F_a and F_b, respectively.

Hypothesis 7. When consumers establish strong dependence on Ared-manufacturing products, they will invest a certain cost C_c. When consumers establish weak dependence on shared-manufacturing products, the consumers incur less cost. Therefore, this paper assumes that there is zero cost for consumers to establish weak dependence on shared-manufacturing products. The income of consumers when establishing a strong dependence on shared-manufacturing products is denoted as R_c. Furthermore, θ $(0 < \theta < 1)$ is the ratio of the income obtained by choosing to establish a weak dependence relationship to the income obtained by choosing a strong dependence relationship. This means that when consumers choose to establish a weak dependence relationship, the return is θR_c. When consumers participate in the unilateral shared manufacturing of enterprises, the income is L. When both companies choose to share manufacturing resources, affected by the degree of collaboration, the benefit to consumers is ηL. η is the shared manufacturing degree between manufacturing enterprise A and manufacturing enterprise B $(\eta > 1)$. Meanwhile, when consumers establish strong dependence, they will bring benefits to shared manufacturing enterprises as R_a and R_b. When consumers choose to form a weak dependence relationship, the invisible losses to the sharing manufacturing enterprises are L_a and L_b.

3. The First-Stage Evolutionary Game Model

3.1. Return Matrix and Replicator Dynamic Equation. This paper constructs the first-stage evolutionary game model of manufacturing enterprise A and manufacturing enterprise B on the shared manufacturing platform. According to the hypothesis of the above several variables, we can get the game payment matrix shown in Table 1.

According to Table 1, the expected profit of manufacturing enterprise A choosing to share manufacturing resources is

$$E_{a1} = y\left(W_a + P_a - C_a\right) + (1 - y)\left(W_a + Q_a - C_a\right). \tag{1}$$

The expected profit of manufacturing enterprise A choosing not to share manufacturing resources is

Table 1: Evolutionary game payment matrix of enterprises on platform.

		Manufacturing enterprise B	
		Share (y)	Not share $(1-y)$
Manufacturing enterprise A	Share (x)	$W_a + P_a - C_a$ $W_b + P_b - C_b$	$W_a + Q_a - C_a$ $W_b - F_b$
	Not share $(1-x)$	$W_a - F_a$ $W_b + Q_b - C_b$,	W_a W_b

$$E_{a2} = y\left(W_a - F_a\right) + (1-y)W_a. \tag{2}$$

Therefore, the average expect profit of manufacturing enterprise A is

$$E_A = xE_{a1} + (1-x)E_{a2}. \tag{3}$$

By the same token, the expected profit of manufacturing enterprise B choosing to share manufacturing resources is

$$E_{b1} = x\left(W_b + P_b - C_b\right) + (1-x)\left(W_b + Q_b - C_b\right). \tag{4}$$

The expected profit of manufacturing enterprise B choosing not to share manufacturing resources is

$$E_{b2} = x\left(W_b - F_b\right) + (1-x)W_b. \tag{5}$$

Therefore, the average expect profit of manufacturing enterprise B is

$$E_B = yE_{b1} + (1-y)E_{b2}. \tag{6}$$

The strategy adjustment process can be simulated by replicating a dynamic mechanism. So, the replicator dynamic equation of manufacturing enterprise A choosing share manufacturing strategy is

$$U_A = x\left(E_{a1} - E_A\right) = x(1-x)\left(Q_a - C_a + yP_a + yF_a - yQ_a\right). \tag{7}$$

The replicator dynamic equation of manufacturing enterprise B choosing share manufacturing strategy is

$$U_B = y\left(E_{b1} - E_B\right) = y(1-y)\left(Q_b - C_b + xP_b + xF_b - xQ_b\right). \tag{8}$$

3.2. Solving the Model. When $U_A = 0$ and $U_B = 0$, we can get the five equilibrium points of the evolutionary game process, respectively, $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, and $E_5((C_b - Q_b/P_b + F_b - Q_b), (C_a - Q_a/P_a + F_b - Q_a))$.

The Jacobian matrix stability decision method can accurately describe the evolution process of game theory subject strategy and judge the equilibrium of the game theory model. Therefore, in order to correctly determine the equilibrium state in the model, deriving U_A and U_B from partial derivatives of x and y, respectively, we get the Jacobian matrix of the system as follows:

$$J = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}. \tag{9}$$

Among them, $a_{11} = (1-2x)(Q_a - C_a + yP_a + yF_a - yQ_a)$, $a_{12} = x(1-x)(P_a + F_a - Q_a)$, $a_{21} = y(1-y)(P_b + F_b - Q_b)$, $a_{22} = (1-2y)(Q_b - C_b + xP_b + xF_b - xQ_b)$.

At the equilibrium point $E_1(0,0)$ of the first-stage evolutionary game model, the Jacobian matrix is

$$\begin{bmatrix} Q_a - C_a & 0 \\ 0 & Q_b - C_b \end{bmatrix}. \tag{10}$$

The characteristic roots of the matrix are $Q_a - C_a$ and $Q_b - C_b$. The calculation method of other Jacobian matrices at other stable points is the same as E_1, so the specific calculation steps of other Jacobian matrices are not written in detail here. Table 2 summarizes the determinant and trace of the Jacobian matrix obtained. It is found that under different conditions, the symbol of the determinant and trace will be different, and the stable point of the evolutionary game model will also be different.

3.3. Evolutionary Stability Analysis. According to the judgment criterion of Jacobian matrix for the equilibrium state of evolutionary game model, the evolutionary stability strategy (ESS) needs to meet the conditions det $J > 0, trJ < 0$.

Among them, $-a_{12}^{*}a_{21}^{*} = -(((P_b + F_b - C_b)(C_b - Q_b)(P_a + F_a - C_a)(C_a - Q_a)/(P_b + F_b - Q_b)(P_a + F_a - Q_a))$.

According to this principle, the ESS of the evolutionary game model in different situations is analyzed, as shown in Table 3. It is known that all parameters are greater than 0 and $0 \le (C_b - Q_b/P_b + F_b - Q_b) \le 1, 0 \le (C_a - Q_a/P_a + F_b - Q_a) \le 1$.

According to the stability conditions of the above five equilibrium points, it can be seen that the difference between income and cost determines the choice of the two subjects. According to different conditions, the possible choice is divided into four cases, and the evolutionary stabilization strategies in the four cases are as follows:

Case 1. When only one company shares manufacturing resources, the additional benefits brought by the upgrading and transformation of the shared manufacturer are lower than the cost of investing in shared manufacturing ($Q_a < C_a$ and $Q_b < C_b$). In this case, the determinant of the Jacobian matrix corresponding to $E_1(0,0)$ is det $J > 0$ and $trJ < 0$. At this time, not sharing the manufacturing strategy is the rational choice of manufacturing enterprise A and manufacturing enterprise B. The cross-cooperation between enterprises is less, and even impossible to

Table 2: det J and trJ of the balance point.

Balance point	det J	trJ
$E_1(0,0)$	$(Q_a - C_a)(Q_b - C_b)$	$Q_a - C_a + Q_b - C_b$
$E_2(0,1)$	$(P_a + F_a - C_a)(C_b - Q_b)$	$P_a + F_a - C_a + C_b - Q_b$
$E_3(1,0)$	$(C_a - Q_a)(P_b + F_b - C_b)$	$C_a - Q_a + P_b + F_b - C_b$
$E_4(1,1)$	$(C_a - P_a - F_a)(C_b - P_b - F_b)$	$C_a - P_a - F_a + C_b - P_b - F_b$
$E_5(x,y)$	$-a_{12}^* a_{21}^*$	0

Table 3: Balance point and satisfying condition.

Balance point	Whether ESS[a] or not	Satisfying condition
$E_1(0,0)$	Yes	$Q_a < C_a$ and $Q_b < C_b$
$E_2(0,1)$	Yes	$P_a + F_a < C_a$ and $C_b < Q_b$
$E_3(1,0)$	Yes	$C_a < Q_a$ and $P_b + F_b < C_b$
$E_4(1,1)$	Yes	$C_a < P_a + F_a$ and $C_b < P_b + F_b$
$E_5(x,y)$	No	No

[a]The meaning of ESS is evolutionary stability strategy.

occur. Neither sides will be affected by the collaborative benefits generated by shared manufacturing.

Case 2. This occurs when both enterprises participate in shared manufacturing. The penalty cost of manufacturing enterprise A is lower than the difference between the shared manufacturing cost and the excess return of shared manufacturing. However, manufacturing enterprise B invests in shared manufacturing costs less than the additional benefits of upgrading ($F_a < C_a - P_a$ and $C_b < Q_b$). In this case, the determinant of the Jacobian matrix corresponding to $E_2(0,1)$ is det $J > 0$ and $trJ < 0$. This means that manufacturing enterprise A does not share manufacturing resources, but manufacturing enterprise B shares manufacturing resources.

