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Research Article

Decision-Making Mechanism of Cooperative Innovation between Clients and Service Providers Based on Evolutionary Game Theory

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With the maturity of the service outsourcing market and the development of business relations, the core of outsourcing is shifting from transactional services to risk sharing and value creation. The client and service provider have an increasing interest in service innovation. Although cooperative innovation between them has many benefits, the two parties do not necessarily establish a cooperative innovation relationship. Regarding this issue, an evolutionary game focusing on client-service provider cooperative innovation behavior is constructed and solved. Based on the results and a corresponding numerical simulation, the decision-making mechanism of the cooperative innovation behavior is studied, and suggestions are provided regarding how to promote cooperative innovation. The results show that the benefits of both the client and service provider when they innovate cooperatively being greater than that when they innovate independently cannot guarantee that the system will certainly evolve to a stable state in which both parties adopt a cooperation strategy. However, as long as a condition in which either party gains more than zero when it innovates independently is established in addition to the preceding condition, the system will certainly evolve to a stable state in which both parties adopt a cooperative strategy. The following measures can be taken to promote client-service provider cooperation: improving the initial probabilities of the two parties choosing the cooperative strategy; increasing the innovation benefit when one party innovates independently; reducing the innovation cost and spillover coefficient when one party innovates independently; increasing the penalty when one party cooperates and the other party does not; decreasing the innovation cost when the two parties both choose the cooperation strategy; increasing the excess benefit when the two parties both cooperate; setting reasonable benefit distribution and cost sharing proportions.

1. Introduction

With the maturity of the service outsourcing market and the development of business relations, the core of outsourcing is shifting from transactional services to risk sharing and value creation [1]. The client and service provider have an increasing interest in service innovation. For clients, the cost-effectiveness due to transactional labor arbitrage is gradually weakening, and they hope to obtain new advantages as well as operational and even strategic benefits through service innovation [2]. Meanwhile, delivering innovative services as a means to strengthen client relations and improve client dependence as well as improve their own competitiveness is becoming a common practice for service providers [3].

Service innovation occurs in the service system. Thus, the characteristics of service, especially the synchronicity of production and consumption [4] and value cocreation [5], mean that the client and service provider must participate or invest in service innovation together [6]. Cooperative innovation between the two parties not only is conducive to service providers delivering high-level innovative services and then improving the overall performance of clients [7] but also helps the two parties establish cooperative partnerships and obtain long-term benefits [8].

Although cooperative innovation can bring many advantages, the client and service provider rarely form a cooperative innovation relationship in reality [9]. For the client, weak innovation awareness, lack of funds, and other factors hinder innovation [10]. For the service provider, the fear that it will be unable to obtain the corresponding benefit but, rather, have to pay the innovation cost reduces the willingness to innovate [11]. In addition, outsourcing contracts often require the service provider to provide services in strict accordance with service level agreements, which greatly shrinks its innovation space [12]. Moreover, even if the synergy effect generated from cooperation stimulates both parties to invest in innovation activity, the spillover effect induces the "free rider" phenomenon, in which one party cooperates but the other does not [13].

Our research objective is to explore how the client and service provider can form a stable cooperative innovation relationship in the process of service innovation. Based on the evolutionary theory, we see the cooperative innovation between the two parties as a dynamic evolution process; the two parties constantly adjust their strategies and make their decision in the evolutionary system. We analyze the inner mechanism of the two parties' strategy choice, as well as the evolutionary trajectory and trend of the two parties' cooperative behavior. Specifically, we address the following questions:

(1) Under what conditions will the client and service provider choose to innovate or not?

(2) How will the system parameters influence the evolution system to an ideal (stable) state in which both the client and service provider choose the cooperation strategy?

Our analysis reveals that the benefits of both the client and service provider when they innovate cooperatively being greater than that when they innovate independently cannot guarantee that the system will certainly evolve to the ideal state. However, as long as the condition that either party gains more than zero when it innovates independently is established along with the preceding state of affairs, the system will certainly evolve to the ideal state.

We also find that the increase of the following factors is helpful for the system to evolve to the ideal state: the initial probabilities of the two parties choosing the cooperative strategy, the innovation benefit when one party innovates independently, the penalty when one party cooperates and the other party does not, and the excess benefit when the two parties both cooperate. In addition, the following measures can be taken to promote client-service provider cooperation: reducing the innovation cost and spillover coefficient when one party innovates independently, decreasing the innovation cost when the two parties both choose the cooperation strategy, and setting reasonable benefit distribution and cost sharing proportions.

