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Evolution Analysis of Manufacturing Supply and Demand Resource Sharing Decision-Making in Complex Assembly Platform Environment

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Abstract

This paper mainly researches the resource sharing with the manufacturer as the platform leader and the supplier as the platform participant in the environment of shared complex assembly platform based on cloud platform. Considering the limited rationality of the game players, the selection process and influencing factors of manufacturing resource sharing strategy are studied based on evolutionary game theory. The main findings are as follows: the excess revenue of supply chain has a positive impact on promoting complex assembly resource sharing and cooperation; cooperative cost and speculative profit can reduce the probability of platform resource sharing and cooperation; there is an optimal proportion of excess revenue distribution which makes the cooperation most likely to succeed. And then, under the conditions of maximizing their own benefit and the boundaries of available benefits, the mapping relationship between the revenue distribution coefficient and the probability of successful cooperation is established, which is verified by numerical simulation experiments. These results can provide decision-making reference for formulating reasonable shared assembly manufacturing supply chain revenue distribution mechanism.

Keywords

Complex Equipment Manufacturing, Electric Assembly Supply Chain, Resource Sharing, Evolutionary Gaming

1. Introduction

With the development of computers and Internet, cloud platforms are gradually forming, which make it possible to share information, resources, and manufacturing capabilities between enterprises (Li et al., 2010; Xu et al., 2015; Xun et al., 2012). Nowadays, no product is completed by one company alone. The shared assembly manufacturing platform based on cloud platform realizes the sharing of assembly manufacturing capabilities and resources, and they are packaged on demand to meet the manufacturing needs of enterprises (Liu et al., 2015a). To win the market, modern complex assembly manufacturing enterprises have gradually built manufacturing supply chain which own high quality management and rapid response to market demand (Yang et al., 2015; Ding, 1996). Market competition among manufacturing enterprises has turned into competition among manufacturing supply chains (Nair, 2001).

However, in the actual supply chain operation, resource idleness and resource shortage often coexist and limit the overall operation efficiency of the manufacturing supply chain. The contradiction between them has become one of the important problems that restrict the overall operation efficiency of the complex assembly manufacturing supply chain. Resource sharing among members can provide a new way to solve the problem. Through resource sharing, the problem of supply chain manufacturing capacity shortage caused by uneven distribution of resources can be solved.

The article is organized into 7 sections. Accordingly, the first section is an introduction of the background and meaning of the paper. The second section is the literature. The third and forth part is the main contest of the paper, which describe the evolutionary game of resource sharing in manufacturing supply chain and analyze the relevant parametric of the model. The fifth and sixth part is another main contest of the paper, which study the optimal supply chain excess income distribution and analyze the trend of system evolution under different revenue states. The seventh part summarizes the content of the paper.

2. Literature Review

2.1. Resource Sharing Strategy for Manufacturing Supply Chain

Scholars have carried out extensive research on manufacturing resource sharing. Pan et al. (2018) studied the pricing strategy and capacity allocation of each participant of cloud platform. Nayak et al. (2016) studied the scheduling problem of shared resources by combining social welfare function. Cao et al. (2020) established a trust model based on the historical information of cloud manufacturing platform. Li et al. (2018) proposed a scheduling model in distributed manufacturing resource sharing environment and Liu et al. (2015b) studied the complexity of business interaction caused by manufacturing resource sharing. Wang & Huang (2012) studied key technologies in cloud manufacturing environment based on the concept of service manufacturing chain and Shi et al. (2017) analyzed the architecture of intelligent manufacturing shared business model by taking Shenyang Machine Tool as an example. Besides, the establishment of cooperative relationship and resource selection among enterprises based on cooperative game theory is also studied (Argoneto & Renna, 2016). The above literatures have carried out a comprehensive study on assembly and manufacturing resource sharing in the aspects of system framework, key technology, and business operation mode.

The studies have mainly focused on the resource sharing game behavior among equal actors in the supply chain, and generally have not considered the relationship between leaders and participants in the manufacturing supply chain, which leads to the inability to accurately portray the competing relationship of resource sharing in this type of supply chain.