Case 3. This occurs when both enterprises participate in shared manufacturing. The penalty cost of manufacturing enterprise B is lower than the difference between the shared manufacturing cost and the excess return of shared manufacturing. Manufacturer A invests in shared manufacturing an amount that costs less than the additional benefits of upgrading ($F_b < C_b - P_b$ and $C_a < Q_a$). In this case, the determinant of the Jacobian matrix corresponding to $E_3(1,0)$ is det $J > 0$ and $trJ < 0$. This means that manufacturing enterprise A shares manufacturing resources, but manufacturing enterprise B does not share manufacturing resources.

Case 4. This occurs when both enterprises participate in shared manufacturing. The penalty cost incurred by both parties for not following the contract is higher than the difference between the shared manufacturing cost and the shared manufacturing excess benefit ($C_a - P_a < F_a$ and $C_b - P_b < F_b$). In this case, the determinant of the Jacobian matrix corresponding to $E_4(1,1)$ is det $J > 0$ and $trJ < 0$. Manufacturing enterprise A and manufacturing enterprise B will adopt the strategy of sharing manufacturing resources at the same time.

Case 5. In this case, $E_5(x,y)$ must not have det $J > 0$ and $trJ < 0$ under any circumstances. Therefore, $E_5(x,y)$ cannot be ESS.

4. The Second-Stage Evolutionary Game Model

The first-stage evolutionary game revolves around manufacturing enterprise A and manufacturing enterprise B and is based on the importance of customer-enterprise interaction and the complexity of consumer influence on business decisions. In this paper, consumers are introduced into the second-stage evolutionary game model to discuss the influence of consumers' strategies on enterprises' choice of shared manufacturing strategies.

4.1. Model Construction and Solution. Based on the hypothesis, this paper constructs the second-stage evolutionary game model of manufacturing enterprise A, manufacturing enterprise B, and consumers. We can get the game payment matrix shown in Tables 4 and 5.

The average expectation of the tripartite evolutionary game is similar to the first stage of the replicator dynamic equation. Considering the limitation of space, the calculation steps are not given in detail. The results are obtained as follows.

The income of manufacturing enterprise A choosing to share and choosing not to share the enterprise resources, respectively, are

$$\begin{aligned} E_1 &= W_a + Q_a - C_a - L_a + zR_a + yP_a - yQ_a + zL_a, \\ E_2 &= W_a - yF_a. \end{aligned} \tag{11}$$

By the same token, the income of manufacturing enterprise B choosing to share and not share are, respectively, as follows:

$$\begin{aligned} E_3 &= W_b + Q_b - C_b - L_b + xP_b + zR_b + zL_b - xQ_b, \\ E_4 &= W_b - xF_b. \end{aligned} \tag{12}$$

Table 4: The tripartite game payment matrix when consumers choose to establish strong dependence (z).

		Manufacturing enterprise B	
		Share (y)	Not share $(1-y)$
Manufacturing enterprise A	Share (x)	$W_a + P_a - C_a + R_a$ $W_b + P_b - C_b + R_b$ $R_c - C_c + \eta L$	$W_a + Q_a - C_a + R_a$ $W_b - F_b$ $R_c - C_c + L$
	Not share $(1-x)$	$W_a - F_a$ $W_b + Q_b - C_b + R_b$ $R_c - C_c + L$	W_a W_b $R_c - C_c$

Table 5: The tripartite game payment matrix when consumers choose to establish weak dependence $(1-z)$.

		Manufacturing enterprise B	
		Share (y)	Not share $(1-y)$
Manufacturing enterprise A	Share (x)	$W_a + P_a - C_a - L_a$ $W_b + P_b - C_b - L_b$ $\theta R_c + \eta L$	$W_a + Q_a - C_a - L_a$ $W_b - F_b$ $\theta R_c + L$
	Not share $(1-x)$	$W_a - F_a$ $W_b + Q_b - C_b - L_b$ $\theta R_c + L$	W_a W_b θR_c

Therefore, the average income of manufacturing enterprise A and manufacturing enterprise B are

$$\begin{aligned} E_5 &= xy\eta L + xL + yL - 2xyL + R_c - C_c, \\ E_6 &= xy\eta L + xL + yL - 2xyL + \theta R_c. \end{aligned} \tag{13}$$

The replicator dynamic equations of the tripartite game subject are

$$\begin{cases} U_A' = x(1-x)\left[z\left(R_a + L_a\right) - yQ_a + yP_a + yF_a + Q_a - C_a - L_a\right], \\ U_B' = y(1-y)\left[xP_b + xF_b - xQ_b + zR_b + zL_b + Q_b - C_b - L_b\right], \\ U_C' = z(1-z)\left(R_c - C_c - \theta R_c\right). \end{cases} \tag{14}$$

When $U_A' = U_B' = U_C' = 0$, we can get the eight equilibrium points of the evolutionary game process, namely, $E_1(0,0,0)$, $E_2(0,0,1)$, $E_3(0,1,0)$, $E_4(0,1,1)$, $E_5(1,0,0)$, $E_6(1,1,0)$, $E_7(1,0,1)$, and $E_8(1,1,1)$.

4.2. Evolutionary Stability Analysis. According to the Friedman stability theorem, when all eigenvalues (λ) of the Jacobian matrix satisfy $\lambda < 0$, the equilibrium point is asymptotically stable, i.e., confluence. When all eigenvalues of the Jacobian matrix follow $\lambda > 0$, the equilibrium point is unstable. In order to analyze the asymptotic stability of the equilibrium points, the Jacobian matrix and its eigenvalue are firstly calculated.

Accordingly, the Jacobian matrix of the system is shown as

$$J = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}. \tag{15}$$

Among them, $a_{11} = (1-2x)\left[z\left(R_a + L_a\right) - yQ_a + yP_a + yF_a + Q_a - C_a - L_a\right]$, $a_{12} = x(1-x)\left(P_a + F_a - Q_a\right)$, $a_{13} = x(1-x)\left(R_a + L_a\right)$, $a_{21} = y(1-y)\left(P_b + F_b - Q_b\right)$, $a_{22} = (1-2y)\left[xP_b + xF_b - xQ_b + zR_b + zL_b + Q_b - C_b - L_b\right]$, $a_{23} = y(1-y)\left(R_b + L_b\right)$, $a_{31} = 0$, $a_{32} = 0$, and $a_{33} = (1-2z)\left(R_c - C_c - \theta R_c\right)$.

Table 6 shows calculation of the eigenvalues of the Jacobian matrix corresponding to each equilibrium point.

In order to facilitate the analysis of the sign of the eigenvalues corresponding to different equilibrium points, general assumptions are made: $W_a + P_a - C_a + R_a > W_a - F_a, W_b + P_b - C_b + R_b > W_b - F_b (P_a + F_a + R_a - C_a > 0, P_b + F_b + R_b - C_b > 0)$. Firstly, when consumers choose to establish strong dependence with shared-manufacturing products and enterprise B chooses to share manufacturing resources. The difference between the benefit and cost obtained by enterprise A choosing to share manufacturing should be higher than the difference between the benefit and cost when it does not share manufacturing. Secondly, when consumers choose to establish a strong dependence relationship with shared-manufacturing products, enterprise A shares manufacturing resources. The difference between the benefit and cost obtained by enterprise B choosing to share manufacturing should be higher than the difference between the benefit and cost when it does not share manufacturing.

Table 6: Eigenvalues of Jacobian matrix corresponding to equilibrium points.

