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Evolutionary Analysis of Cloud Manufacturing Platform Service Innovation Based on a Multiagent Game Perspective

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ABSTRACT With the rapid development of cloud computing, the Internet of Things (IoT) and other new generation information technologies, a new service-oriented networked intelligent manufacturing mode—cloud manufacturing (CMfg), is emerged. In the CMfg paradigm, cloud manufacturing platform service innovation is an effective way to improve the service function, service quality and service efficiency of cloud manufacturing platforms. However, the service innovation of cloud manufacturing platforms is complex system engineering, which needs to consider many participants with independent interests simultaneously. If one party's behaviour strategy changes, the whole system will be affected. In order to adapt the decision-making management of manufacturing service innovation in cloud manufacturing system, to provide the effective decision-making support for service innovation of cloud manufacturing system in uncertain environment, to explore the interaction mechanism and equilibrium strategy of various stakeholders in the evolution process of cloud manufacturing system. This research constructs a tripartite evolutionary game model among participants based on evolutionary game theory, Analyses the influence of participants' strategy choices, The Cloud manufacturing platform's service quality coefficients and users' preference Coefficients on the equilibrium state stability of cloud manufacturing systems, and uses MATLAB software for numerical simulation. The results show that the evolutionary stability strategy of cloud manufacturing enterprises plays a decisive role in the service innovation of the cloud manufacturing platform. When cloud manufacturing enterprises choose a noncooperation strategy, the evolutionary stability strategy of the cloud manufacturing platform is innovation. When cloud manufacturing enterprises choose a cooperation strategy, the evolutionary stability strategy of the cloud manufacturing platform is affected by the platform's service quality coefficient and the user's preference coefficient, and both factors can promote the evolution of cloud manufacturing platform service innovation. The platform's service quality coefficient has a threshold value, which depends on the relative size of benefits, costs and user's preference coefficient generated by the service innovation of the platform. Therefore, in the cloud manufacturing mode, the cloud manufacturing platform must rely on different enterprises to provide their own innovation resources to realize the service innovation of the cloud manufacturing platform, so the cloud manufacturing platform should focus on introducing a group of high-quality cloud manufacturing enterprises for cooperation. In addition, users' strong demand for high-quality services can provide sufficient impetus for cloud manufacturing enterprises to choose cooperation and cloud manufacturing platforms to choose innovation, which can not only encourage cloud manufacturing platforms to provide personalized services for users but also avoid the extra waste of resources.

INDEX TERMS cloud manufacturing platform, service innovation, tripartite evolutionary game, multiagent perspective.

I. INTRODUCTION

With the rapid development of cloud computing, the Internet of Things (IoT) and other new generation information technologies, manufacturing enterprises are facing a drastic change in the market competition pattern, and the shift from traditional manufacturing to service manufacturing has become an inevitable trend in the manufacturing industry [1], [2]. Therefore, in view of the problems existing in the traditional manufacturing mode, Li *et al*. [3] proposed a new service-oriented networked intelligent manufacturing mode—cloud manufacturing, combining advanced manufacturing technology, cloud computing, the Internet of Things (IoT), service computing, intelligent science and other emerging technologies [4]. Some manufacturing enterprises have applied cloud manufacturing modes in production practice and built cloud manufacturing service modes centring on cloud manufacturing platforms to meet the personalized and diversified needs of users [5], [6].

In the cloud manufacturing mode, through the Internet of Things (IoT) and virtualization technology, manufacturing enterprises can package highly heterogeneous manufacturing resources (software, data) and manufacturing capabilities (computing capabilities, design capabilities) into manufacturing cloud services and publish them to cloud manufacturing platforms, form a shared resource pool, and implement unified and centralized intelligent management. Then, cloud manufacturing platforms can provide users with all stages of product life cycle services through the internet, such as demonstration services, design services, production and processing services, experimental services, simulation services and integration services [7]-[9]. Through the cloud manufacturing platform, enterprises realize the supply and demand matching and collaboration of manufacturing services, which not only improves the utilization rate of resources but also meets the personalized needs of users. However, in practice, with the increasing complexity of manufacturing tasks and users' demands, the existing level of cloud manufacturing services can no longer meet the needs of users. For example, current cloud manufacturing services do not take into account dynamic changes in demand and manufacturing resources, such as dynamic entry and exit of manufacturing resources, temporary submission and cancellation of production orders, and changes in the relationship between manufacturing tasks of complex production orders. Therefore, how to select the service resources that meet users' requirements from the massive cloud services for service matching [10], [11], service composition [12], [13] and service collaboration [14], [15] has introduced great challenges to the operation and management of cloud manufacturing platforms. Many studies have proven that cloud manufacturing platform service innovation is an effective way to improve the service function, quality and efficiency of cloud manufacturing platforms [16], [17]. Therefore, cloud manufacturing platforms should accelerate service innovation to solve the above realistic problems. Service innovation specifically refers to the adoption of methods such as resource integration, algorithm optimization and supply chain management to improve the service efficiency and resource utilization rate of the platform to meet the increasingly complex manufacturing needs of users [18], [19]. During service innovation of cloud manufacturing platforms, most innovation resources and innovation ability supporting service innovation are not owned by cloud manufacturing platforms but are mainly distributed in different geographical locations and highly autonomous enterprises [20], [21]. Therefore, the service innovation of cloud manufacturing platforms is complex system engineering, which needs to consider many participants with independent interests simultaneously, including platform builders and platform operators upstream of the industrial chain (cloud manufacturing platform), resource providers in the middle of the industrial chain (cloud manufacturing enterprises) and consumers downstream of the industrial chain (users) [22-24]. If one party's behaviour strategy changes, the whole system will be affected. Given this interdependence, this research fully considers the multiple participants of cloud manufacturing platform service innovation. On the premise of bounded rationality, this paper constructs a three-party evolutionary game model that includes cloud manufacturing enterprises, cloud manufacturing platforms and users to analyse the strategic evolution path and the main factors influencing the strategic evolution of cloud manufacturing platform service innovation.

Since the introduction of the concept of CMfg in 2010, over the past decade, the problem of CMfg service innovation management has attracted the attention of many scholars. At present, research on CMfg platform service innovation focuses mainly on service innovation supporting technology, the service innovation organization mode and the service innovation knowledge resources.