The study is organized as follows. We review the related literature in the next section. In the subsequent section, we illustrate the problem description and formulation. We conduct the evolutionary game analysis in Section 4 and numerical simulation under double equilibrium in Section 5. We then summarize our work and conclude by providing key managerial insights. The source code is presented in Appendix A.

2. Literature Review

This study builds upon two major streams of research: the cooperative innovation between clients and service providers and the evolutionary game theory.

2.1. Cooperative Innovation between Clients and Service Providers. Many scholars have investigated cooperative innovation between clients and service providers. Whitley and Willcocks [14] proposed a cooperative innovation framework including four steps (leadership, contract, organization, and implementation) and illustrated how the framework could be applied to the practice process based on three actual cases of information technology and business process outsourcing. Sutter and Sutter [15] studied how clients and logistics service providers carry out cooperative innovation projects and obtain benefits from them. Lacity and Willcocks [16] proposed the concept of dynamic innovation and studied how clients and service providers cultivate dynamic innovation together. Kranz and Leonhardt [17] studied how knowledge transfer and successful cooperative innovation in the context of information service outsourcing affect clients' employees' ability to find entrepreneurial opportunities and start businesses. Nardelli and Broumels [18] analyzed how various stakeholders manage the innovation process to achieve value cocreation. Sinkovics et al. [7] studied how to realize value cocreation between clients and logistics service providers. Wang et al. [19] introduced the concept of collaborative innovation in the context of logistics service outsourcing, analyzed what actions should be taken to achieve collaborative innovation, and discussed the impact of collaborative innovation on logistics service performance and client market performance.

The previous research mainly examines the implementation process of cooperative innovation between clients and service providers as well as the impact of important factors on the implementation process, while introducing specific guidance frameworks and implementation methods. A small number of studies focus on the benefit that successful cooperative innovation can bring to the client, the service provider, and the relationship between the two. However, there is a lack of research on the decision-making mechanism of cooperative innovation behavior between clients and service providers and how to promote such cooperative innovation.

2.2. Evolutionary Game Theory. Being different classical game theory, which assumes that the participants are all completely rational [20–22], evolutionary game theory focuses more on the dynamics of strategy change [23]. In the evolutionary game process, participants are bounded rationally and dynamically adjust their strategies based on observing and learning other participants' strategy [24]. Evolutionary game theory has been deeply developed and widely used in many fields, such as social physics [25], computer science [26], and management [27]. For instance, Helbing et al. [28] employed evolutionary game theory to analyze the crime-fighting problem. Deng et al. [26] studied the information fusion and combination of evidence by utilizing evolutionary game theory. Li et al. [29] carried out a research on the green behavior of construction and demolition waste recycling units with and without remanufacturing capabilities. Long et al. [30] investigated the effect of green development performance and the government's reward–penalty mechanism on the decision-making process of production and recycling units by using evolutionary game theory. Wang et al. [31] utilized evolutionary game theory method to study how to promote the developments of hydrogen powered vehicle, hydrogen production, and solar powered vehicle industry in China. Utsumi et al. [32] investigated whether a resource-storing mechanism effectively propels based on cooperation evolutionary game theory. Wang et al. [33] employed a model based on evolutionary game theory to investigate crisis communication on social media. Pan et al. [34] adopted evolutionary game theory to analyze the sustainability of professional liability insurance market in the construction industry.

As rational "economic entities," clients and service providers determine whether to cooperate in service innovation based on their payoffs [35]. In fact, the process of cooperative innovation is a long-term one, and the two parties constantly adjust their strategies of cooperating or not under the premise of limited rationality [36]. Their cooperative innovation behavior dynamically evolves over the course of a long-term game, and the corresponding decision-making process is actually a dynamic evolution process [37]. Therefore, this study utilizes evolutionary game theory as the theoretical basis to conduct the research.

To the author's best knowledge, no study has been conducted on decision-making mechanism of cooperative innovation between clients and service providers based on evolutionary game theory. To fill this gap, this paper constructs an evolutionary game model of the cooperative innovation behavior of clients and service providers, explores the decision-making mechanism of their cooperative innovation behavior, reveals the internal mechanism of the strategic choice of clients and service providers' cooperative behavior, analyzes how clients and service providers can form a stable cooperative relationship in the process of service innovation, and provides management suggestions regarding how to promote client-service provider cooperative innovation.