Balance point	λ_1	λ_2	λ_3
$E_1(0,0,0)$	$Q_a - C_a - L_a$	$Q_b - C_b - L_b$	$R_c - C_c - \theta R_c$
$E_2(0,0,1)$	$R_a + Q_a - C_a$	$R_b + Q_b - C_b$	$-(R_c - C_c - \theta R_c)$
$E_3(0,1,0)$	$P_a + F_a - C_a - L_a$	$-(Q_b - C_b - L_b)$	$R_c - C_c - \theta R_c$
$E_4(0,1,1)$	$R_a + P_a + F_a - C_a$	$-(R_b + Q_b - C_b)$	$-(R_c - C_c - \theta R_c)$
$E_5(1,0,0)$	$-(Q_a - C_a - L_a)$	$P_b + F_b - C_b - L_b$	$R_c - C_c - \theta R_c$
$E_6(1,1,0)$	$-(P_a + F_a - C_a - L_a)$	$-(P_b + F_b - C_b - L_b)$	$R_c - C_c - \theta R_c$
$E_7(1,0,1)$	$-(R_a + Q_a - C_a)$	$P_b + F_b + R_b - C_b$	$-(R_c - C_c - \theta R_c)$
$E_8(1,1,1)$	$-(R_a + P_a + F_a - C_a)$	$-(P_b + F_b + R_b - C_b)$	$-(R_c - C_c - \theta R_c)$

Under this assumption, the eigenvalue λ_1 of the equilibrium solution $E_4(0,1,1)$ is positive, and the eigenvalue λ_2 of the equilibrium solution $E_7(1,0,1)$ is positive. They do not satisfy Friedman's stability theory and can be ruled out directly. Since there are many parameters in the constructed evolutionary game model, the following will be divided into two cases to discuss the stability strategy of the evolutionary game:

Case 1. This occurs if $R_c - \theta R_c - C_c > 0$; that is, for consumers, the profit brought by the establishment of a strong dependence relationship is higher than the net profit when the weak dependence relationship is established. At this time, the λ_3 of the equilibrium solutions $E_1(0,0,0)$, $E_3(0,1,0)$, $E_5(1,0,0)$, and $E_6(1,1,0)$ are all nonnegative, which do not satisfy Friedman stability theory, so it can be ruled out directly. In this case, it is only necessary to analyze the stability of the equilibrium points E_2, E_8, and the results are shown in Table 7. Only when $R_a + Q_a - C_a < 0$ and $R_b + Q_b - C_b < 0$, $E_2(0,0,1)$ is the evolutionary stable equilibrium point reached. This means that consumers in the choice of strong dependence to bring the manufacturing enterprise revenue and its upgrading of the additional revenue is lower than the cost of upgrading the enterprise. For the equilibrium point $E_8(1,1,1)$, the eigenvalues are consistent with the stability theory, and $E_8(1,1,1)$ is the evolutionary stable equilibrium point.

Case 2. This occurs if $R_c - \theta R_c - C_c < 0$; that is, for consumers, the profit brought by the establishment of a strong dependence relationship is lower than the net profit when the weak dependence relationship is established. At this time, the λ_3 of the equilibrium solutions $E_2(0,0,1)$, $E_4(0,1,1)$, $E_7(1,0,1)$, and $E_8(1,1,1)$ are all nonnegative, which does not satisfy Friedman stability theory, so it can be ruled out directly. In this case, it is only necessary to analyze the stability of the equilibrium points E_1, E_3, E_5, and E_6, and the results are shown in Table 7. Under this assumption, there are two situations. The first is $Q_a - C_a - L_a < 0, Q_b - C_b - L_b < 0$ and $P_a + F_a - C_a - L_a > 0, P_b + F_b - C_b - L_b > 0$. This means that when consumers choose to establish weak dependence with shared-manufacturing products, the difference between the benefit and cost of unilaterally shared manufacturing by manufacturer A or B is less than zero. In addition, the difference between benefit and costs shared by both manufacturing enterprises is greater than zero. In this case, $E_1(0,0,0)$ and $E_6(1,1,0)$ are evolutionary equilibrium points. The second situation is $Q_a - C_a - L_a > 0, Q_b - C_b - L_b > 0$ and $P_a + F_a - C_a - L_a < 0, P_b + F_b - C_b - L_b < 0$. When consumers choose to establish a weak dependence on shared-manufacturing products, the difference between the profit and cost of the manufacturing enterprises A and B is greater than zero. In addition, the difference between the benefits and costs shared by both manufacturing companies is less than zero. In this case, $E_3(0,1,0)$ and $E_5(1,0,0)$ are evolutionary equilibrium points.

5. Simulation Analysis

In order to intuitively show the evolution regularity of the evolutionary stable strategy between manufacturing enterprise A, manufacturing enterprise B, and consumers, in this section, taking manufacturing enterprises as an example, we further discuss the equilibrium point of the evolution and stability of the two-party game strategy and the tripartite game strategy. This study uses Matlab to simulate the evolutionary game process dynamically and discusses the influence of parameter changes on resource-sharing enthusiasm and strategy selection. Referring to the research ideas of Qi et al. [33], the values of each parameter are shown in Table 8.

5.1. Simulation Analysis of Initial Policy Selection in the First Stage. This section describes a simulation study on the strategy selection of manufacturing enterprise A. In this paper, the probability of manufacturing enterprise B choosing the sharing strategy is fixed on different values. Based on this, this paper analyzes the influence of the probability of enterprise B choosing the sharing strategy on enterprise A's strategy selection. The calculations fix the probability of manufacturing enterprise B choosing the sharing strategy at the levels of 0.1, 0.5, and 0.9. The simulation diagram of strategy selection of manufacturing enterprise A is shown in Figure 1. Figure 1 demonstrates that under different probabilities, the probability of manufacturing enterprise A choosing the sharing strategy will eventually converge to 1. This shows that no matter how manufacturer B adjusts its strategy, manufacturer A will choose the sharing manufacturing resources strategy.

Table 7: Local stability of the equilibrium point.

Balance point	Case 1				Case 2①				Case 2②			
	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability
$E_1\,(0,0,0)$	+/−	+/−	+	Saddle point	−	−	−	ESS	+	+	−	Unstable point
$E_2\,(0,0,1)$	+/−	+/−	−	ESS	Uncertain	Uncertain	+	Uncertain	Uncertain	Uncertain	+	Uncertain
$E_3\,(0,1,0)$	+/−	+/−	+	Saddle point	Uncertain	+	−	Uncertain	−	−	−	ESS
$E_4\,(0,1,1)$	+	+/−	−	Unstable point	+	Uncertain	+	Uncertain	Uncertain	Uncertain	+	Uncertain
$E_5\,(1,0,0)$	+/−	+/−	+	Saddle point	+	Uncertain	−	Uncertain	−	−	−	ESS
$E_6\,(1,1,0)$	+/−	+/−	+	Saddle point	−	−	−	ESS	+	+	−	Unstable point
$E_7\,(1,0,1)$	+/−	+	−	Unstable point	Uncertain	+	+	Uncertain	Uncertain	+	+	Uncertain
$E_8\,(1,1,1)$	−	−	−	ESS	−	−	+	Unstable point	−	−	+	Unstable point

Table 8: The values of each parameter.

Parameter	Assignment
W_a	13
W_b	13
Q_a	18
Q_b	18
C_a	3
C_b	3
P_a	2.2
P_b	2
F_a	5
F_b	5
C_c	3
R_c	11
L	7
R_a	2
R_b	2
L_a	4
L_b	4
θ	0.5
η	3

In order to conduct simulation research on the strategy selection of manufacturing enterprise B, in this paper, the probability of manufacturing enterprise A choosing the sharing strategy is fixed on different values. Based on this, this paper analyzes the influence of the probability of enterprise A choosing the sharing strategy on enterprise B's strategy selection. The calculations fix the probability of manufacturing enterprise A choosing the sharing strategy at the levels of 0.1, 0.5, and 0.9. Figure 2 shows the simulation diagram of manufacturing enterprise B's strategy selection. Figure 2 demonstrates that under different probabilities, the probability of manufacturing enterprise B choosing the sharing strategy will eventually converge to 1. This shows that no matter how manufacturer A adjusts its strategy, manufacturer B will choose the strategy of sharing manufacturing resources.

The paper comprehensively considers a simulation study on the strategy choice of manufacturing enterprise A and manufacturing enterprise B. In this paper, the probability of manufacturing enterprise A choosing the shared manufacturing resources strategy and manufacturing enterprise B choosing the shared manufacturing resources strategy are fixed at the level of 0.1 to 0.9. The simulation results are shown in Figure 3.

Obviously, under different probabilities, the probability of manufacturing enterprise A choosing the shared manufacturing resources policy will eventually converge to 1. The probability of manufacturing enterprise B choosing the shared manufacturing resources policy also converges to 1. This shows that no matter how the initial strategy probabilities of manufacturing company A and manufacturing company B are adjusted, they will eventually choose a (share, share) strategy. This conclusion conforms to Case 4 of the first-stage evolutionary game.

5.2. Simulation Analysis of Initial Policy Selection in the Second Stage. The first-stage evolutionary game model has a unique ESS $(1, 1)$. This means that manufacturing enterprise A and manufacturing enterprise B will adopt the strategy of sharing manufacturing resources at the same time. However, whether the participation of consumers will affect the above conclusions and how consumers' strategic choices affect the enterprises on the shared manufacturing platform still need to be demonstrated. On this basis, this paper conducts a simulation analysis of the evolutionary game model in the second stage. Fixing the strategy choice probability of manufacturing enterprise A and manufacturing enterprise B, the study analyzes the influence of consumers' dependence on shared-manufacturing products on enterprises. The results are as follows.

According to the initial parameters for evolution research, the participation of consumers will affect the evolution results of enterprises. When consumers join, manufacturing enterprise A and manufacturing enterprise B choose the (share, share) strategy. Furthermore, this makes the tripartite evolutionary game eventually converge to ESS $(1, 1, 1)$, namely, (share, share, establish strong dependence). In addition, even if consumers' reliance on sharing manufacturing products is low, manufacturing enterprises will still choose to share manufacturing resources, as shown in Figure 4(a).