2.2. Influence Factors for Resource Sharing

The research of factors influencing resource sharing and incentive strategies in manufacturing supply chain has attracted scholars' attention. Zhao & Run (2018) established a game model and studied the influence of sharing strategy on profits of supply chain members under cloud manufacturing. Qi et al. (2017) established an evolutionary game model to analyze the influence of different income parameters on the evolutionary results. Hao & Zhao (2021) constructed a three-party group evolutionary game model and discussed the influence of parameters on the game strategies of all parties. The operation process of manufacturing supply chain is complex. Therefore, it's inevitable to establish cooperative relations among supply chain members (Zeng et al., 2005; Huang et al., 2005). In automobile supply chain, for example, the factory establishes the cloud manufacturing platform and takes on a leadership role to promote resources sharing (Li, 2015). Similarly, Airbus, Dassault Aviation, Safran and Thales have jointly established Boost Aerospace, Xi'an Aircraft Industry built a cloud manufacturing platform to solved the problem of remote collaboration with suppliers (Wang et al., 2017). However, the leaders or participants cannot formulate their own revenue maximization strategies for bounded rationality, and they expect other members to make more efforts which called "free-riding". Therefore, it's necessary to explore the sharing strategy between the leaders and participants.

This paper constructs an evolutionary game model of resource sharing in the electronics assembly manufacturing supply chain in the cloud platform environment with the manufacturer as the leader and the supplier as the participant. And the paper systematically analyzes the evolutionary paths and influencing factors of their decisions, and designs a benefit distribution mechanism to facilitate the supply chain to finally reach a stable cooperation.

3. Evolutionary Game of Resource Sharing in Manufacturing Supply Chain

3.1. Modeling

To better diatribe the model scenario, we take a manufacturing supply chain for electronics assembly as an example. There exist three main assembly processes in the assembly of electronic products: printed circuit board assembly (PCA), complete electronic assembly and cable assembly. Electronic assembly has a standard assembly process and the demand for parts is relatively fixed, which can be used as a representative of the manufacturing supply chain. The manufacturing supply chain mentioned below refers to the supply chain for electronic assembly.

In the cloud platform environment of complex assembly supply chain, manufacturers are in a leading position, and establish resource sharing platform. Suppliers can choose whether to participate in the platform and share their resources. Based on this, the following hypotheses are proposed.

1) Both the manufacturers and suppliers make decisions for benefit maximization, and they are hard to find the best strategy at the beginning of the game. But they will adjust strategies with other's strategy.

2) Both manufacturers and suppliers have two strategies as the leader of the platform, manufacturers can choose to actively manage the platform, for example, to improve the efficiency of resource matching on the platform. But manufacturers are also likely to choose passive management to reduce operating costs after forming the platform. Therefore, the manufacturer's policy set is (active management, passive management). Similarly, the supplier's strategy set is (participate, not participate). Manufacturer's active management strategy and supplier's participation strategy is cooperation strategy. Manufacturer negative management strategy and supplier non-participation strategy is speculative strategies.

3) The probability that the manufacturer chooses active management strategy is x and the probability that the supplier chooses to participate is y. Among them, $0 \le x \le 1$, $0 \le y \le 1$.

In the game, the influencing factors of manufacturer and supplier strategy selection are shown as **Table 1**.

Based on the above assumptions, the payment game matrix is established as shown in **Table 2**.

The benefit that manufacturer chooses active management strategy is:

$$E_{M1} = y\left[U + (1-\alpha)\Delta U_1 - D - G\right] + (1-y)(U - D - G) \tag{1}$$

The benefit that manufacturer choose negative management strategies is:

$$E_{M2} = y\left[U + \Delta U_2 - D\right] + (1-y)(U - D) \tag{2}$$

The expected revenue of manufacturer's mixed strategy is:

$$E_M = xE_{M1} + (1-x)E_{M2} \tag{3}$$

Similarly, the return for suppliers choosing to participate is E_{S1}, non-participation strategy is E_{S2} and mixed strategy E_S are as follows:

$$E_{S1} = x(R + \alpha\Delta U_1 - C + \Delta R_1) + (1-x)(R - C + \Delta R_2) \tag{4}$$

$$E_{S2} = x(R + W) + (1-x)R \tag{5}$$

Table 1. Model parameters and significance.

Parameters	Significance
U	The net income that a manufacturer can obtain by operating alone
R	The net income that a supplier can obtain by operating alone
D	The cost invested by the manufacturer to establish the resource sharing platform
G	The extra overhead that the manufacturer pays to choose an aggressive strategy
C	The cost of hardware and software upgrades or purchases by the supplier for participating platforms
ΔU_1	Excess revenue increment of supply chain when manufacturer actively manages and supplier participates
ΔU_2	The incremental speculative revenue of the manufacturer when manufacturer passively manages and supplier participates
ΔR_1	The incremental revenue of supplier when supplier participates in resource-sharing platform and manufacturer manages actively
ΔR_2	The incremental revenue of supplier when supplier participates in resource-sharing platform but manufacturer manages passively
w	The spillover benefits of platform technology when manufacturer actively manages and supplier doesn't participate
α	Incremental distribution coefficient of excess revenue in supply chain when manufacturer actively manages and supplier participates

Table 2. Payment matrix of manufacturer and supplier game.