3. Problem Description and Formulation

We consider two groups: one of clients and one of service providers. One client and one service provider are randomly matched in each iteration to play a game. The client and service provider are bounded rationally and constantly change their strategies through learning until they reach an equilibrium [38]. The strategy set of client and service provider in the process of service innovation is both (cooperation and noncooperation). The party that chooses a cooperation strategy is required to invest time and effort in innovation activity and exchanges knowledge and information. In contrast, choosing a noncooperation strategy means that the party does not conduct or participate in innovation activity.

We make the following basic assumptions.

Assumption 1. When both parties adopt the noncooperation strategy, neither party invests in innovation activity, and such activities do not occur. Both parties only obtain their own basic benefit on the basis of the signed service contract between them: the client accepts services provided by the service provider, and the service provider receives remuneration from the client. The basic benefits of the client and service provider are π_c, π_s, respectively.

Assumption 2. If one party adopts the cooperation strategy, it makes an investment in innovation activity. When innovation activity occurs, both parties can obtain additional benefits through it. In this case, the total benefit obtained by both parties is the sum of the basic benefit and additional benefit.

Assumption 3. When both parties adopt the cooperation strategy, the internal knowledge of the client and the professional ability of the service provider are complementary [39], resulting in a "$1 + 1 > 2$" synergy effect [40] and generating innovation benefit (excess benefit) π', but the two parties must share innovation cost C'.

By adopting the revenue sharing and cost sharing mechanisms [41], the additional benefits obtained by the client and service provider through innovation activity are $\mu\pi' - \theta C'$, $(1 - \mu)\pi' - (1 - \theta)C'$, and the total benefits obtained by them are $\Pi_{cc}^{c} = \pi_c + \mu\pi' - \theta C'$, $\Pi_{cc}^{s} = \pi_s + (1 - \mu)\pi' - (1 - \theta)C'$, where μ, $1 - \mu$ are the benefit distribution proportions of the client and service provider, and $\theta, 1 - \theta$ are their cost sharing proportions.

Assumption 4. When one party adopts the cooperation strategy while the other party does not, the party adopting the cooperation strategy performs innovation activity independently. According to the logic of the spillover effect, the party that adopts a non-cooperative strategy gains a spillover benefit [42]. For example, when the client performs innovation activity while the service provider does not, the service provider can experience and learn the innovation achievements and apply them to the other clients, thus obtaining spillover benefits. When the service provider performs innovation activity and the client does not, the innovative achievements can not only optimize the service processes and reduce the service costs but also bring higher quality services to the client, and the client gains the spillover benefit [43].

In addition, a punishment mechanism [44] is introduced to encourage the two parties to participate in innovation activity: when one party cooperates and the other does not, the noncooperative party pays a fine, P, to the cooperative one.

Specifically, when the client cooperates and the service provider does not (i.e., the client innovates independently), the innovation benefit obtained by the client is π_c', the

Table 1: Payoff matrix.

		Service provider	
		Cooperation	Noncooperation
Client	Cooperation	$\pi_c + \mu\pi' - \theta C'$; $\pi_s + (1-\mu)\pi' - (1-\theta)C'$	$\pi_c + \pi_c' - C_c + P$; $\pi_s + \beta\pi_c' - P$
	Noncooperation	$\pi_c + \alpha\pi_s' - P$; $\pi_s + \pi_s' - C_s + P$	π_c; π_s

corresponding innovation cost is C_c, and the spillover benefit obtained by the service provider due to the spillover effect is $\beta\pi_c'$, where β is the client's spillover coefficient [45, 46]. In this case, the additional benefits obtained by the client and service provider through innovation activity are $\pi_c' - (C_c + P)$ and $(\beta\pi_c' - P)$, respectively, and the final benefits obtained by the client and service provider are $\Pi_{cn}^{c} = \pi_c + \pi_c' - C_c + P$, $\Pi_{cn}^{s} = \pi_s + \beta\pi_c' - P$.