Figures 5(a) and 5(b) show that under the different initial probabilities of the strategy choices of manufacturer A, manufacturer B, and consumers, the tripartite evolutionary game eventually converges to ESS $(1, 1, 1)$. Manufacturing enterprise A finally chooses the share strategy, manufacturing enterprise B finally chooses the share strategy, and consumers finally choose the strategy of establishing strong dependence on shared-manufacturing

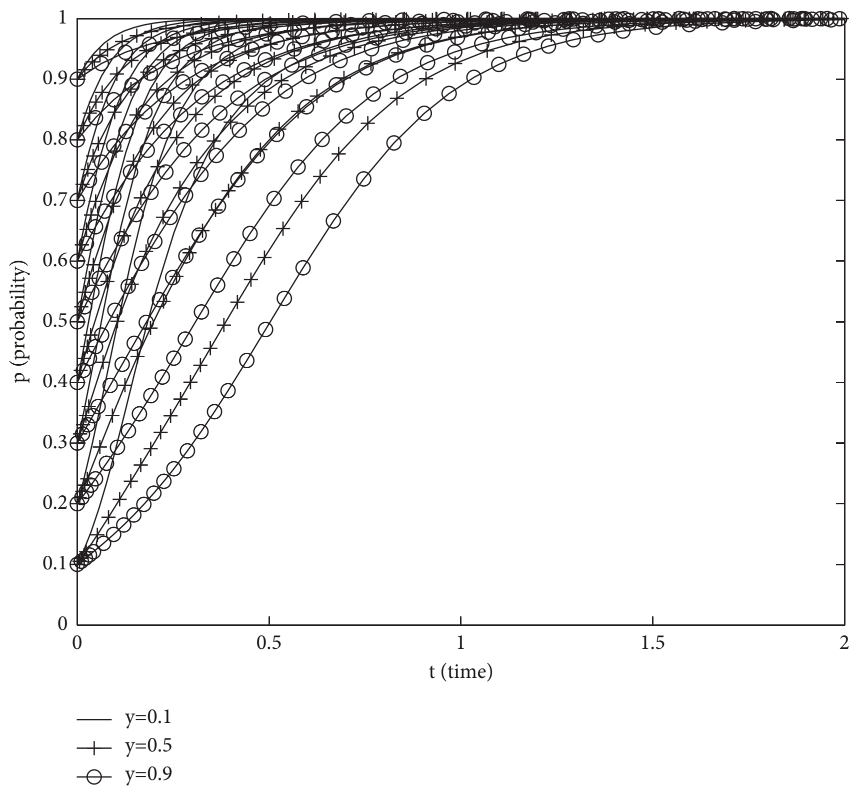


Figure 1: Dynamic evolution process diagram of manufacturing enterprise A's strategy selection.

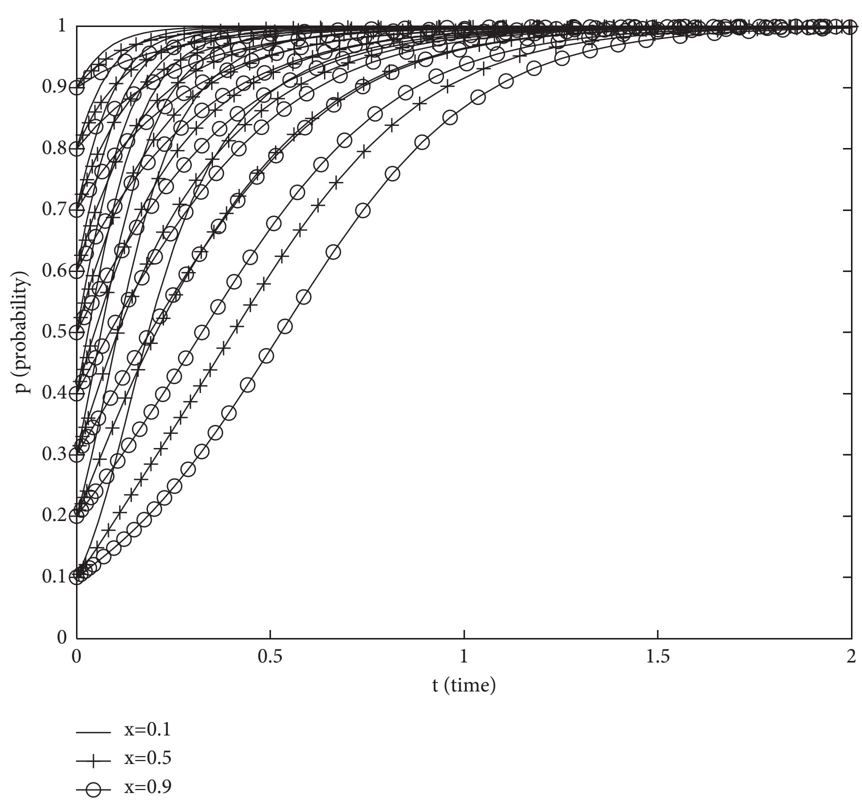


Figure 2: Dynamic evolution process diagram of manufacturing enterprise B's strategy selection.

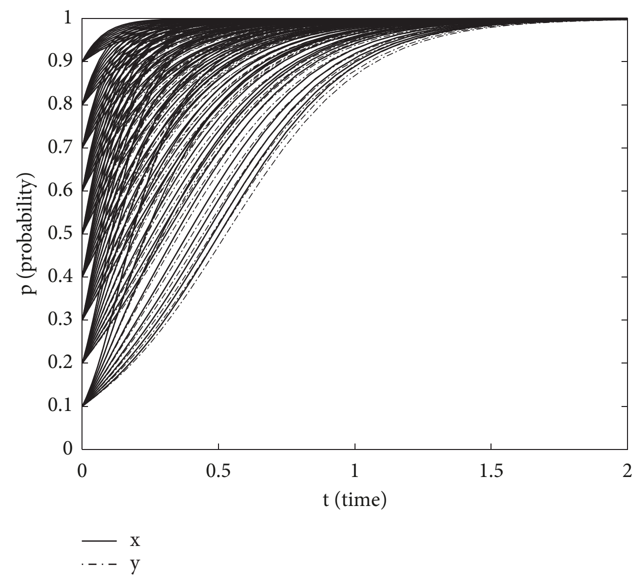


Figure 3: Dynamic evolution process diagram of dual-agent strategy selection.