The game		Manufacturer (Leader)	
		Active management	Passive management
Supplier (participant)	Participation	$U+(1-\alpha)\Delta U_1-D-G$, $R+\alpha\Delta U_1-C+\Delta R_1$	$U+\Delta U_2-D$, $R-C+\Delta R_2$
	Nonparticipation	$U-D-G$, $R+W$	$U-D$, R

$$E_S = yE_{S1} + (1-y)E_{S2} \tag{6}$$

The dynamic equation of the system's evolutionary game replication is:

$$\begin{cases} F(x) = \frac{\mathrm{d}x}{\mathrm{d}t} = x(1-x)\left[y(1-\alpha)\Delta U_1 - y\Delta U_2 - G\right] \\ F(y) = \frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y)\left[x(\Delta R_1 + \alpha\Delta U_1 - \Delta R_2 - W) - C + \Delta R_2\right] \end{cases} \tag{7}$$

Let $F(x)=0$, $F(y)=0$, get the answer that (0, 0), (0, 1), (1, 1), (1, 0) and (x^*, y^*) are the five local equilibrium points of the system, and

$$x^* = \frac{C-\Delta R_2}{\Delta R_1 + \alpha\Delta U_1 - \Delta R_2 - W}, \quad y^* = \frac{G}{(1-\alpha)\Delta U_1 - \Delta U_2}.$$

3.2. Model Solution

The evolutionary stability strategy (ESS) of the system can be obtained by analyzing the local stability of the Jacobi matrix (Friedman, 1998). According to

Equation (7), the Jacobi matrix (*J*) of the system is:

$$J=\begin{bmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y}\end{bmatrix}=\begin{bmatrix}a_1 & a_2\\ b_1 & b_2\end{bmatrix} \tag{8}$$

s. t.

$$a_1=(1-2x)\left[y(1-\alpha)\Delta U_1-y\Delta U_2-G\right]$$

$$a_2=x(1-x)\left[(1-\alpha)\Delta U_1-\Delta U_2\right]$$

$$b_1=y(1-y)\left[\Delta R_1+\alpha\Delta U_1-\Delta R_2-W\right]$$

$$b_2=(1-2y)\left[x(\Delta R_1+\alpha\Delta U_1-\Delta R_2-W)-C+\Delta R_2\right]$$

Therefore, it is easy to obtain the specific values of them at the equilibrium points, as shown in Table 3.

Where $A=\frac{(C-\Delta R_2)(\Delta R_1+\alpha\Delta U_1-U-C-W)\left[(1-\alpha)\Delta U_1-\Delta U_2\right]}{(\Delta R_1+\alpha\Delta U_1-\Delta R_2-W)^2}$, $B=\frac{G\left[(1-\alpha)\Delta U_1-\Delta U_2-G\right](\Delta R_1+\alpha\Delta U_1-\Delta R_2-W)}{\left[(1-\alpha)\Delta U_1-\Delta U_2\right]^2}$.

According to the judgment method of system evolution stability strategy to discuss the stability of system equilibrium point under different values of ΔR_2-C, $(1-\alpha)\Delta U_1-\Delta U_2-G$ and $\Delta R_1+\alpha\Delta U_1-W-C$.

1) $\Delta R_2-C>0$

$\Delta R_2-C>0$ indicates that when the manufacturer is in negative management, the net income that the supplier choosing to participate is positive. As can be seen from Table 2, under this condition, point (0, 0) is not a stable strategy. The stability of the remaining equilibrium points can be analyzed according to the different conditions of $(1-\alpha)\Delta U_1-\Delta U_2-G$ and $\Delta R_1+\alpha\Delta U_1-W-C$, and the results are shown in Table 4.

Case (1): $(1-\alpha)\Delta U_1-\Delta U_2-G<0$ and $\Delta R_1+\alpha\Delta U_1-W-C>0$

Under the condition that suppliers choose to participate, the benefit of manufacturer's active management strategy is smaller than negative strategy, and the benefit of suppliers choosing to participate is greater than not to participate in resource sharing if manufacturers choose to manage actively.