From the perspective of supporting technology, the realization of cloud manufacturing service innovation is inseparable from the support of digital technologies. Digital technologies that support innovation in cloud manufacturing services is a collective term for technologies pertaining to cloud computing business model and applications, including network technology, information technology, platform management and application technologies [25]. Li *et al*. [4] classified supporting technologies for cloud manufacturing service innovation into 10 categories (overall technology, resource awareness and access technology, resource capability virtualization and service technology, service environment construction and management technology, service environment operation technology, service environment assessment technology, credible and secure service technology, universal human-computer interaction technology, service platform application technology and information manufacturing technology). On this basis, Lim *et al*. [1] draws on the results of Yao *et al*. [26] and Yi *et al*. [27] and divides supporting technologies into two categories: service environment-related technologies and service life cycle-related technologies. Service environment-related technologies aim to build a service innovation environment to ensure the flexibility, convenience and security of the service innovation life cycle. Service life cycle-related technologies aim to ensure the smooth and efficient service innovation [1]. It can be seen that digital technology innovation not only improves the cooperation efficiency between manufacturing and producer services, but also increases the benefits of service output while reducing resource consumption. Digital innovation is the application of information, computing, communication, and connectivity technologies to improve or even reconstruct the original innovation process framework [28]. Through digital technology innovation, cloud manufacturing platforms can the maximum service benefits with the smallest service cost [29]. The innovation and development of digital technology have created many new business forms and models for cloud manufacturing enterprises.

From the perspective of organization mode, The implementers of CMfg service innovation include multiple rational agents with joint value and complicated associations, such as partners, customers, colleges and universities, financial institutions, intermediaries, and the government [30]-[32]. they constitute an ecosystem of services characterized by autonomy and intelligence. Gomes *et al*. [33] pointed out that the service innovation ecosystem enables different participants to share their services, tools, technologies, and knowledge, the shared services mainly include includes providing computing and manufacturing services to both consumers and providers [25]. Service model innovation may occur whenever the platform modifies or improves at least one of the service value dimensions [34]. In addition, service mode innovation means exploring new possibilities related to value creation, distribution and capture for customers, suppliers and partners [35]. Platformization is a noticeable feature of service innovation ecosystems. As a key player in the service ecosystem to manage different stakeholders and cope with volatile markets, platforms can enable cloud manufacturing systems to complement and collaborate with each other in a more dynamic structure by facilitating efficient interaction and responsibility allocation among participants [36]. In addition, the characteristics of service innovation ecosystems include openness [37], diversity [38], symbiosis [39], compatibility [40], flexibility [41] and dynamicity [42]. These characteristics mark the existence of cloud manufacturing service ecosystem as a new mode of collaborative organization. In addition, advanced digital information technologies provide an open and reliable platform for cloud manufacturing services ecosystems to interact, aiming to eliminate the boundaries between companies, producers and consumers, and physical production and digital representation [43]. Through organizational mode innovation, cloud manufacturing platform can achieve more effective decentralized service control and management.

From the perspective of knowledge resources, since CMfg is a knowledge-based intelligent manufacturing paradigm, the essence of CMfg service innovation is the creation of knowledge [44]. Knowledge and resources in CMfg permeate almost every aspect of the cloud service life cycle. Knowledge plays an important role in promoting innovation and improving efficiency at all stages of the CMfg life cycle. The concept of knowledge in CMfg is general, including various information, rules, models, algorithms and standards [25]. Resources are entities that can support the activities or functions involved in the CMfg lifecycle. The resources in cloud manufacturing can be classified into two categories, hard resource and soft resource. A hard resource could be a manufacturing cell included machine tool and robot [45]. A soft resource could be software, data, or other intellectual elements [45]. However, most manufacturing resources in cloud platform are not owned by cloud manufacturing platforms but are mainly distributed in different geographical locations and highly autonomous enterprises. Therefore, establishing an integrated Internet of manufacturing resources had been a difficult problem in the cloud manufacturing service management. With the development and application of advanced digital information technologies such as big data, cloud computing and Internet of Things, it is possible to establish an intelligent management system with complete cloud manufacturing knowledge and resources [28], [44].

The development of evolutionary game theory derives from the biological theory of evolution. In this method, it uses the percentage of individuals who choose different pure strategies in the group to replace the mixed strategies in game theory [46]. Bounded rational individuals achieve dynamic equilibrium through imitation, learning, mutation, and other processes and finally reach the Evolutionary Stable Strategy (ESS) of the system [47]. This theory has also been widely applied in decision-making management. Recently, evolutionary game theory has been gradually applied to the research theme of CMfg service innovation management. For instance, Wang *et al*. [48] established an evolutionary game model from the perspective of population, observed the configuration trend of different manufacturing services, and used evolutionary game theory to distribute manufacturing services to achieve fairness among users. Wang *et al*. [49] established a system dynamics model with evolutionary game theory and simulated the CMfg mode diffusion process. Chen *et al*. [50] established an evolutionary game model between manufacturing enterprises with evolutionary game theory and analysed in detail the dynamic evolution of the innovation process. Xiao *et al*. [51] revealed how the optimal UAV relay strategy depends on the transmit cost and the UAV channel model by the Nash equilibrium of the dynamic game.

In summary, existing studies on service innovation of CMfg focus mainly on service innovation supporting technology, the service innovation organization mode and the service innovation knowledge resources, while relatively few studies consider the dynamic game relationship between CMfg participants. Moreover, the only game studies on CMfg strategy often do not focus on the CMfg mode or do not fully consider the multiple participants in the CMfg mode. In the cloud manufacturing mode, participants are all bounded rational subjects seeking to maximize their own interests and constantly adjust their strategy accordingly during the game. Because evolutionary game theory is based on the bounded rationality hypothesis and the long-term dynamic evolution process, it is more practical and convincing for explaining the evolution process of cloud manufacturing platform service innovation. In practice, service innovation is a continuous and dynamic process, and few studies have analyzed the evolution process and its conditions under multiagent participation from a systems perspective. Therefore, in order to deal with this research gap, we study the cloud manufacturing platform service innovation strategy evolution path and the main factors affecting the evolution of its strategy. This paper constructs a three-party evolutionary game model that includes cloud manufacturing enterprises, a cloud manufacturing platform and users with evolutionary game theory, analyses the influence of participants' strategy choice, the cloud manufacturing platform's service quality coefficients and users' preference coefficients on the equilibrium state stability of cloud manufacturing service innovation systems, and uses MATLAB software for numerical simulation. Last, this article provides targeted suggestions for promoting cloud manufacturing platform service innovation and offers decision-making support and guidance for cloud manufacturing platform service innovation.

The remainder of the paper is organized as follows: Section 2 describes the research problems, presents the basic assumptions, provides the parameter symbols and meanings, and constructs a three-party evolutionary game model involving cloud manufacturing enterprises, cloud manufacturing platforms and users. Section 3 analyses the strategy selections of the three parties and determines the stable equilibrium state of the model. Section 4 establishes the numerical simulation model and analyses the corresponding results. Finally, Section 5 concludes the paper and proposes suggestions.