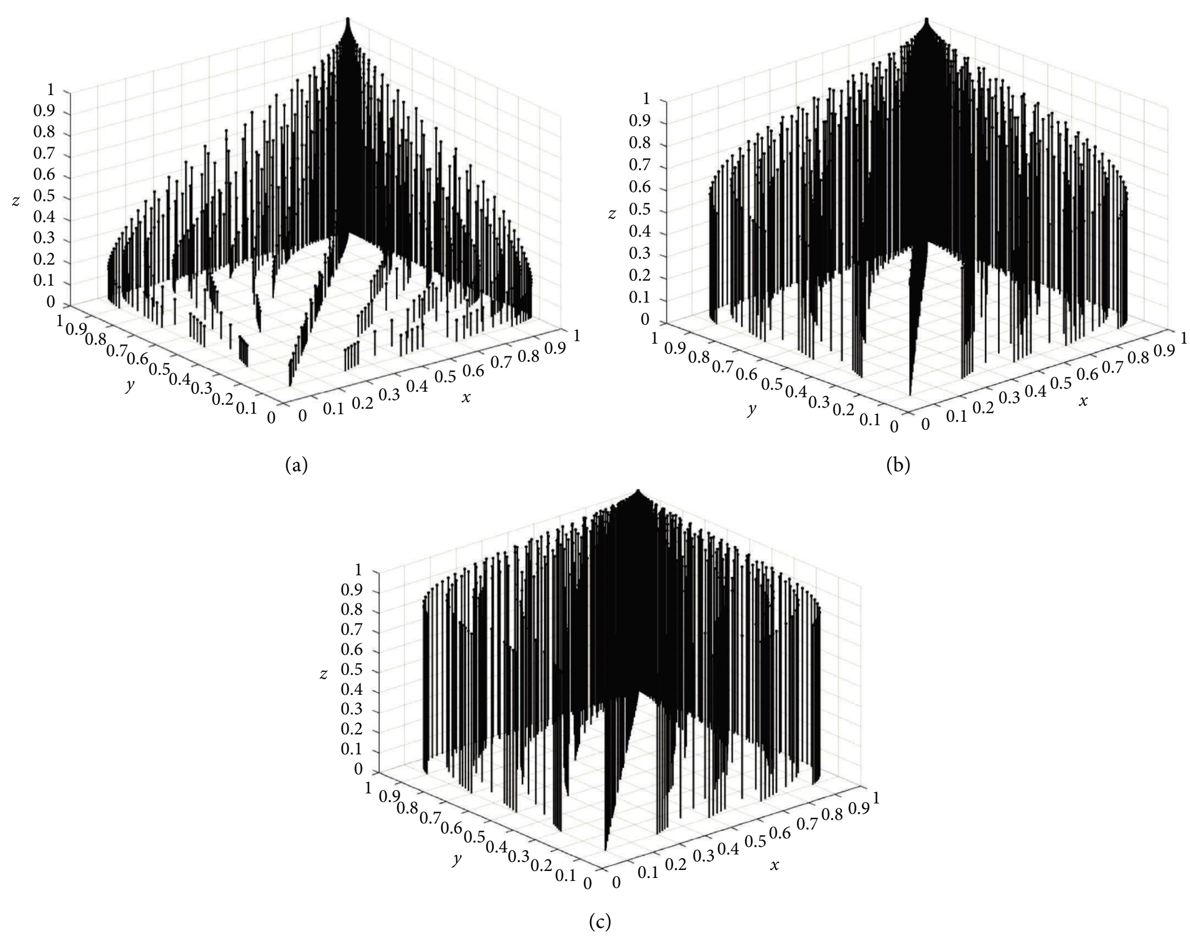
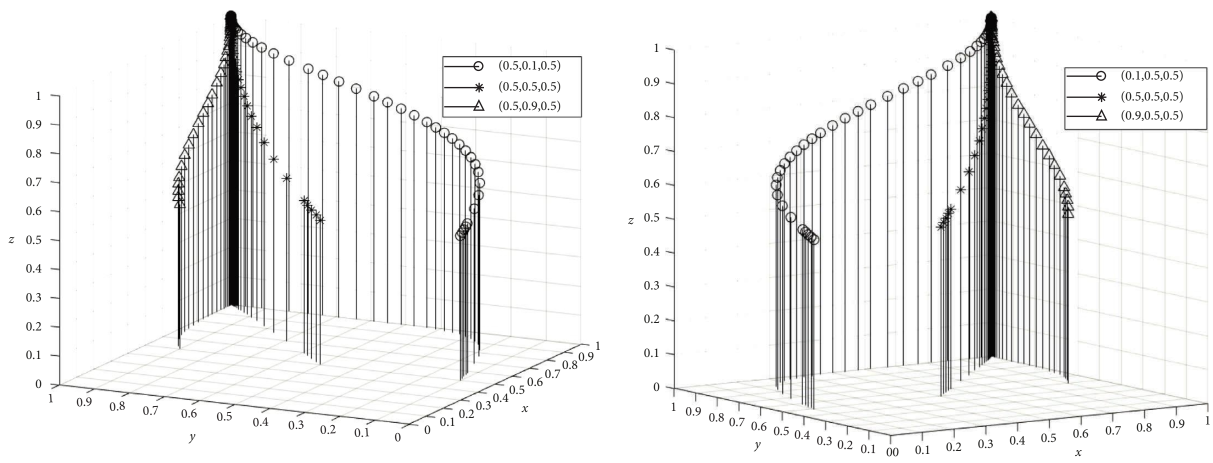


Figure 4: The influence of consumers establishing strong dependence on evolutionary results: (a) $z = 0.1$, (b) $z = 0.5$, and (c) $z = 0.8$.

products. Moreover, the convergence rate of the model increases with the probability. This shows that when manufacturing enterprise A or manufacturing enterprise B has strong willingness to share manufacturing resources, this will promote the dynamic evolution of evolutionary game model to ESS $(1, 1, 1)$.



(a) (b)

FIGURE 5: Dynamic evolution process diagram of manufacturing enterprise strategy choice changes. (a) The effect of "y" on the evolution result. (b) The effect of "x" on the evolution result.

5.3. Simulation and Analysis of Strategy under Dynamic Factors. The driving factors between enterprises and consumers on the shared manufacturing platform are divided into two dimensions: endogenous factors and exogenous factors. Endogenous power refers to the selection of internal dynamic capabilities of sharing manufacturing enterprises, including the ability of manufacturing enterprises to express business needs, and the cost of internal upgrading and transformation. The exogenous dynamic factor refers to the pulling effect of consumers on enterprise sharing manufacturing, including the active participation of consumers and the value brought by consumer incentive systems.

5.3.1. Strategy Simulation and Analysis under the Influence of Endogenous Dynamic Factors. Figure 6 shows the simulation result of the combination evolution of manufacturing enterprise A, manufacturing enterprise B, and consumer strategy when manufacturing enterprise A changes the cost of sharing manufacturing. Figure 6 demonstrates that with the increase in the collaboration cost of manufacturing enterprise A, manufacturing enterprise B is more willing to choose shared manufacturing. The cost increase of manufacturer A does not affect the choice of strategy but only affects the speed of collaboration. Additionally, consumers will form a strong dependence on shared-manufacturing products. The result is that tripartite evolution approaches equilibrium point $(1, 1, 1)$. The simulation results show that with the participation of enterprises and consumers, the unilateral upgrading of shared manufacturing is beneficial to adjust the cooperative relationship of enterprises on the shared manufacturing platform. It can also promote consumers to choose shared-manufacturing products.

Figure 7 shows the simulation result of the combination evolution of manufacturing enterprise A, manufacturing enterprise B, and consumer strategy when manufacturing enterprise B changes the cost of sharing manufacturing. Figure 7 demonstrates that manufacturing enterprise A is not sensitive to the change of upgrading cost of manufacturing enterprise B. On the contrary, due to the increase of internal cost, the convergence rate of manufacturing enterprise B close to the deep synergy intention decreases. However, the increase in internal cost does not lead to the breakdown of the final collaboration, and the evolution results will approach the equilibrium point $(1, 1, 1)$. The conclusion is that unilateral cost changes cannot affect the willingness of each subject to choose to share manufacturing resources. Consumers are hardly affected by the benefits and costs of shared manufacturing enterprise members.

5.3.2. Strategy Simulation and Analysis under the Influence of Exogenous Dynamic Factors. Figure 8 shows the simulation result of the evolution of the strategy combination of manufacturing company A, manufacturing company B, and consumers when θ is changed. As the value of θ continues to rise, the convergence rate of consumers' strong willingness to share manufactured goods will decrease. The convergence rate has little effect on the convergence time of the strategy choice of manufacturing enterprise A and manufacturing enterprise B. Finally, x, y, z approach 1, and the evolution approaches the equilibrium point $(1, 1, 1)$. The results show that when consumers choose to establish a weak dependence on sharing manufacturing products, manufacturing enterprises also tend to choose the strategy of sharing manufacturing resources. The reason is that consumers go deep into the manufacturing process of enterprises in this case. Enterprises directly connect with consumer demand. The participation of consumers in corporate manufacturing makes the relationship between the two parties closer. In addition, the sharing of manufacturing resources among enterprises can promote strong dependence between consumers and enterprises.

Figure 9 shows the simulation result of changing the relationship between input cost and revenue when consumers rely heavily on shared-manufacturing products.

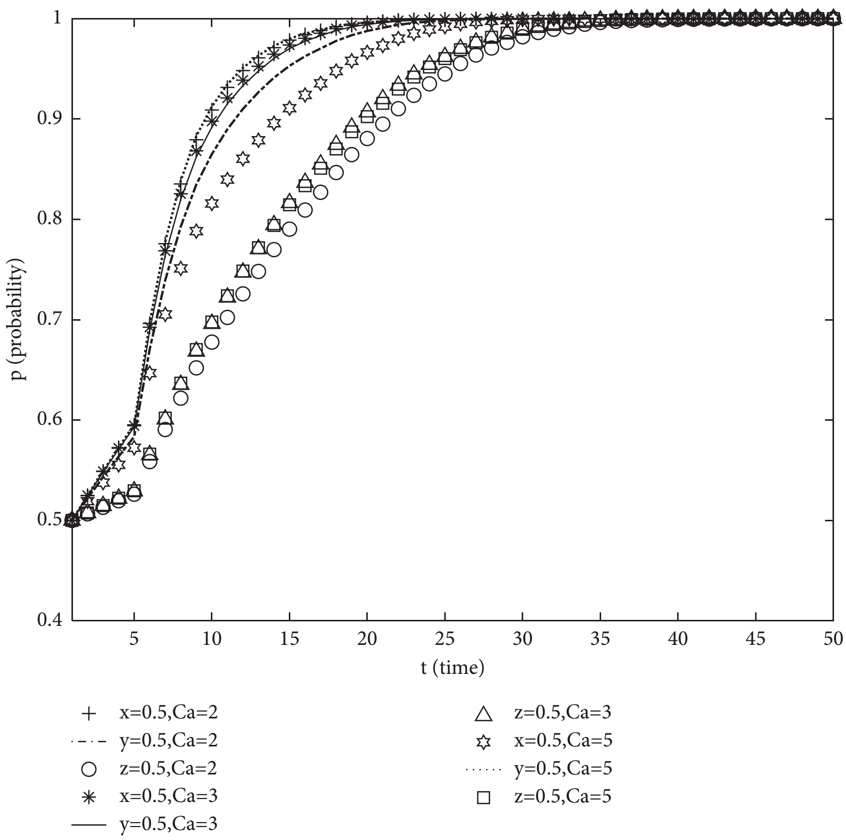


Figure 6: The result of C_a change on relationship evolution.