Table 3. Values of local equilibrium points.

equilibrium point	a_1	a_2	b_1	b_2
(0, 0)	$-G$	0	0	ΔR_2-C
(0, 1)	$(1-\alpha)\Delta U_1-\Delta U_2-G$	0	0	$-(\Delta R_2-C)$
(1, 0)	G	0	0	$\Delta R_2+\alpha\Delta U_1-W-C$
(1, 1)	$G+\Delta U_2-(1-\alpha)\Delta U_1$	0	0	$W+C-\Delta R_1-\alpha\Delta U_1$
(x^*,y^*)	0	A	B	0

Table 4. Stability analysis of system equilibrium points in 4 cases under $\Delta R_2 - C > 0$.

	Case (1)			Case (2)			Case (3)			Case (4)		
equilibrium point	*deJ*	*trJ*	Stability	*deJ*	*trJ*	Stability	*deJ*	*trJ*	Stability	*deJ*	*trJ*	Stability
(0, 0)	−	N/A	Saddle point	−	N/A	Saddle point	−	N/A	Saddle point	−	N/A	Saddle point
(0, 1)	+	−	ESS	+	−	ESS		N/A	Saddle point	+	+	Unstable point
(1, 0)	+	+	Unstable point	−	N/A	Unstable point	+	+	Unstable point	−	N/A	Saddle point
(1, 1)	−	N/A	Saddle point	−	N/A	Saddle point	+	−	ESS	−	N/A	Saddle point

Case (2): $(1-\alpha)\Delta U_1 - \Delta U_2 - G < 0$ and $\Delta R_1 + \alpha \Delta U_1 - W - C < 0$

Case (1) and case (2) illustrate that the members pursuit to maximize their own benefit: when the manufacturer's net income is negative to choose active strategy, that is $(1-\alpha)\Delta U_1 - \Delta U_2 - G < 0$, whether suppliers participate or not, manufacturers tend to choose negative strategies. When $\Delta R_2 - C > 0$, the supplier tends to participate, so the system converges to (0, 1) after long-term evolution.

Case (3): $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$ and $\Delta R_1 + \alpha \Delta U_1 - W - C > 0$

When the supplier chooses to participate, the manufacturer chooses the active management strategy can get more benefit than the passive management strategy. Meanwhile, if the manufacturer manages actively, supplier chooses the participation strategy will get more benefit. Point (1, 1) is the evolution stable strategy.

Case (4): $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$ and $\Delta R_1 + \alpha \Delta U_1 - W - C < 0$

When suppliers choose to participate, if the manufacturer chooses active management strategy could get more benefit, but under the condition of manufacturer's active management, the benefit of suppliers choose to participate is less than not to participate, then the system will show periodic fluctuation.

2) $\Delta R_2 - C < 0$

When $\Delta R_2 - C < 0$, it can be seen from Table 3 that point (0, 0) is the system evolution stability strategy. However, for points (0, 1) and (1, 0), because $G > 0$ and $-(\Delta R_2 - C) > 0$, the two points cannot evolve a stable strategy. At the same time, when $G + \Delta U_2 - (1-\alpha)\Delta U_1 < 0$ and $W + C - \Delta R_1 - \alpha \Delta U_1 < 0$ occurs, point (1, 1) may also become a stable strategy.

The establishment conditions of evolutionary stability strategies under different conditions are summarized as shown in Table 5.

4. Parametric Analysis

According to Table 5, when $\Delta R_2 - C < 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$ and $\Delta R_1 + \alpha \Delta U_1 - W - C > 0$ are satisfied simultaneously, the system emerges with two evolutionary stabilization strategies (0, 0) or (1, 1). The phase diagram of the game evolution is shown in Figure 1.

In the diagram, the convergence trend of the system can be divided into two types: when the initial state is in the quadrilateral ABEC, the system eventually converges to A (0, 0). When the initial state is in the quadrilateral CDBE, the system eventually converges to D (1, 1). This indicates that both parties will continue to adjust their own strategies, and the evolutionary results depend on the benefits of different strategies.

Table 5. System evolution stability strategies under different conditions.

ESS	Condition
(0, 0)	$\Delta R_2 - C < 0$
(1, 0)	N/A
(0, 1)	$\Delta R_2 - C > 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G < 0$, $\Delta R_1 + \alpha\Delta U_1 - W - C > 0$
	$\Delta R_2 - C > 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G < 0$, $\Delta R_1 + \alpha\Delta U_1 - W - C < 0$
(1, 1)	$\Delta R_2 - C > 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$, $\Delta R_1 + \alpha\Delta U_1 - W - C > 0$
N/A	$\Delta R_2 - C > 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$, $\Delta R_1 + \alpha\Delta U_1 - W - C < 0$
(0, 0) or (1, 1)	$\Delta R_2 - C < 0$, $(1-\alpha)\Delta U_1 - \Delta U_2 - G > 0$, $\Delta R_1 + \alpha\Delta U_1 - W - C > 0$