II. EVOLUTIONARY GAME MODEL CONSTRUCTION

A. PROBLEM DESCRIPTION

A typical cloud manufacturing system consists of three main bodies: service provider, service demander and cloud manufacturing service platform [52]. Service providers refer mainly to cloud manufacturing enterprises with a high degree of autonomy and distributed in different geographical locations, which encapsulate their idle manufacturing resources and manufacturing capabilities into cloud services and register them on cloud manufacturing platforms through virtualization technology [53]. The cloud manufacturing service platform is responsible for publishing, managing, and maintaining all kinds of virtual service resources [54]. The cloud manufacturing platform specific service process is as follows. First, manufacturing tasks are decomposed into multiple subtasks according to their complexity. Then, services that meet users' requirements are selected from the virtual service resource pool of the cloud manufacturing platform. Then, the selected services are combined in a logical order to form a service process. Finally, through effective coordination of the idle manufacturing resources of service providers, manufacturing tasks can be carried out jointly [55]. Service demanders refer mainly to organizations, enterprises or individuals that search for and use CMfg services [56]. They can obtain and use all kinds of service resources with the support of cloud manufacturing service platforms according to their distinct needs [57].

The service innovation process of a cloud manufacturing platform involves interaction among manufacturing enterprises, users and the cloud manufacturing service platform. In this process, the strategies of the cloud manufacturing platform are "innovation" and "not innovation". Innovation refers to providing better services for manufacturing enterprises and users by means of algorithm improvement, technology research and development and supply chain coordination. Not innovation refers to the fact that it only maintains the basic service matching function, regardless of the quality of service (QoS), resource utilization and service efficiency. The strategies of cloud manufacturing enterprises are "cooperation" and "noncooperation". Cooperation refers to the entrusting of idle manufacturing resources (such as machine tools and robots) to a cloud manufacturing platform for operation and management. Noncooperation means that not delegating idle manufacturing resources to the cloud manufacturing platform. The strategies of users are "demand" and "not demand". Demand refers to users having a more obvious preference for innovative services with more complementary functions and higher efficiency provided by the cloud service platform. Not demand refers to the fact that users only need the cloud service platform to provide basic services.

As the centre of the CMfg system, the CMfg platform provides services for CMfg enterprises and users and charges certain fees. Specifically, when cloud manufacturing enterprises are connected to the cloud manufacturing platform, the cloud manufacturing platform will charge a certain membership fee to the cloud manufacturing enterprises for service resources maintenance and management [58]. When users complete a transaction, the cloud manufacturing platform charges users a certain transaction fee for the complex task decomposition, matching, combination and coordination of the tasks published by users [59].

To construct a evolutionary game model, it is necessary to clarify the variables that affect a cloud manufacturing platform, cloud manufacturing enterprises and users decision-making. For the choice of a cloud manufacturing platform variables, Geng et al. [60] used service quality to measure trade fees in a study of cloud manufacturing platform cooperative game. Ehsan et al. [61] introduced service quality level into cloud manufacturing service composition model based on game theory. For the choice of users variables, Huo et al. [9] provided personalized manufacturing services for users according to consumer preferences based on the Evolutionary Game Algorithm. Wang et al. [62]compared multi-user oriented and multi-task oriented cloud manufacturing service scheduling model, considered the influence of user preference and scheduled time on the model, and described user preference by comparison of preference criteria and fuzzy terms. For the choice of cloud manufacturing enterprises variables, Zhang et al. [63] believes that Business requirements, profits, costs, and risks are the factors affecting cloud manufacturing enterprises choice of cloud services. Wang et al. [64] added a competitive losses as a variable in the evolutionary game as a result of the cloud manufacturing enterprise's untrustworthy nature.

Based on these previous research results, to more reasonably study the interaction between multiple agents in a cloud manufacturing innovation system, we propose the following basic assumptions and build the model accordingly.

B. BASIC ASSUMPTIONS

In the process of cloud manufacturing service innovation, participants will adjust their behaviours in terms of both benefits and costs. Considering real world conditions, this paper puts forward the following basic assumptions.

H1: There are three important players in the game: cloud manufacturing enterprises, a cloud manufacturing platform and users. Suppose that the probability of cloud manufacturing enterprises choosing the "cooperation" strategy is x $(0 \leq x \leq 1)$; and the probability of cloud manufacturing enterprises choosing the "noncooperation" strategy is 1-x. The probability of the cloud manufacturing platform choosing the "innovation" strategy is y $(0 \leq y \leq 1)$; and the probability of the cloud manufacturing platform choosing the "not innovation" strategy is 1-y. The probability of users choosing the "demand" strategy is z $(0 \leq z \leq 1)$; and the probability of users choosing the "not demand" strategy is 1-z.

H2: When cloud manufacturing enterprises choose a cooperation strategy and a cloud manufacturing platform chooses an innovation strategy, enterprises can obtain a direct benefit P_1. When the cloud manufacturing platform chooses an innovation strategy, enterprises can obtain not only a direct benefit but also an indirect benefit βP_1 generated by platform service innovation. β is the service quality coefficient of the cloud manufacturing platform, representing the value obtained by cloud manufacturing enterprises and users when the cloud manufacturing platform chooses an innovation strategy, which is jointly determined by cloud manufacturing enterprises and users. When cloud manufacturing enterprises choose a noncooperation strategy, they gain a base benefit P_2. If enterprises choose the cooperation strategy, they need to pay a cost C_1; if the users choose the demand strategy at this time, the enterprises can also obtain an indirect benefit αC_1 caused by the users' participation, and α is the service preference coefficient of users. When cloud manufacturing enterprises choose a cooperation strategy, it is often accompanied by the risk of information leakage, and the risk to the enterprises is $(1-\beta)R$, where R is the risk of the enterprises choosing a cooperation strategy. When the enterprises choose the noncooperation strategy and the users choose the demand strategy, the enterprises will lose some users and incur an additional loss L.

H3: When cloud manufacturing enterprises choose a cooperation strategy, cloud manufacturing platforms gain a direct benefit E_1. When cloud manufacturing enterprises choose a noncooperation strategy, cloud manufacturing platforms gain a base benefit E_2. When the cloud manufacturing platform chooses an innovation strategy, it can also obtain a reputation benefit βE_1 due to platform service quality; at the same time, it needs to pay cost C_2. When the cloud manufacturing platform does not choose an innovation strategy, it needs to pay cost C_3. When users choose a demand strategy, the cloud manufacturing platform can obtain an indirect benefit αC_2 generated by users' preferences when carrying out service innovation. The cloud manufacturing platform can obtain a potential benefit αC_3 generated by users' preferences when not carrying out service innovation.