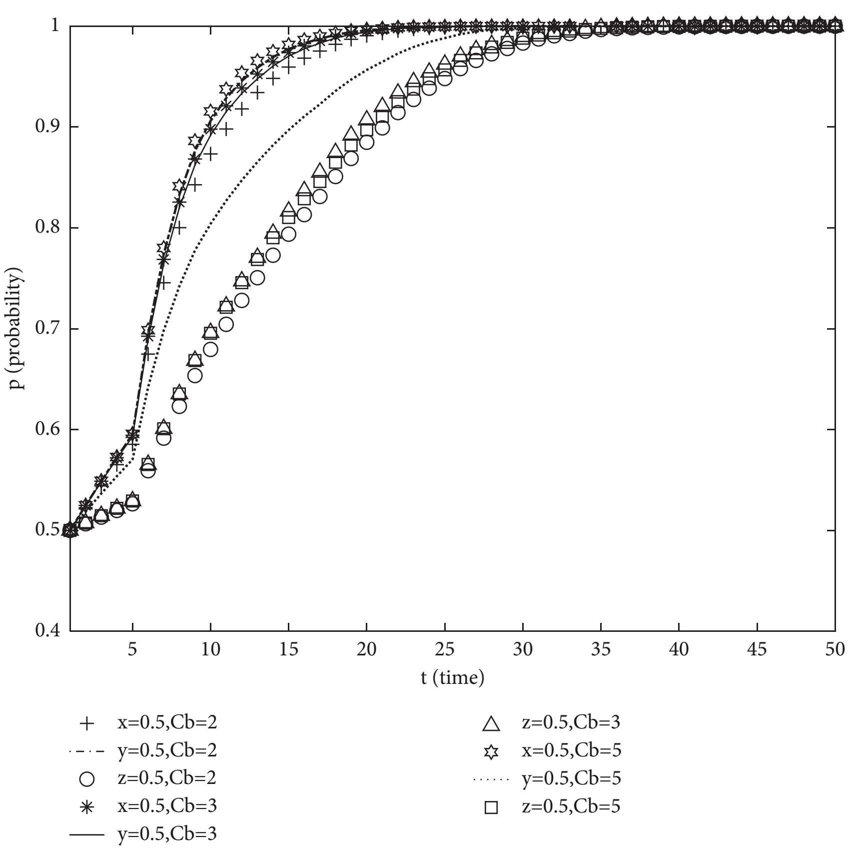


Figure 7: The result of C_b change on relationship evolution.

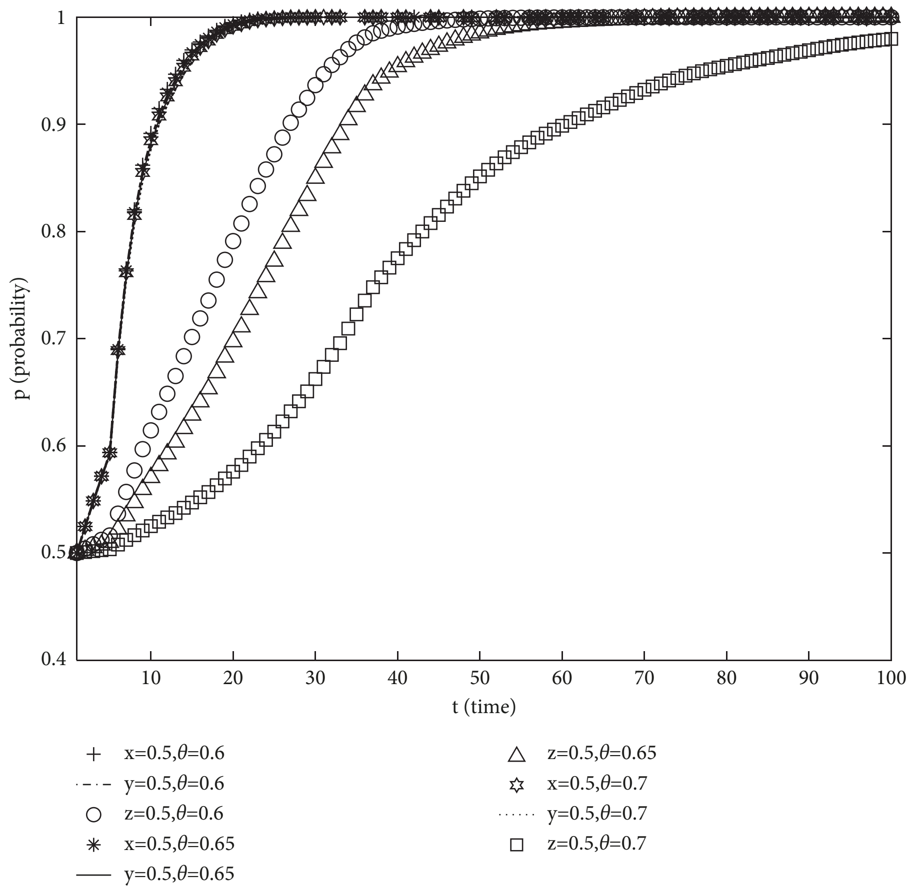


Figure 8: The result of θ change on relationship evolution.

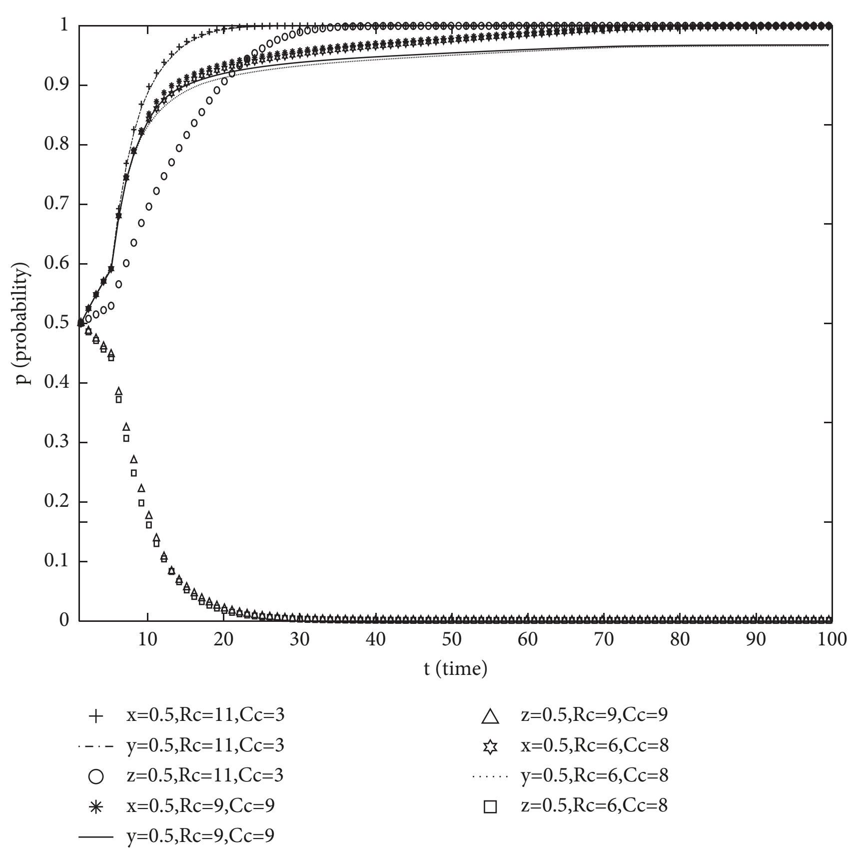


Figure 9: The result of changes in R_c and C_c on relationship evolution.