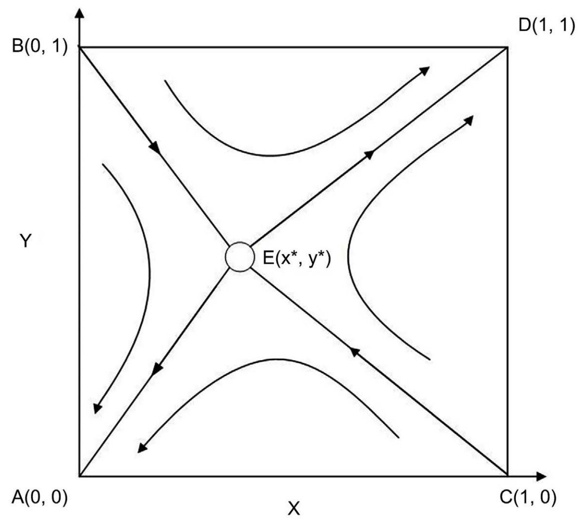


Figure 1. Phase diagram of the game evolution.

We can study the factors influencing the evolutionary trend by analyzing the factors influencing the area of quadrilateral ABEC (Huang, 2010). The formula for the area of quadrilateral ABEC is:

$$S_{ABEC} = \frac{1}{2}\left(\frac{C - \Delta R_2}{\Delta R_1 + \alpha\Delta U_1 - \Delta R_2 - W} + \frac{G}{(1-\alpha)\Delta U_1 - \Delta U_2}\right) \tag{9}$$

Further analysis leads to the following proposition.

Proposition 1: When the other parameters are determined, the higher the input costs for managing the platform actively and particating, the higher the probability that manufacturers chooses a negative strategy and suppliers chooses a non-participation strategy, and the higher the probability that the system converges to (0, 0).

Proof: Taking the partial derivative of S_{ABEC} with respect to G and C respectively, we get $\frac{\partial S_{ABEC}}{\partial G} = \frac{1}{2} \times \frac{1}{(1-\alpha)\Delta U_1 - \Delta U_2} > 0$, $\frac{\partial S_{ABEC}}{\partial C} = \frac{1}{2} \times \frac{1}{\Delta R_1 + \alpha\Delta U_1 - \Delta R_2 - W} > 0$, so S_{ABEC} is an increasing function with respect to G and C. Therefore, the greater the cost and cost C the greater of S_{ABEC}. The system will be more likely to converge to A (0, 0).

Proposition 2: The greater the incremental benefit by participating in a resource sharing platform, a supplier will more likely to participate, given other parameters are certain.

Proof: The partial derivative of S_{ABEC} with respect to ΔR_1 and ΔR_2 respectively gives $\frac{\partial S_{ABEC}}{\partial R_1} = -\frac{1}{2} \times \frac{1}{\left(\Delta R_1 + \alpha \Delta U_1 - \Delta R_2 - W\right)^2} < 0$ and $\frac{\partial S_{ABEC}}{\partial R_2} = -\frac{1}{2} \times \frac{C - \Delta R_1 - \alpha \Delta U_1 + W}{\left(\Delta R_1 + \alpha \Delta U_1 - \Delta R_2 - W\right)^2} < 0$, so S_{ABEC} is a decreasing function with respect to ΔR_1 and ΔR_2. Therefore, the supplier will be more likely to engage in resource sharing if they obtain more incremental benefit.

Proposition 3: The greater the excess returns available to the manufacturer from active management and the smaller the speculative returns from negative management, the greater the probability that the manufacturer will choose an active strategy, given other parameters are determined.

Proof: Taking the partial derivative of S_{ABEC} with respect to ΔU_1 and ΔU_2 respectively, we get

$$\frac{\partial S_{ABEC}}{\partial \Delta U_1} = \frac{1}{2} \times \frac{\alpha\left(C - \Delta R_2\right)}{\left(\Delta R_1 + \alpha \Delta U_1 - \Delta R_2 - W\right)^2} - \frac{1}{2} \times \frac{\left(1-\alpha\right)G}{\left[\left(1-\alpha\right)\Delta U_1 - \Delta U_2\right]^2} < 0,$$

$\frac{\partial S_{ABEC}}{\partial \Delta U_2} = \frac{1}{2} \times \frac{G}{\left[\left(1-\alpha\right)\Delta U_1 - \Delta U_2\right]^2} > 0$, so S_{ABEC} is a decreasing function with respect to ΔU_1, but an increasing function with respect to ΔU_2.