H4: When cloud manufacturing enterprises choose a cooperation strategy and cloud manufacturing platforms choose a noninnovation strategy, the benefit of users choosing the demand strategy is U_1, and the benefit of users choosing the nondemand strategy is U_2. When cloud manufacturing enterprises choose a cooperation strategy and cloud manufacturing platforms choose an innovation strategy, the benefit of users choosing the demand strategy is βU_1, and the benefit of users choosing the no demand strategy is βU_2. When users choose the demand strategy and the CMfg platform chooses the innovation strategy, they need to pay a cost $\alpha(C_1 + C_2)$. When users choose the demand strategy and the CMfg platform does not choose the innovation strategy, users need to pay a cost $\alpha(C_1 + C_3)$.

The symbols and meanings of the parameters used throughout this research are provided below in Table 1.

TABLE 1. Parameter symbols and meanings.

Parameter	Meanings
P_1	The benefits when enterprises choose "cooperation"
P_2	The benefits when enterprises choose "noncooperation"
E_1	The benefits when the platforms chooses "innovation" and enterprises choose "cooperation"
E_2	The benefits when the platforms chooses "not innovation" and enterprises choose "cooperation"
U_1	The benefits when users choose "demand" and enterprises choose "cooperation"
U_2	The benefits when users choose "not demand" and enterprises choose "cooperation"
C_1	The enterprise's cost when it chooses "cooperation"
C_2	The platform's cost when it chooses "innovation"
C_3	The platform's cost when it chooses "not innovation"
R	The enterprise's risk when it chooses "cooperation"
L	The enterprise's loss when it chooses "noncooperation" and users choose "demand"
α	The service preference coefficient of users when they demand high quality service
β	The service quality coefficient of the platform when it carries out service innovation
x	The probability of cloud manufacturing enterprises choosing "cooperation"
y	The probability of the cloud manufacturing platform choosing "innovation"
z	The probability of users choosing "demand"

C. MODEL CONSTRUCTION

Based on the above assumptions, after setting the strategies and parameters of each subject in the tripartite evolutionary game model, the profit matrix of each party under different strategies can be found through analysis, as shown in Tables 2 and 3.

TABLE 2. The payment matrix of the three parties.

Enterprises	Platform	Users: Demand	Users: Not demand
Cooperation	Innovation	(E_x, P_y, U_z)	(E_x, P_y, U_{1-z})
	Not innovation	(E_x, P_{1-y}, U_z)	(E_x, P_{1-y}, U_{1-z})
Noncooperation	Innovation	(E_{1-x}, P_y, U_z)	(E_{1-x}, P_y, U_{1-z})
	Not innovation	(E_{1-x}, P_{1-y}, U_z)	$(E_{1-x}, P_{1-y}, U_{1-z})$

TABLE 3. The payment matrix of the three parties.

Strategy combination	Enterprises	Platform	Users
(E_x, P_y, U_z)	$(1+\beta)P_1-(1-\alpha)C_1-(1-\beta)R$	$(1+\beta)E_1-(1-\alpha)C_2$	$(1+\beta)U_1-\alpha(C_1+C_2)$
(E_x, P_y, U_{1-z})	$(1+\beta)P_1-C_1-(1-\beta)R$	$(1+\beta)E_1-C_2$	$(1+\beta)U_2$
(E_x, P_{1-y}, U_z)	$P_1-(1-\alpha)C_1-R$	$E_2-(1-\alpha)C_3$	$U_1-\alpha(C_1+C_3)$
(E_x, P_{1-y}, U_{1-z})	P_1-C_1-R	E_2-C_3	U_2
(E_{1-x}, P_y, U_z)	P_2-L	$\beta E_1-(1-\alpha)C_2$	$-\alpha C_2$
(E_{1-x}, P_y, U_{1-z})	P_2	$-C_2$	0
(E_{1-x}, P_{1-y}, U_z)	P_2-L	$-(1-\alpha)C_3$	$-\alpha C_3$
$(E_{1-x}, P_{1-y}, U_{1-z})$	P_2	$-C_3$	0

III. TRIPARTITE EVOLUTIONARY GAME ANALYSIS

As seen from Tables 2 and 3, the cooperation, noncooperation, and average expected revenue functions of the enterprises are π_{11}, π_{12}, and $\bar{\pi}_1$.

$$\pi_{11} = yz[(1+\beta)P_1-(1-\alpha)C_1-(1-\beta)R]+z(1-y)[P_1-(1-\alpha)C_1-R]+y(1-z)[(1+\beta)P_1-C_1-(1-\beta)R]+(1-y)(1-z)[P_1-C_1-R] \quad (1)$$

$$\pi_{12} = yz[P_2-L]+z(1-y)[P_2-L]+y(1-z)P_2+(1-y)(1-z)P_2 \quad (2)$$

$$\bar{\pi}_1 = x\pi_{11}+(1-x)\pi_{12} \quad (3)$$

Thus, the dynamic replication equation of the enterprises can be obtained from equations (1-3):

$$F(x) = dx/dt = x(1-x)(\pi_{11}-\pi_{12}) = x(1-x)[P_1-P_2-C_1-R+z(\alpha C_1+L)+y(\beta P_1+\beta R)] \quad (4)$$

In the same way, the innovation, not innovation, and average expected revenue functions of the platform are π_{21}, π_{22}, and $\bar{\pi}_2$.

$$\pi_{21} = xz[(1+\beta)E_1-(1-\alpha)C_2]+x(1-z)[(1+\beta)E_1-C_2]+z(1-x)[\beta E_1-(1-\alpha)C_2]-(1-x)(1-z)C_2 \quad (5)$$

$$\pi_{22} = xz[E_2-(1-\alpha)C_3]+x(1-z)[E_2-C_3]+z(1-x)[-(1-\alpha)C_3]-(1-x)(1-z)C_3 \quad (6)$$

$$\bar{\pi}_2 = y\pi_{21}+(1-y)\pi_{22} \quad (7)$$

Thus, the dynamic replication equation of the platform can be obtained from equations (5-7):

$$F(y) = dy/dt = y(1-y)(\pi_{21}-\pi_{22}) = y(1-y)[C_3-C_2+x(\beta E_1+E_1-E_2)+z(\beta E_1+\alpha C_2-\alpha C_3)-xz\beta E_1] \quad (8)$$

The demand, not demand, and average expected revenue functions of the users are π_{31}, π_{32}, and $\bar{\pi}_3$.

$$\pi_{31} = xy[(1+\beta)U_1 - \alpha(C_1+C_2)] + x(1-y)[U_1 - \alpha(C_1+C_3)] - y(1-x)\alpha C_2 - (1-x)(1-y)\,\alpha C_3 \tag{9}$$

$$\pi_{32} = xy[(1+\beta)U_2] + x(1-y)[U_2] \tag{10}$$

$$\bar{\pi}_3 = z\pi_{31} + (1-z)\pi_{32} \tag{11}$$

Thus, the dynamic replication equation of the users

can be obtained from equations (9-11):

$$F(z) = dz/dt = z\,(1-z)(\,\pi_{31} - \pi_{32}\,) = z\,(1-z)[-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2)] \tag{12}$$