When the service provider cooperates and the client does not (i.e., the service provider innovates independently), the innovation benefit obtained by the service provider is π_s', the corresponding innovation cost is C_s, and the spillover benefit obtained by the client due to the spillover effect is $\alpha\pi_s'$, where α is the service provider's spillover coefficient [45, 46]. In this case, the additional benefits obtained by the client and service provider through innovation activity are $(\alpha\pi_s' - P)$ and $\pi_s' - (C_s + P)$, respectively, and the final benefits obtained by the client and service provider are $\Pi_{nc}^{c} = \pi_c + \alpha\pi_s' - P$; $\Pi_{nc}^{s} = \pi_s + \pi_s' - C_s + P$.

A payoff matrix based on the preceding assumptions is provided in Table 1.

For ease of reference, a list of notations is provided in Table 2.

4. Evolutionary Game Analysis

Based on evolutionary game theory, we consider two groups: a client group and a service provider group. In the client group, the proportion of the members choosing the cooperation strategy to all the members is $x\,(0 \le x \le 1)$, and the proportion of the members choosing the noncooperation strategy to all the members is $(1 - x)$. Thus, when a client is randomly selected to pair up and play a game with a service provider, the probability of the client choosing the cooperative strategy is x, whereas the probability of the client choosing the noncooperative strategy is $(1 - x)$ [24].

In the service provider group, the proportion of the members choosing the cooperation strategy to all the members is $y\,(0 \le y \le 1)$, and the proportion of the members choosing the noncooperation strategy to all the members is $(1 - y)$. Thus, when a service provider is randomly selected to pair up and play a game with a client, the probability of the service provider choosing the cooperative strategy is x, whereas the probability of the service provider choosing the noncooperative strategy is $(1 - x)$ [24].

Thus, when the client chooses the cooperation strategy, its benefit is as follows:

$$U_{cc} = y\left(\pi_c + \mu\pi' - \theta C'\right) + (1-y)\left(\pi_c + \pi_c' - C_c + P\right). \tag{1}$$

When the client chooses the noncooperation strategy, its benefit is as follows:

$$U_{cn} = y\left(\pi_c + \alpha\pi_s' - P\right) + (1-y)\pi_c. \tag{2}$$

The client's average revenue is as follows:

$$\overline{U_c} = xU_{cc} + (1-x)U_{cn}. \tag{3}$$

The corresponding duplicate dynamic equation is as follows:

$$\begin{aligned}
F(x) &= \frac{dx}{dt} = x(1-x)\left(U_{cc} - U_{cn}\right)\\
&= x(1-x)\left[y\left(\mu\pi' - \theta C' - \alpha\pi_s' - \pi_c' + C_c\right) + \pi_c' - C_c + P\right],\\
U_{sc} &= x\left(\pi_s + (1-\mu)\pi' - (1-\theta)C'\right)\\
&\quad + (1-x)\left(\pi_s + \pi_s' - C_s + P\right),\\
U_{sn} &= x\left(\pi_s + \beta\pi_c' - P\right) + (1-x)\pi_s.
\end{aligned} \tag{4}$$

Similarly, the service provider's average revenue is as follows:

$$\overline{U_s} = yU_{sc} + (1-y)U_{sn}. \tag{5}$$

The corresponding duplicate dynamic equation is as follows:

$$F(y) = \frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y)\left[x\left((1-\mu)\pi' - (1-\theta)C' - \beta\pi_c' - \pi_s' + C_s\right) + \pi_s' - C_s + P\right]. \tag{6}$$

Assigning $(x) = 0, F(y) = 0$, we can obtain four pure strategy equilibrium points $A(0,0), B(0,1), C(1,0), D(1,1)$ and one possible mixed strategy equilibrium point $E(x^*, y^*)$, where

$$\begin{aligned}
x^* &= \frac{\pi_s' - C_s + P}{(1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' + \pi_s' - C_s},\\
y^* &= \frac{\pi_c' - C_c + P}{\theta C' + \alpha\pi_s' - \mu\pi' + \pi_c' - C_c}.
\end{aligned} \tag{7}$$

Table 2: List of notations.