Proposition 4: Given other parameters are determined, the greater the platform technology spillover revenue that suppliers can obtain, the greater the possibility that suppliers choose not to participate.

Proof: Taking the partial derivative of S_{ABEC} with respect to W, we get $\frac{\partial S_{ABEC}}{\partial \Delta U_1} = \frac{1}{2} \times \frac{C - \Delta R_2}{\left(\Delta R_1 + \alpha \Delta U_1 - \Delta R_2 - W\right)^2} > 0$, so S_{ABEC} is an increasing function with respect to W.

At this point, suppliers can gain enough through speculative behavior. Therefore, manufacturers should strengthen the security management of intellectual property rights.

5. Optimal Supply Chain Excess Income Distribution

In practice, if manufacturers actively manage and suppliers choose to participate in the resource sharing platform, they can generate resource sharing synergies and gain excess revenue. However, as supply chain members pursue their own benefit maximization, a reasonable supply chain excess benefit distribution ratio needs to be formulated to promote successful cooperation in resource sharing.

Proposition 5: Given other parameters, there is an optimal supply chain excess revenue allocation factor α^*, but this allocation factor does not have a unique value due to the supply chain members' own benefit maximization pursuit and the constraints of the available revenue frontier.

Proof: Taking the partial derivative and the second order derivative of S_{ABEC} with respect to α, we get

$$\frac{\partial S_{ABEC}}{\partial \alpha}=\frac{1}{2}\times\left(\frac{\Delta U_1(C-\Delta R_2)}{(\Delta R_1+\alpha\Delta U_1-\Delta R_2-W)^2}-\frac{\Delta U_1 G}{\left[(1-\alpha)\Delta U_1-\Delta U_2\right]^2}\right)$$ and

$$\frac{\partial S_{ABEC}}{\partial^2 \alpha}=\frac{1}{2}\times\left(\frac{\Delta U_1^2(C-\Delta R_2)}{(\Delta R_1+\alpha\Delta U_1-\Delta R_2-W)^4}-\frac{\Delta U_1^2 G}{\left[(1-\alpha)\Delta U_1-\Delta U_2\right]^4}\right)>0$$, so there

exists α_1 that makes $\frac{\partial S_{ABEC}}{\partial \alpha}=0$ and S_{ABEC} can obtain a minimal value at α and the system evolves to (1, 1) with maximum probability. At this point,

$$\alpha^*=\alpha_1=\frac{\partial S_{ABEC}}{\partial \alpha}=\frac{\sqrt{C-\Delta R_2}(\Delta U_1-\Delta U_2)+\sqrt{G}(\Delta R_2+W-\Delta R_1)}{\Delta U_1\sqrt{C-\Delta R_2}+\Delta U_2\sqrt{G}}.$$

Also, according to scenario 3, the benefits of sharing manufacturing resources need to satisfy $(1-\alpha)\Delta U_1-\Delta U_2-G>0$ and $\Delta R_1+\alpha\Delta U_1-W-C>0$, so α is bounded by $\frac{W+C-\Delta R_1}{\Delta U_1}<\alpha<\frac{\Delta U_1-\Delta U_2-G}{\Delta U_1}$. Because the uncertainty of the revenue parameters, α_1 is not necessarily within the boundaries. When $\frac{W+C-\Delta R_1}{\Delta U_1}<\alpha_1<\frac{\Delta U_1-\Delta U_2-G}{\Delta U_1}$, the minimum value of S_{ABEC} is obtained at $\alpha^*=\alpha_1$; when $\frac{\Delta U-\Delta U_2-G}{\Delta U_1}<\alpha_1$, the minimum value of S_{ABEC} is obtained at $\alpha^*=\alpha_2=\frac{\Delta U_1-\Delta U_2-G}{\Delta U_1}$; when $\frac{W+C-\Delta R_1}{\Delta U_1}>\alpha_1$, the minimum value of S_{ABEC} is obtained at $\alpha^*=\alpha_3=\frac{W+C-\Delta R_1}{\Delta U_1}$. Three different values α^* occur for three benefit conditions.

Although the manufacturer will share the value-added revenue with suppliers to motivate them to participate in the platform, but the manufacturers also pursue profits, i.e., $(1-\alpha)\Delta U_1-G>\Delta U_2$ need to be satisfied, otherwise, the manufacturer will not choose the active strategy. At the same time, for suppliers, the incremental net benefit of participating in the platform should be higher than the benefit of technology spillover, i.e., $\alpha\Delta U_1+\Delta R_1-C>W$ needs to be satisfied, otherwise suppliers will tend to choose the non-participation strategy. In actual operation, a reasonable supply chain excess revenue allocation ratio needs to be formulated for different revenue scenarios to promote the sharing of supply chain resources to form stable cooperation.