According to the stability theorem of differential equations, the stable point of the dynamic equation should meet the following two conditions: $F(x) = 0$ and $\frac{dF(x)}{dx} < 0$. Take the derivatives of $F(x)$, $F(y)$, and $F(z)$ with respect to x, y, and z, respectively:

$$\frac{dF(x)}{dx} = (1-2x)[P_1 - P_2 - C_1 - R + z(\alpha C_1 + L) + y(\beta P_1 + \beta R)] \tag{13}$$

$$\frac{dF(y)}{dy} = (1-2y)[C_3 - C_2 + x(\beta E_1 + E_1 - E_2) + z(\beta E_1 + \alpha C_2 - \alpha C_3) - xz\beta E_1] \tag{14}$$

$$\frac{dF(z)}{dz} = (1-2z)[-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2)] \tag{15}$$

According to Equation (13), when $P_1 - P_2 - C_1 - R + z(\alpha C_1 + L) + y(\beta P_1 + \beta R) = 0$, then $F(x) \equiv 0$. Thus, all x are in an evolutionary stable strategy. When $P_1 - P_2 - C_1 - R + z(\alpha C_1 + L) + y(\beta P_1 + \beta R) > 0$, $\frac{dF(x)}{dx}\Big|_{x=1} < 0$, and $\frac{dF(x)}{dx}\Big|_{x=0} > 0$, x=1 is the evolutionary stability point, and "cooperation" is the evolutionary stability strategy of cloud manufacturing enterprises. When $P_1 - P_2 - C_1 - R + z(\alpha C_1 + L) + y(\beta P_1 + \beta R) < 0$, $\frac{dF(x)}{dx}\Big|_{x=1} > 0$, and $\frac{dF(x)}{dx}\Big|_{x=0} < 0$, $x = 0$ is the evolutionary stability point, and "noncooperation" is the evolutionary stability strategy of cloud manufacturing enterprises.

According to Equation (14), when $C_3 - C_2 + x(\beta E_1 + E_1 - E_2) + z(\beta E_1 + \alpha C_2 - \alpha C_3) - xz\beta E_1 = 0$, then $F(y) \equiv 0$. Thus, all y are in an evolutionary stable strategy. When $C_3 - C_2 + x(\beta E_1 + E_1 - E_2) + z(\beta E_1 + \alpha C_2 - \alpha C_3) - xz\beta E_1 > 0$, $\frac{dF(y)}{dy}\Big|_{y=1} < 0$, and $\frac{dF(y)}{dy}\Big|_{y=0} > 0$, y=1 is the evolutionary stability point, and "innovation" is the evolutionary stability strategy of the cloud manufacturing platform. When $C_3 - C_2 + x(\beta E_1 + E_1 - E_2) + z(\beta E_1 + \alpha C_2 - \alpha C_3) - xz\beta E_1 < 0$, $\frac{dF(y)}{dy}\Big|_{y=1} > 0$, and $\frac{dF(y)}{dy}\Big|_{y=0} < 0$, y=0 is the evolutionary stability point, and "not innovation" is the evolutionary stability strategy of the cloud manufacturing platform.

According to Equation (15), when $-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2) = 0$, then $F(z) \equiv 0$. Thus, all z are in an evolutionary stable strategy. When $-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2) > 0$, $\frac{dF(z)}{dz}\Big|_{z=1} < 0$, and $\frac{dF(z)}{dz}\Big|_{z=0} > 0$, z=1 is the evolutionary stability point, and "demand" is the evolutionary stability strategy of users. When $-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2) < 0$, $\frac{dF(z)}{dz}\Big|_{z=1} > 0$, and $\frac{dF(z)}{dz}\Big|_{z=0} < 0$, z=0 is the evolutionary stability point, and "not demand" is the evolutionary stability strategy of users.

The above analysis is conducted from the perspective of cloud manufacturing enterprises, cloud manufacturing platforms and users and comprehensively analyses the above three-party game main body strategies. The Jacobian matrix of the system is constructed according to Equations (4), (8) and (12), and the evolutionary stability strategy of the dynamic system can be obtained through the analysis of the Jacobian matrix.

The Jacobian matrix of the dynamic system is:

$$J = \begin{bmatrix} \frac{dF(x)}{dx} & \frac{dF(x)}{dy} & \frac{dF(x)}{dz} \\ \frac{dF(y)}{dx} & \frac{dF(y)}{dy} & \frac{dF(y)}{dz} \\ \frac{dF(z)}{dx} & \frac{dF(z)}{dy} & \frac{dF(z)}{dz} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix} \tag{16}$$

In Equation (16): $J_{11} = (1-2x)[P_1 - P_2 - C_1 - R + z(\alpha C_1 + L) + y(\beta P_1 + \beta R)]$; $J_{12} = x(1-x)\,(\beta P_1 + \beta R)$; $J_{13} = x(1-x)\,(\alpha C_1 + L)$; $J_{21} = y(1-y)\,(\beta E_1 + E_1 - E_2 - z\beta E_1)$; $J_{22} = (1-2y)[\,C_3 - C_2 + x(\beta E_1 + E_1 - E_2) + z(\beta E_1 + \alpha C_2 - \alpha C_3) - xz\beta E_1]$; $J_{23} = y(1-y)(\beta E_1 + \alpha C_2 - \alpha C_3 - x\beta E_1)$; $J_{31} = z(1-z)\,[U_1 - U_2 - \alpha C_1 + y\,(\beta U_1 - \beta U_2)]$; $J_{32} = z(1-z)[\,\alpha C_3 - \alpha C_2 + x\,(\beta U_1 - \beta U_2)\,]$; $J_{33} = (1-2z)[-\alpha C_3 + x(U_1 - U_2 - \alpha C_1) - y(\alpha C_2 - \alpha C_3) + xy(\beta U_1 - \beta U_2)]$

If $F(x)$=0, $F(y)$=0, $F(z)$=0, it means that the system will no longer evolve and achieve equilibrium, eight local equilibrium points A(0, 0, 0), B(0, 0, 1), C(0, 1, 0), D(0, 1,1), E(1,0,0), F(1,0,1), G(1,1,0), H(1,1,1) can be obtained in the dynamic system composed of three game players. In an asymmetric game, the sufficient and necessary condition for the evolutionary stable equilibrium is a strict Nash equilibrium. If evolutionary stable equilibrium is an asymptotically stable equilibrium, it must be a strict Nash equilibrium, which is also a pure strategic equilibrium. Substituting Numerical x, y, z of the combination strategy into the Jacobian matrix can be got eigenvalue λ_1, eigenvalue λ_2, eigenvalue λ_3. The Jacobian matrix eigenvalues of the above eight equilibrium points are shown in Table 4. According to Lyapunov's first method, when all eigenvalues of the Jacobian matrix are negative, the equilibrium point is the evolutionary stable point of the system.