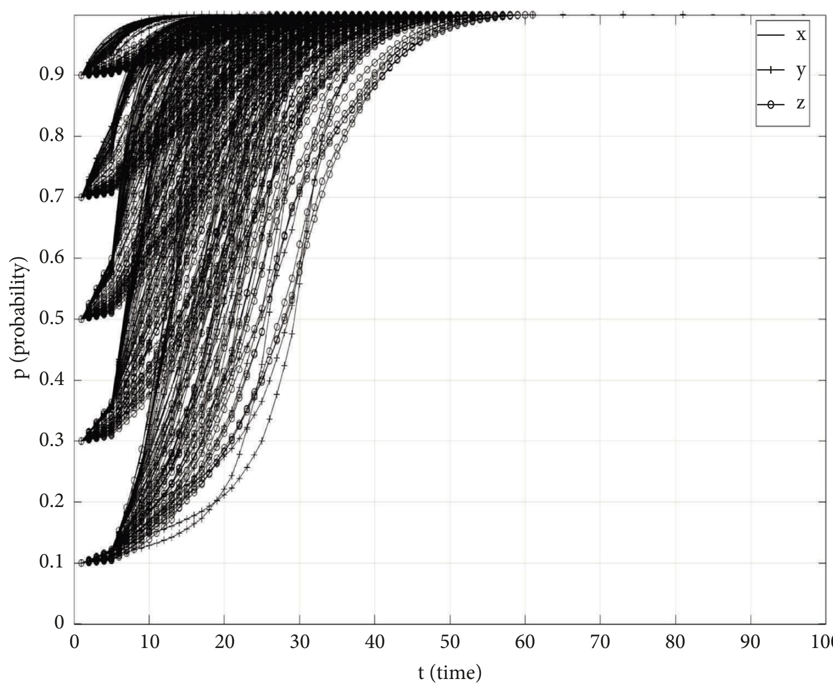


Figure 10: The dynamic evolution process diagram of the strategy selection of tripartite game subject.

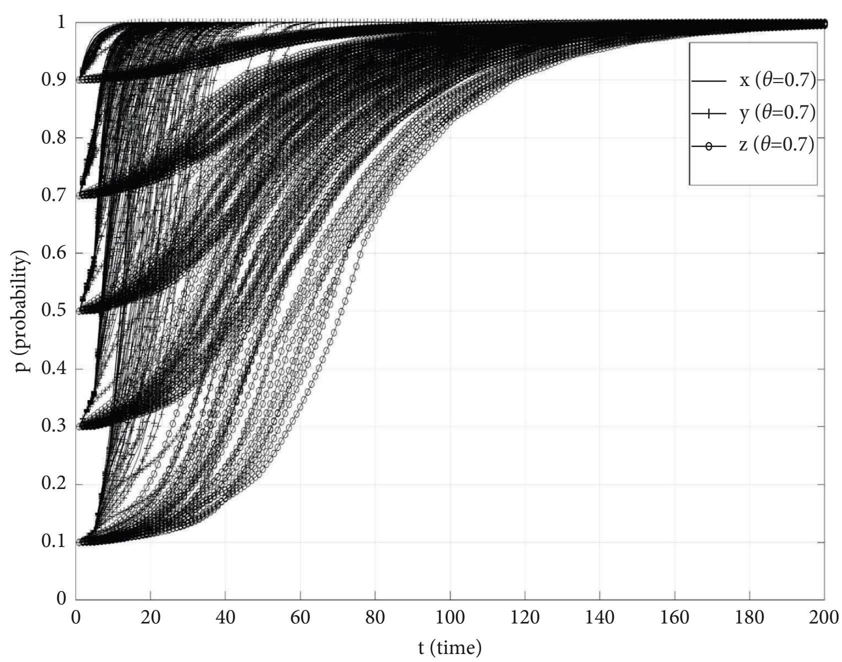


Figure 11: The dynamic evolution process diagram of the strategy selection of the tripartite game subject when $\theta = 0.7$.

Figure 9 demonstrates that when the cost of establishing a strong dependence relationship for the shared manufacturing product is lower than the benefit, the evolutionary strategies of manufacturing enterprise A, manufacturing enterprise B, and consumers eventually converge to the equilibrium point $(1, 1, 1)$, namely, (share, share, establish strong dependence). When the cost of establishing a strong dependency on a shared manufactured product is equal to the benefit, manufacturing company A chooses shared manufacturing, consumers choose to establish weak dependence on shared-manufacturing products, and manufacturing company B has no equilibrium state. At this time, the tripartite evolution model has no equilibrium point. When consumers build strong dependencies on shared manufactured products, the cost of investment is higher than the benefit, manufacturing company A chooses shared manufacturing, consumers choose to establish weak dependence on shared-manufacturing

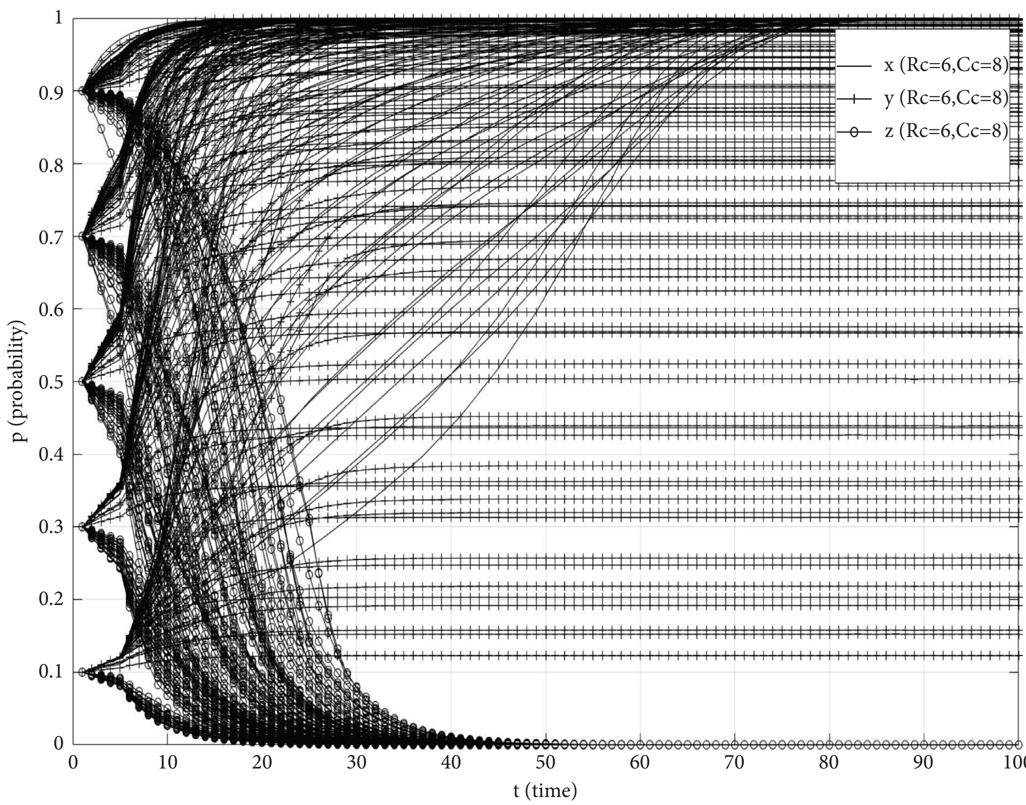


FIGURE 12: The dynamic evolution process diagram of the strategy selection of the tripartite game subject when $R_c < C_c$.

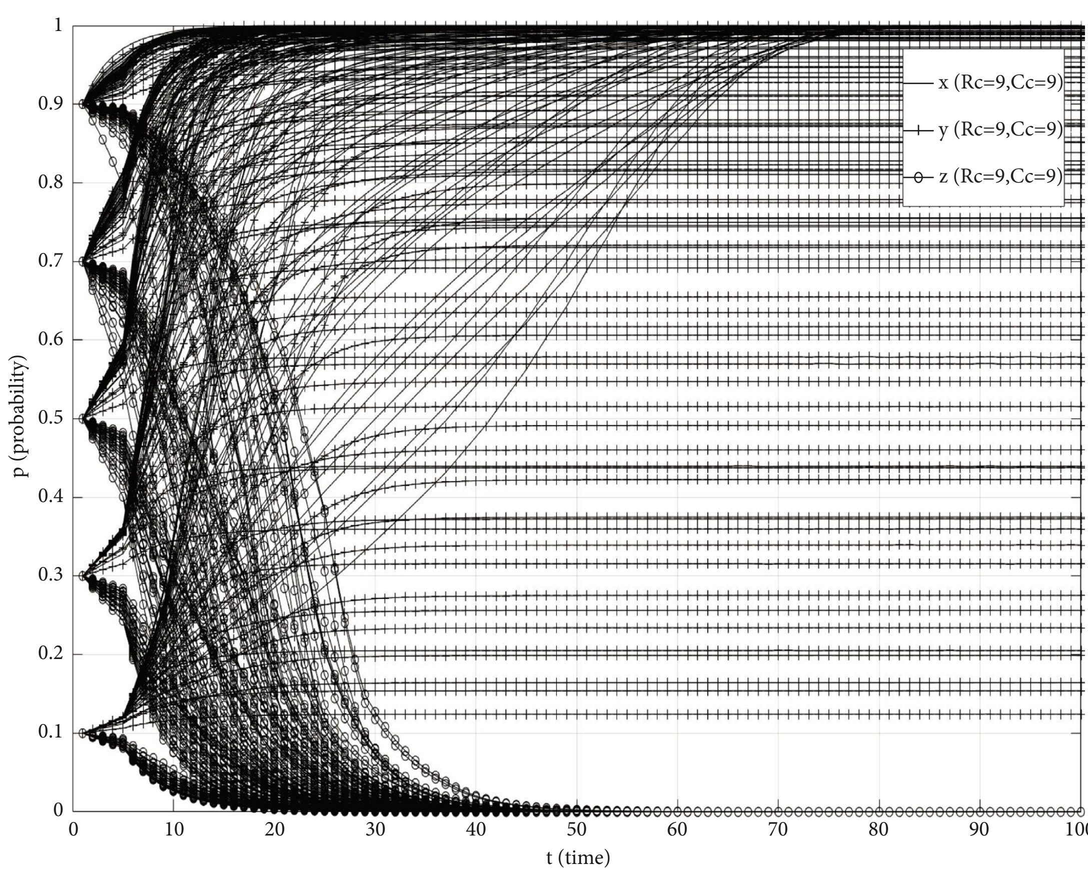


FIGURE 13: The dynamic evolution process diagram of the strategy selection of the tripartite game subject when $R_c = C_c$.