6. Numerical Simulations

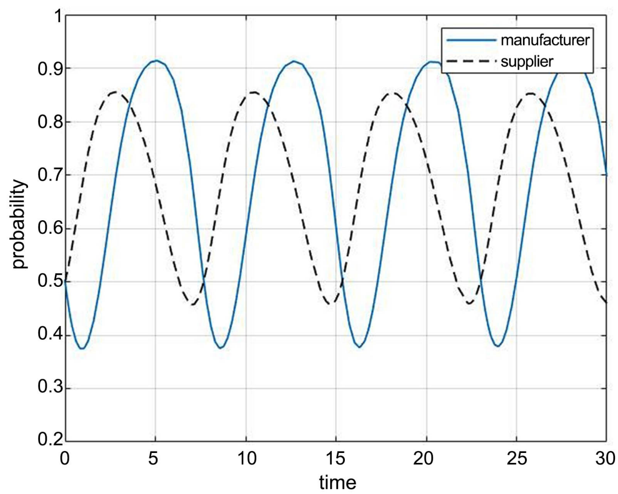
Take an electronics assembly manufacturing supply chain as an example, and analyze the system evolution trend under different revenue states of supply chain members through numerical simulation. Suppose $G=4$, $C=3$, $\Delta U_1=11$, $\Delta U_2=4$, $\Delta R_1=6$, $\Delta R_2=5$, $W=5$, $x=0.5$, $y=0.5$.

When $\alpha = 0.1$, the system evolves as shown in Figure 2(a). At this point, for both manufacturers and suppliers, when the other party chooses the cooperative strategy, the speculative strategy gains more than the cooperative strategy, but when the other party chooses the non-cooperative strategy, the benefit of cooperative strategy will be greater than the speculative strategy, so they both want the other party to adopt the cooperative strategy while they benefit from the speculative strategy. This makes it difficult for the system to evolve a stable strategy because of the cyclical changes in resource sharing cooperation.

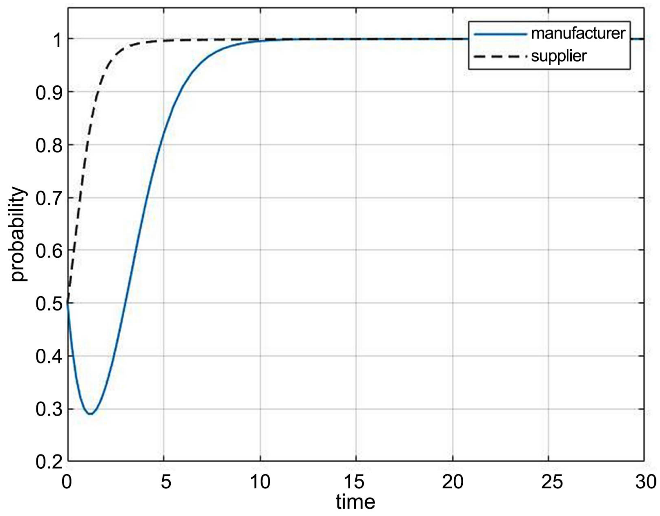
When the allocation factor increases to $\alpha = 0.2$, the system evolves as shown in Figure 2(b). At this point, the manufacturer increases the revenue allocation to the suppliers so that the suppliers' speculative strategy revenue is smaller than the cooperative strategy, while ensuring that the difference between its own cooperative strategy revenue and speculative strategy revenue is positive, then the system converges to (1, 1). However, if this allocation coefficient is too large, so that the manufacturer's profit of cooperating is less than the choice of the speculative strategy, the system evolves continues to change, as shown in Figure 2(c). When $\alpha = 0.6$, the system converges to (0, 1).

If $\Delta R_2 = 2$, $G = 1$, $W = 2$, then $\Delta R_2 - C < 0$. It can be calculated according to proposition 5 that $\alpha_1 \approx 0.33$, $\alpha_2 \approx 0.54$, $\alpha_3 \approx -0.09$, therefore, the optimal supply chain excess revenue allocation ratio coefficient $\alpha^* = \alpha_1 = 0.33$, the system evolves as shown in Figure 2(d), the system evolves to a stable equilibrium of (1, 1), and a stable manufacturing resource sharing cooperation relationship is formed.