TABLE 4. Eigenvalues of the Jacobian matrix.

Strategy combination	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
(0, 0, 0)	$P_1 - P_2 - C_1 - R$	$C_3 - C_2$	$-\alpha C_3$
(0, 0, 1)	$P_1 - P_2 - C_1 - R + \alpha C_1 + L$	$C_3 - C_2 + \beta E_1 + \alpha C_2 - \alpha C_3$	αC_3
(0, 1, 0)	$P_1 - P_2 - C_1 - R_1 + \beta P_1 + \beta R$	$C_2 - C_3$	$-\alpha C_2$
(0, 1, 1)	$P_1 - P_2 - C_1 - R + \alpha C_1 + L + \beta P_1 + \beta R$	$C_2 - C_3 - \beta E_1 + \alpha C_3 - \alpha C_2$	αC_2
(1, 0, 0)	$P_2 - P_1 + C_1 + R$	$C_3 - C_2 + \beta E_1 + E_1 - E_2$	$-\alpha C_3 + U_1 - U_2 - \alpha C_1$
(1, 0, 1)	$P_2 - P_1 + C_1 + R - \alpha C_1 - L$	$(1-\alpha)(C_3 - C_2) + \beta E_1 + E_1 - E_2$	$-\alpha C_3 + U_1 - U_2 - \alpha C_1$
(1, 1, 0)	$P_2 - P_1 + C_1 + R - \alpha C_1 - L$	$C_2 - C_3 - \beta E_1 + E_2 - E_1$	$U_1 - U_2 - \alpha C_1 - \alpha C_2 + \beta U_1 - \beta U_2$
(1, 1, 1)	$P_2 - P_1 + C_1 + R - \alpha C_1 - L - \beta P_1 - \beta R$	$(1-\alpha)(C_2 - C_3) - \beta E_1 - E_1 + E_2$	$U_2 - U_1 + \alpha C_1 + \alpha C_2 + \beta U_2 - \beta U_1$

Here, A(0,0,0) is substituted into matrix J to obtain the eigenvalues of the Jacobian matrix are $\lambda_1 = P_1 - P_2 - C_1 - R$, $\lambda_2 = C_3 - C_2$, $\lambda_3 = -\alpha C_3$. If $P_1 - P_2 < C_1 + R$, Then $\lambda_1 < 0$, $\lambda_2 < 0$, $\lambda_3 < 0$, equilibrium point A(0,0,0) is the evolutionary stable point.

Similarly, B(0,0,1) is substituted into matrix J to obtain the eigenvalues of the Jacobian matrix are $\lambda_1 = P_1 - P_2 - C_1 - R + \alpha C_1 + L$, $\lambda_2 = C_3 - C_2 + \beta E_1 + \alpha C_2 - \alpha C_3$, $\lambda_3 = \alpha C_3$. Because $\lambda_3 > 0$, so A(0,0,1) is unstable.

In the same way, the asymptotic stability of the rest of equilibrium point can be obtained.

Based on the eigenvalues of each equilibrium point corresponding to the Jacobian matrix in the table above, the stability of each equilibrium point can be discussed in the following five cases according to the value range of each parameter in the eigenvalue.

Case 1: When $P_1 - P_2 < C_1 + R$, equilibrium point A(0,0,0) is the only evolutionary stable point. When the difference between the benefits obtained by enterprises when they choose "cooperation" and the benefits obtained by enterprises when they choose "not cooperation" is less than the sum of costs and risks required by enterprises to choose "cooperation", enterprises will choose "not cooperation", the cloud manufacturing platform will choose "innovation", and users will choose "not demand". The system will be stabilized by the strategy combination of noncooperation, no innovation, and no demand.

Case 2: When $P_1 - P_2 > C_1 + R$ and $E_1 - E_2 + \beta E_1 < C_2 - C_3$ and $U_1 - U_2 < \alpha C_1 + \alpha C_3$, equilibrium point E(1,0,0) is the only evolutionary stable point. When the difference between the benefits obtained by enterprises when they choose "cooperation" and when they choose "not cooperation" is more than the sum of costs and risks incurred by enterprises under "cooperation", enterprises will choose "cooperation". When the difference between the benefits obtained by the platform when it chooses "innovation" and when it chooses "not innovation" is less than the difference between the cost incurred by the platform under "innovation" and that under "not innovation", the platform will choose "not innovation". When the difference between the benefits obtained by users when they choose "demand" and when they choose "not demand" is less than the sum of the costs incurred by the platform under "not innovation" and the costs incurred by enterprises under "cooperation", users will choose "not demand". The system will be stabilized by the strategy combination of cooperation, no innovation, and no demand.

Case 3: When $P_1 - P_2 + \alpha C_1 + L > C_1 + R$ and $E_1 - E_2 + \beta E_1 < (1-\alpha)(C_2 - C_3)$ and $U_1 - U_2 > \alpha C_1 + \alpha C_3$, equilibrium point F(1,0,1) is the only evolutionary stable point. When the difference between the benefits obtained by enterprises when they choose "cooperation" and when they choose "not cooperation" is more than the difference between the costs and risks incurred by enterprises under "cooperation" and the loss incurred by enterprises under "not cooperation", enterprises will choose "cooperation". When the difference between the benefits obtained by the platform when it chooses "innovation" and when it chooses "not innovation" is less than the difference between the cost incurred by the platform under "innovation" and under "not innovation", the platform will choose "not innovation". When the difference between the benefits obtained by users when they choose "demand" and the benefits obtained by users when they choose "not demand" is more than the sum of the costs incurred by the platform under "not innovation" and the costs incurred by enterprises under "cooperation", users will choose "demand". The system will be stabilized by the strategy combination of cooperation, no innovation, and demand.

Case 4: When $P_1 - P_2 + \beta P_1 + \beta R > C_1 + R_1$ and $E_1 - E_2 + \beta E_1 > C_2 - C_3$ and $(1+\beta)(U_1 - U_2) < \alpha C_1 + \alpha C_2$, equilibrium point G(1,1,0) is the only evolutionary stable point. When the difference between the benefits obtained by enterprises when they choose "cooperation" and when they choose "not cooperation" is more than the sum of costs and risks incurred by enterprises under "cooperation", enterprises will choose "cooperation". When the difference between the benefits obtained by the platform when it chooses "innovation" and when it chooses "not innovation" is more than the difference between the cost incurred by the platform under "innovation" and under "not innovation", the platform will choose "not innovation". When the difference between the benefits obtained by users when they choose "demand" and the benefits obtained by users when they choose "not demand" is less than the sum of the costs incurred by the platform under "not innovation" and the costs incurred by enterprises under "cooperation", users will choose "not demand". The system will be stabilized by the strategy combination of cooperation, innovation, and no demand.