Symbol	Description
π_c	Basic benefit of the client when both parties adopt the noncooperation strategy
π_s	Basic benefit of the service provider when both parties adopt the noncooperation strategy
π_c'	Innovation benefit obtained by client when it innovates independently
C_c	Innovation cost bore by client when it innovates independently
β	Spillover coefficient when the client innovates independently
π_s'	Innovation benefit obtained by the service provider when it innovates independently
C_s	Innovation cost bore by the service provider when it innovates independently
α	Spillover coefficient when the service provider innovates independently
P	Penalty amount for the party that does not adopt the cooperation strategy while the other party does
π'	Excess benefit when the two parties both adopt the cooperation strategy
μ	Benefit distribution proportion of the client when the two parties both adopt the cooperation strategy
C'	Innovation cost when the two parties both adopt the cooperation strategy
θ	Cost sharing proportion of the client when the two parties both adopt the cooperation strategy

The Jacobian matrix of the evolutionary system is as follows:

$$J=\begin{bmatrix} (1-2x)\left[y\left(\mu\pi'-\theta C'-\alpha\pi_s'-\pi_c'+C_c\right)+\pi_c'-C_c+P\right] & x(1-x)\left(\mu\pi'-\theta C'-\alpha\pi_s'-\pi_c'+C_c\right) \\ y(1-y)\left[(1-\mu)\pi'-(1-\theta)C'-\beta\pi_c'-\pi_s'+C_s\right] & (1-2y)\left[x\left((1-\mu)\pi'-(1-\theta)C'-\beta\pi_c'-\pi_s'+C_s\right)+\pi_s'-C_s+P\right] \end{bmatrix}. \tag{8}$$

The determinant and the trace of the Jacobian matrix are as follows:

$$\begin{aligned} \det J &= \frac{\partial F(x)}{\partial x}\frac{\partial F(y)}{\partial y}-\frac{\partial F(y)}{\partial x}\frac{\partial F(x)}{\partial y}, \\ \operatorname{tr} J &= \frac{\partial F(x)}{\partial x}+\frac{\partial F(y)}{\partial y}. \end{aligned} \tag{9}$$

The determinant and trace of the Jacobian matrix corresponding to each (possible) equilibrium point are shown in Table 3. It can be inferred that the following four polynomials being positive or negative not only determines the number of equilibrium points but also influences the nature of each equilibrium point and the evolution stable state of the system:

$$\begin{aligned} &\pi_s'-C_s+P, \pi_c'-C_c+P, (1-\theta)C'+\beta\pi_c'-(1-\mu)\pi'-P, \\ &\theta C'+\alpha\pi_s'-\mu\pi'-P. \end{aligned} \tag{10}$$

4.1. Equilibrium Characteristics.

According to the positive and negative of the preceding four polynomials, the following 8 conditions can be defined.

Condition 1. $\mu\pi'-\theta C'<\pi_s'-P$; that is, when the service provider chooses the cooperation strategy, the additional benefit obtained by the client when it chooses the cooperation strategy is less than that of choosing the noncooperation strategy.

Condition 2. $(1-\mu)\pi'(1-\theta)C'\beta\pi_c'-P$; that is, when the client chooses the cooperation strategy, the additional benefit obtained by the service provider when it chooses the cooperation strategy is less than that of choosing the noncooperation strategy.

Condition 3. $(\pi_s'-C_s)+P<0$; that is, when the client chooses the noncooperation strategy and the service provider chooses the cooperation strategy, the additional benefit obtained by the service provider is less than zero.

Condition 4. $\pi_c'-C_c+P<0$; that is, when the service provider chooses the noncooperation strategy and the client chooses the cooperation strategy, the additional benefit obtained by the client is less than zero.

Condition 5. $\mu\pi'-\theta C'>\alpha\pi_s'-P$; that is, when the service provider chooses the cooperation strategy, the additional benefit obtained by the client when it chooses the cooperation strategy is more than that of choosing the noncooperation strategy.

Condition 6. $(1-\mu)\pi'-(1-\theta)C'>\beta\pi_c'-P$; that is, when the client chooses the cooperation strategy, the additional benefit obtained by the service provider when it chooses the cooperation strategy is more than that of choosing the noncooperation strategy.

Condition 7. $(\pi_s'-C_s)+P>0$; that is, when the client chooses the noncooperation strategy and the service provider chooses the cooperation strategy, the additional benefit obtained by the service provider is more than zero.

Condition 8. $(\pi_c'-C_c)+P>0$; that is, when the service provider chooses the noncooperation strategy and the client chooses the cooperation strategy, the additional benefit obtained by the client is more than zero.

Table 3: Determinant and trace of the Jacobian matrix corresponding to each (possible) equilibrium point.