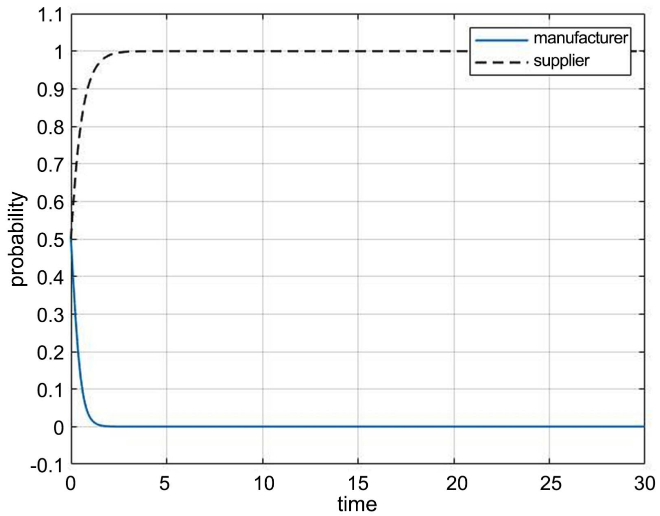
It can be seen from the above simulation results that the variation of different parameters will have different effects on the evolutionary trends. Most of the parameters can be obtained from the actual operational data, such as the cost of setting up the resource sharing platform, the net revenue and the cost of purchasing equipment, etc. In addition, the application of game theory is mature which strength the practical feasibility of applying it in cloud manufacturing environment.



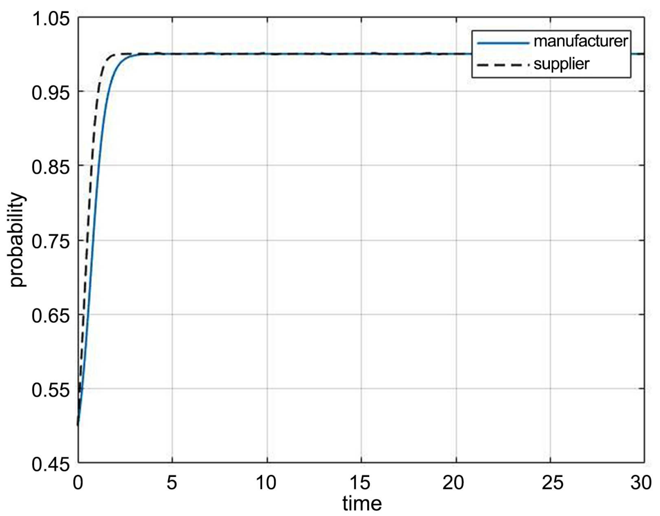
(a) $\alpha = 0.1$



(b) $\alpha = 0.2$



(c) $\alpha = 0.6$



(d) $\alpha = 0.33$

Figure 2. Schematic diagram of the system evolution trend.

7. Conclusion

This paper uses the evolutionary game approach to analyze the evolution process and influencing factors of manufacturing supply chain resource sharing decision in complex assembly cloud platform environment, and studies the problem of supply chain excess benefit distribution, finally draws the following conclusions: 1) When the manufacturers obtain a negative net benefit for managing actively, and the supplies obtain a positive net benefit for choosing to participate resource sharing, then both strategy choices do not depend on the other's choice, the manufacturer will choose the negative strategy, and the supplier will participate resource sharing. 2) When manufacturers manage negatively, suppliers gain more for choosing to participate. However, when the manufacturer manages actively, suppliers will get less benefit to participate in the platform. And when the supplier participates in resource sharing and the manufacturers gain more for positive management strategy, the system doesn't have a stable strategy and the periodic shocks occur. 3) For manufacturers, the higher the excess supply chain benefits obtainable under active management, the lower the speculative benefits obtainable under negative management, and the lower the cost of investment required for active management, they are more likely to choose to manage positively. Meanwhile, for suppliers, the higher cost of participation and the higher spillover benefits will weaken the suppliers' willingness to participate the platform. 4) A reasonable distribution of excess revenue is conducive to establishment resource sharing partnerships, but it's necessary to choose the optimal allocation coefficient to promote the stable resource sharing in the manufacturing supply chain.

The above analysis results have some implications for the operation and management of manufacturing cloud platforms. The resource sharing leader could facilitate the formation of cooperative sharing strategies between suppliers and manufacturers by setting reasonable overcharge ratios. Besides, the development of secrecy technology and government support will both promote resource sharing. This paper constructs a resource sharing game model of electronics assembly manufacturing supply chain composed of suppliers and manufacturers. Further research can consider the problem of resource sharing of multi-party supply chain participants; and other contractual models and incentive strategies to promote resource sharing in manufacturing supply chains are also subsequent research directions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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