Case 5: When $P_1 - P_2 + \beta P_1 + \beta R + \alpha C_1 + L_1 > C_1 + R$ and $E_1 - E_2 + \beta E_1 > (1-\alpha)(C_2 - C_3)$ and $(1+\beta)(U_1 - U_2) > \alpha C_1 + \alpha C_2$, equilibrium point H(1,1,1) is the only evolutionary stable point. When the difference between the benefits obtained by enterprises when they choose "cooperation" and when they choose "not cooperation" is more than the sum of costs and risks incurred by enterprises under "cooperation", enterprises will choose "cooperation". When the difference between the benefits obtained by the platform when it chooses "innovation" and when it chooses "not innovation" is more than the difference between the cost incurred by the platform under "innovation" and under "not innovation", the platform will choose "not innovation". When the difference between the benefits obtained by users when they choose "demand" and when they choose "not demand" is more than the sum of the costs incurred by the platform under "not innovation" and the costs incurred by enterprises under "cooperation", users will choose "demand". The system will be stabilized by the strategy combination of cooperation, innovation, and demand.

Based on the above situation, if the system is stable at point A(0,0,0), the strategy choice of cloud manufacturing enterprises will eventually stabilize at "noncooperation", and the strategy choice of the cloud manufacturing platform will finally stabilize at "not innovation". If the system is stable at points E (1,0,0), F (1,0,1), G (1,1,0) and H (1,1,1), cloud manufacturing enterprises' strategy choice will finally stabilize at "cooperation", and the evolutionary stable strategy of the cloud manufacturing platform depends on users' evolutionary stable strategy and the service quality coefficient of the cloud manufacturing platform.

When the users' strategy selection finally stabilizes at "not demand", if the service quality coefficient of the cloud manufacturing platform $\beta < \frac{C_2 - C_3 + E_2 - E_1}{E_1}$, the strategy selection of the cloud manufacturing platform will stabilize at the strategy of "not innovation". If the service quality coefficient of the cloud manufacturing platform $\beta > \frac{C_2 - C_3 + E_2 - E_1}{E_1}$, the strategy selection of the cloud manufacturing platform will eventually stabilize at "innovation".

When users' strategy selection finally stabilizes at "demand", if the service quality coefficient of cloud manufacturing platform $\beta < \frac{(1-\alpha)(C_2 - C_3) + E_2 - E_1}{E_1}$, the strategy selection of the cloud manufacturing platform will stabilize at "no innovation". If the service quality coefficient of the cloud manufacturing platform $\beta > \frac{(1-\alpha)(C_2 - C_3) + E_2 - E_1}{E_1}$, the strategy selection of the cloud manufacturing platform will eventually stabilize at "innovation".

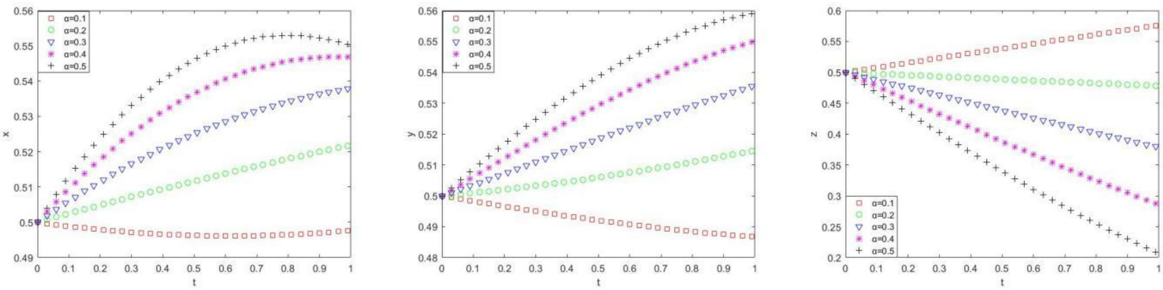
Among the various factors affecting the service innovation of the cloud manufacturing platform, the evolution and stability strategy of cloud manufacturing enterprises plays a decisive role in the service mode innovation of the cloud manufacturing platform. If the evolutionary stability strategy of cloud manufacturing enterprises finally stabilizes at "noncooperation", the evolutionary stability strategy of the cloud manufacturing platform will only stabilize at "not innovation". Only when the evolutionary stability strategy of cloud manufacturing enterprises finally stabilizes at "cooperation" will other factors affect the service mode innovation of the cloud manufacturing platform.

IV. NUMERICAL SIMULATION

In the evolutionary game process, influencing factors of different initial values have significant differences on the final game results of the evolutionary game to analyse the influence of the service quality coefficient and user preference coefficient of the CMfg platform on the stability of the equilibrium state of the service mode of the CMfg platform. The simulation parameters of this study mainly refer to the numerical simulation parameter rules set in [64]-[65], and also refer to some existing research results [66] in the field of cloud manufacturing innovation management. Assign the initial value of each parameter and make the initial parameters $C_1 = 3.0, C_2 = 3.6, C_3 = 1.5, P_1 = 3.0, P_2 = 0.5, E_1 = 4.5, E_2 = 2.0$, $U_1 = 2.0$, $U_2 = 0.7$, $\alpha = 0.2$, $\beta = 0.2$, $R = 0.5$, $L = 0.9$. According to the above initial parameters and the replication dynamic equation, we simulate the strategy selection of cloud manufacturing enterprises, cloud manufacturing platforms and users in different initial states and obtain the following results.

A. THE INFLUENCE OF THE USER PREFERENCE COEFFICIENT ON THE SERVICE INNOVATION OF THE CLOUD MANUFACTURING PLATFORM

The user's preference coefficients are set to 0.1, 0.2, 0.3, 0.4 and 0.5, and the other initial parameters remain unchanged. Through numerical simulation, the evolution trajectory of the CMfg system under different user preference coefficients can be obtained, as shown in Figure 1.



(a) (b) (c)

FIGURE 1. System evolutionary trajectory under different user preference coefficients.