Equilibrium points	det$J$	tr$J$
$(0, 0)$	$(\pi_c' - C_c + P)(\pi_s' - C_s + P)$	$\pi_c' - C_c + \pi_s' - C_s + 2P$
$(0, 1)$	$(\mu\pi' - \theta C' - \alpha\pi_s' + P)(C_s - \pi_s' - P)$	$\mu\pi' - \theta C' - \alpha\pi_s' + P + C_s - \pi_s' - P$
$(1, 0)$	$[(1-\mu)\pi' - (1-\theta)C' - \beta\pi_c' + P](-\pi_c' + C_c - P)$	$(1-\mu)\pi' - (1-\theta)C' - \beta\pi_c' + P - \pi_c' + C_c - P$
$(1, 1)$	$(\theta C' + \alpha\pi_s' - \mu\pi' - P) * [(1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' - P]$	$\theta C' + \alpha\pi_s' - \mu\pi' + (1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' - 2P$
(x^*, y^*)	$- [(1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' - P](\pi_s' - C_s + P)/$ $(1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' + \pi_s' - C_s(\theta C' + \alpha\pi_s' - \mu\pi' - P)(\pi_c' - C_c +$ $P)\ /\theta C' + \alpha\pi_s' - \mu\pi' + \pi_c' - C_c$	0

Table 4: Properties of the equilibrium points in Cases 1 and 2.

Equilibrium points	Case 1			Case 2		
	det$J$	tr$J$	Properties	det$J$	tr$J$	Properties
$A(0, 0)$	+	+	Unstable	+	−	Stable
$B(0, 1)$	+	−	Stable	+	+	Unstable
$C(1, 0)$	+	−	Stable	+	+	Unstable
$D(1, 1)$	+	+	Unstable	+	−	Stable
$E(x^*, y^*)$	−	0	Saddle point	−	0	Saddle point

According to the preceding conditions, there may be 16 different cases in the evolution system. The properties of each equilibrium point of the different cases can be obtained by analyzing its corresponding Jacobian matrix. When the determinant of its Jacobian matrix is negative, the equilibrium point is a saddle point; when the determinant of its Jacobian matrix is positive and the trace is negative, the equilibrium point is stable; and when both the determinant and trace are positive, the equilibrium point is an unstable point [24].

When Conditions 1, 2, 7, and 8 are simultaneously established (Case 1) or Conditions 3, 4, 5, and 6 are simultaneously established (Case 2), $0 < x^*, y^* < 1$, there are five equilibrium points in the evolution system: $A(0, 0), B(0, 1), C(1, 0), D(1, 1)$,

$$E\left(\frac{\pi_s' - (C_s + P)}{(1-\theta)C' + \beta\pi_c' - (1-\mu)\pi' + \pi_s' - C_s}, \frac{\pi_c' - (C_c + P)}{\theta C' + \alpha\pi_s' - \mu\pi' + \pi_c' - C_c}\right). \tag{11}$$

In the other 14 cases, there are four equilibrium points in the evolution system: $A(0, 0), B(0, 1), C(1, 0), D(1, 1)$.

4.2. System Evolution Path and Analysis. The properties of the equilibrium points in Cases 1 and 2 are shown in Table 4. The properties of the equilibrium points in Cases 3–16 are shown in Table 5. The system evolution path in each case is shown in Figure 1.

Case 1. When Conditions 1, 2, 7, and 8 are simultaneously established, there are two stable points $B(0, 1), C(1, 0)$ in the system. If the initial state is in the region ABDE, the system converges to the stable point $B(0, 1)$, and the evolutionary stability strategy of the set is (noncooperation, cooperation). If the initial state is in the region ACDE, the system converges to the stable point $C(1, 0)$, and the evolutionary stability strategy set is (cooperation, noncooperation).

Case 2. When Conditions 3, 4, 5, and 6 are simultaneously established, there are two stable points $A(0, 0), D(1, 1)$ in the system. If the initial state is in the region CABE, the system converges to the stable point $A(0, 0)$, and the evolutionary stability strategy set is (noncooperation, noncooperation). If the initial state is in the region BDCE, the system converges to the stable point $D(1, 1)$, and the evolutionary stability strategy set is (cooperation, cooperation).

Case 3. When Conditions 3, 5, 6, and 8 are simultaneously established, there is one stable point $D(1, 1)$ in the system. Regardless of initial state, the system converges to the stable point $D(1, 1)$, and the evolutionary stability strategy set is (cooperation, cooperation).