products, and manufacturing company B has no equilibrium state. The tripartite evolution model also has no equilibrium point. In summary, only when the cost of consumers' investment in establishing a strong dependence on shared-manufacturing products is lower than the benefit, the evolution results will converge to the equilibrium point $(1, 1, 1)$. In other cases, the equilibrium cannot be reached. This suggests that consumer participation influences strategic choices among manufacturing firms. Consumers need to control the relationship between investment and income of their dependence on shared-manufacturing products in order to promote shared manufacturing between manufacturing enterprises. Otherwise, consumers will only promote the sharing of manufacturing resources by unilateral enterprises. Consumers' dependence on shared-manufacturing products will also be reduced.

5.4. Simulation and Analysis of Subject Strategy Selection in the Tripartite Game. This section comprehensively considers the impact of the initial strategies of manufacturer A, manufacturer B, and consumers on the stability point of the evolutionary game model. In the simulation process, the probability initial value of the tripartite game subject is fixed at the level of 0.1 to 0.9 according to the initial parameters, and the results are shown in Figure 10. Obviously, the strategy selection of manufacturing enterprise A eventually converges to the sharing manufacturing resource strategy, and the strategy selection of manufacturing enterprise B finally converges to the sharing manufacturing resource strategy. Consumers finally choose the strategy of establishing strong dependence on shared-manufacturing products. The above results are consistent with the second-stage evolutionary game Case 1. Compared with the first-stage evolutionary game model, it is found that consumer choice will affect the convergence time of manufacturing enterprise strategy selection but will not lead to the breakdown of the final deep synergy. When the probability of consumers' strong dependence on shared manufactured products gradually increases, the speed of the game model's convergence to ESS $(1, 1, 1)$ will be accelerated.

If changing the initial parameter setting, change θ to 0.7. This situation weakens the strong dependence of consumers on shared manufactured products. The initial probability of the strategy selection of the tripartite game subject is fixed at the level of 0.1 to 0.9, and the simulation results are shown in Figure 11. The change of θ value does not change the tripartite equilibrium strategy, but the convergence rate of consumers' strong dependence on shared-manufacturing products is reduced. The evolution will eventually converge to the equilibrium point $(1, 1, 1)$, namely, (share, share, establish strong dependence).

Both of the two situations described above in this paper are the evolution process when consumers' input cost of establishing strong dependence on shared-manufacturing products is lower than the income. Excluding the above situation, the initial value of the strategy selection of the tripartite game subject is fixed at the level of 0.1 to 0.9, and the simulation results are shown in Figures 12 and 13. The result is that manufacturing enterprise A finally chooses the sharing strategy, and consumers finally choose strong dependence on shared-manufacturing products. The probability of manufacturing enterprise B's strategy selection is not stable. Therefore, the participation of consumers will affect the strategy choice between manufacturing enterprises. When consumers choose shared manufacturing, products can gain profits, the enthusiasm of consumers to participate in enterprise shared manufacturing will be greatly enhanced, and consumers are more willing to choose shared-manufacturing products. Under this trend, enterprises have the motivation to share manufacturing resources, which is conducive to promoting the collaboration between manufacturing enterprises on the platform.

6. Conclusions and Implications

6.1. Discussion. These basic findings are consistent with the hypothesis. When the two enterprises on the shared manufacturing platform play game, no matter how the parameter value changes, the two enterprises will choose the shared manufacturing strategy. This is consistent with the research studies of most former scholars. The shared manufacturing strategy can reduce costs, improve enterprise efficiency, and promote high-quality development of enterprises. In the process of adding consumers to the game, consumers' strategic choices will affect the results of the tripartite game. They are influenced by costs, benefits, consumer dependence, penalties, etc.

Compared with previous studies, our research broadens the perspective of evolutionary game. On the basis of exploring the influence between enterprises, this paper further introduces the strategic influence of consumers, which enriches the research of shared manufacturing and has certain value.

6.2. Conclusions. Based on the premise of bounded rationality, this paper deeply analyzes the driving benefits and internal mechanism of enterprise resources sharing on the shared manufacturing platform. The study constructs a two-stage evolutionary game model, and combined with the theory of system dynamics, it analyzes in detail the strategy choice and evolutionary behavior of each participant.

The results show the following: (1) On the shared manufacturing platform, in the evolutionary game model of enterprises A and B, the two sides are more inclined to adopt the shared manufacturing resources strategy with high resource utilization and good benefit. (2) When consumers participate in the tripartite game model of manufacturing enterprise A, manufacturing enterprise B, and consumers, this participation will have a certain impact on the strategic choice of manufacturing enterprises. There are two main aspects. First, when θ is larger, consumers' strong dependence on shared-manufacturing products decreases. The change of θ value does not change the equilibrium strategy of the three parties, but the convergence rate of consumers' strong dependence on shared-manufacturing products is reduced. The tripartite equilibrium strategy is (share, share, establish strong dependence). The second aspect is the relationship between the cost of consumer input and the benefit obtained when consumers strongly rely on shared-manufacturing products. When the input cost is lower than the benefit, the tripartite equilibrium strategy does not change. In other cases, manufacturing enterprise A eventually chooses the share strategy, and consumers finally choose to establish a strong dependence on shared-manufacturing products. The probability of manufacturing enterprise B strategy selection is not stable. (3) Consumers' strong dependence on shared-manufacturing products facilitates shared manufacturing among enterprises. However, even if consumers are less dependent, manufacturing enterprises still choose to share manufacturing resources. (4) Enterprises on a shared manufacturing platform are affected by sharing manufacturing costs, benefits, consumer dependence, and penalties. Changes in any of the above parameters may cause tripartite players to adjust their strategies, but the direct benefit of a single cooperation has no effect on evolutionarily stable strategies. This shows that enterprises pay more attention to the long-term benefits brought by sharing manufacturing resources rather than just a single cooperative benefit.

6.3. Implications. As a strategic basis, shared manufacturing is crucial to the digital transformation and high-quality development of the manufacturing industry. Compared with the existing literature, this paper not only provides a different perspective for enterprise decision-making on the shared manufacturing platform but also provides ideas for consumers' decision-making behavior. The simulation results of this paper are of great significance both in theory and in practice. From the above analysis, firstly, strengthen technical support. Enterprises should coordinate the construction of technical facilities such as industrial Internet, blockchain, 5G, and artificial intelligence to provide technical support for the sharing of manufacturing resources between enterprises and enhance the digital capabilities involved in production and operation. Secondly, reduce shared manufacturing costs. In order to realize shared manufacturing, enterprises need to consider the cost-benefit ratio of transformation. For different types of manufacturing resources, standardized equipment and transmission technology should be developed to ensure the stability and control of shared manufacturing processes. Finally, strengthen customer enterprise interaction. Enterprises should build a real-time interactive platform for customers. Customers gain a sense of engagement and build strong dependencies on shared manufactured products. Consumers should pay attention to identity conversion. Consumers are not traditional passive value recipients, but dominant in value creation. They should actively participate in the interaction between themselves and enterprises and control their own input costs in the process of participation, so as to better promote the shared manufacturing of enterprises.

6.4. Limitations. The conclusions of this paper provide a decision-making basis for whether the enterprises on the shared manufacturing platform participate in the sharing and consumers' participation strategies. The limitation of this paper is that the assumptions and parameter settings are ideal and cannot meet the complex situation of real activities. In the future, research should further study the influence mechanism of consumer uncertainty behavior on enterprise shared manufacturing and the difference of strategy selection.

Data Availability

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

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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