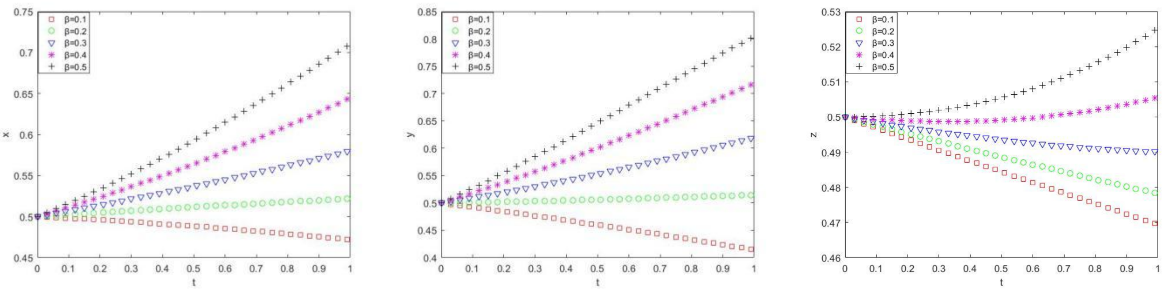
As seen from Figure 1 (a), when the user preference coefficient is between 0.1 and 0.2, there is a threshold value. When the value is higher than this threshold, cloud manufacturing enterprises tend to eventually adopt the "cooperation" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, cloud manufacturing enterprises tend to eventually adopt a "noncooperation" strategy, and the lower the value is, the faster the speed is.

As seen from Figure 1 (b), when the user preference coefficient is between 0.1 and 0.2, there is a threshold value. When the value is higher than this threshold, the cloud manufacturing platform tends to eventually adopt the "innovation" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, the cloud manufacturing platform tends to eventually adopt the "not innovation" strategy, and the lower the value is, the faster the speed is.

As seen from Figure 1 (c), when the user preference coefficient is between 0.1 and 0.2, there is a threshold value. When the value is higher than this threshold, users tend to adopt the "not demand" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, users tend to eventually adopt the "demand" strategy, and the lower the value is, the faster the speed is.

B. THE INFLUENCE OF THE PLATFORM SERVICE QUALITY COEFFICIENT ON THE SERVICE INNOVATION OF THE CLOUD MANUFACTRUING PLATFORM

Assume that the service quality coefficient of the CMfg platform is set to 0.1, 0.2, 0.3, 0.4 and 0.5, and the other initial parameters remain unchanged. Through numerical simulation, the evolution trajectory of the CMfg system under the service quality coefficient of different CMfg platforms can be obtained, as shown in Figure 2.



(a) (b) (c)

FIGURE 2. System evolution trajectory under the service quality coefficient of different platforms.

As seen from Figure 2 (a), when the platform service quality coefficient is between 0.1 and 0.2, there is a threshold value. When the value is higher than this threshold, cloud manufacturing enterprises tend to eventually adopt the "cooperation" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, cloud manufacturing enterprises tend to eventually adopt a "noncooperation" strategy, and the lower the value is, the faster the speed is.

As seen from Figure 2 (b), when the platform service quality coefficient is between 0.1 and 0.2, there is a threshold value. When the value is higher than this threshold, the cloud manufacturing platform tends to eventually adopt the "innovation" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, the cloud manufacturing platform tends to eventually adopt the "not innovation" strategy, and the lower the value is, the faster the speed is.

As seen from Figure 2 (c), when the platform service quality coefficient is between 0.3 and 0.4, there is a threshold value. When the value is higher than this threshold, users tend to adopt the "demand" strategy, and the higher the value is, the faster the speed is. When the value is lower than this threshold, users tend to eventually adopt the "not demand" strategy, and the lower the value is, the faster the speed is.

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V. CONCLUSION AND RECOMMENDATIONS

Cloud manufacturing platform service innovation is an effective way to improve the service function, service quality and service efficiency of the cloud manufacturing service model. To explore how cloud manufacturing enterprises and users in cloud manufacturing systems affect the service innovation of cloud manufacturing platforms, based on the hypothesis of bounded rationality, this paper uses the ideas and methods of evolutionary game theory to construct a three-party evolutionary game model that includes manufacturing enterprises, a cloud manufacturing platform and users, analyses the influence of the cloud manufacturing platform service quality coefficient and user preference coefficient on the stability of the service equilibrium state of the cloud manufacturing system, and uses MATLAB software for numerical simulation. Based on the above evolutionary game analysis, we comprehensively consider the influence of many factors, including the strategy choice of the three participants, user preference coefficient, platform service quality coefficient, platform service income and platform service cost, on the service innovation of cloud manufacturing platforms and draw the following conclusions:

(1) The evolution and stability strategy of cloud manufacturing enterprises plays a decisive role in the service innovation of the cloud manufacturing platform. If the evolutionary stability strategy of cloud manufacturing enterprises will finally stabilize at the noncooperation strategy, the evolutionary stability strategy of the cloud manufacturing platform will stabilize only at the noninnovation strategy. Only when the evolutionary stability strategy of cloud manufacturing enterprises finally stabilizes at the cooperation strategy will other factors affect the service innovation of the cloud manufacturing platform.

(2) If the cloud manufacturing enterprises choose the cooperation strategy, the strategy of the cloud manufacturing platform depends on the relative size of the service quality coefficient threshold of the cloud manufacturing platform. When the service quality coefficient of the cloud manufacturing platform is less than a certain threshold, the strategy of the cloud manufacturing platform will stabilize at the noninnovation strategy. When the service quality coefficient of the cloud manufacturing platform is greater than a certain threshold, the strategy of the cloud manufacturing platform will be stabilize at the innovation strategy. The threshold value is determined by the user's strategy, and the threshold value can be effectively reduced by the user's demand strategy, the degree of which reduction depends on the user preference coefficient.

(3) With the increase in the user preference coefficient and the benefit when the platform chooses innovation and the cost when it chooses not innovation, the threshold value will decrease, which can promote the evolution of the cloud manufacturing platform towards innovation. With the increase in the benefit when the platform chooses not to innovate and the cost when the platform chooses to innovate, the threshold value will increase, which can promote the evolution of the CMfg platform in the direction of not innovating.

The above conclusions suggest that the service innovation of cloud manufacturing platforms is highly dependent on cloud manufacturing enterprises. Since the cooperation of cloud manufacturing enterprises will provide high-quality innovation resources for cloud manufacturing platforms and innovation resources are highly complex and diverse, no cloud manufacturing platform can independently provide all the resources required to build a complete cloud manufacturing platform. In this case, the cloud manufacturing platform must rely on different enterprises to provide their own innovation resources to realize the service innovation of the cloud manufacturing platform, so the cloud manufacturing platform should focus on introducing a group of high-quality cloud manufacturing enterprises for cooperation. When choosing cooperation, enterprises should promote the service innovation of cloud manufacturing platforms by improving the service quality benefits and user preferences of cloud manufacturing platforms. In the cloud manufacturing mode, users' strong demand for high-quality services can provide sufficient impetus for cloud manufacturing enterprises to choose cooperation and cloud manufacturing platforms to choose innovation, which can not only encourage cloud manufacturing platforms to provide personalized services for users but also avoid the extra waste of resources.

On this basis, subsequent research can consider environmental factors, introduce the government, scientific research institutions and other parties, study the evolution path of the cloud manufacturing system service innovation mode, and grasp its evolution direction to provide a theoretical basis for the government, platform and other parties to formulate and select policies and strategies.

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