Case 4. When Conditions 5, 6, 7, and 8 are simultaneously established, there is one stable point $D(1, 1)$ in the system. Regardless of initial state, the system converges to the stable point $D(1, 1)$, and the evolutionary stability strategy set is (cooperation, cooperation).

Case 5. When Conditions 4, 5, 6, and 7 are simultaneously established, there is one stable point $D(1, 1)$ in the system. Regardless of initial state, the system converges to the stable point $D(1, 1)$, and the evolutionary stability strategy set is (cooperation, cooperation).

Case 6. When Conditions 2, 3, 4, and 5 are simultaneously established, there is one stable point $A(0, 0)$ in the system. Regardless of initial state, the system converges to the stable point $A(0, 0)$, and the evolutionary stability strategy of set is (noncooperation, noncooperation).

Table 5: Properties of the equilibrium points in Cases 3–16.

Equilibrium points	Properties													
	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16
$A(0,0)$	Saddle point	Unstable	Saddle point	Stable	Saddle point	Saddle point	Unstable	Saddle point	Stable	Saddle point	Unstable	Saddle point	Stable	Saddle point
$B(0,1)$	Unstable	Saddle point	Saddle point	Unstable	Unstable	Saddle point	Saddle point	Stable	Saddle point	Saddle point	Stable	Stable	Saddle point	Saddle point
$C(1,0)$	Saddle point	Saddle point	Unstable	Saddle point	Stable	Saddle point	Stable	Saddle point	Saddle point	Stable	Saddle point	Unstable	Unstable	Saddle point
$D(1,1)$	Stable	Stable	Stable	Saddle point	Saddle point	Saddle point	Saddle point	Unstable	Unstable	Unstable	Saddle point	Saddle point	Saddle point	Saddle point

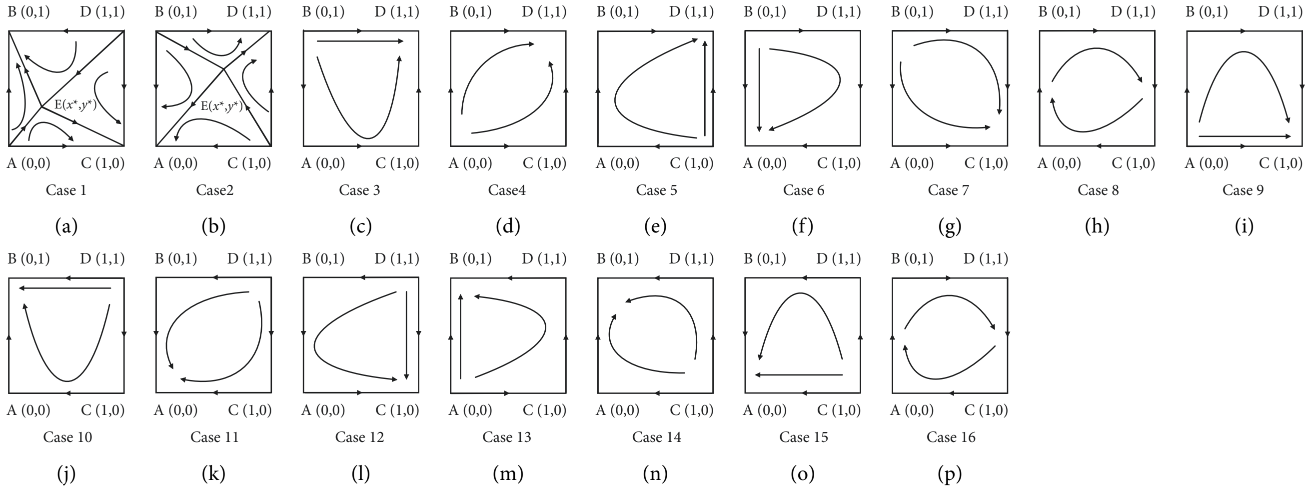


Figure 1: System evolution path in each case. (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4; (e) Case 5; (f) Case 6; (g) Case 7; (h) Case 8; (i) Case 9; (j) Case 10; (k) Case 11; (l) Case 12; (m) Case 13; (n) Case 14; (o) Case 15; (p) Case 16.

Case 7. When Conditions 2, 3, 5, and 8 are simultaneously established, there is one stable point $C(1,0)$ in the system. Regardless of initial state, the system converges to the stable point $C(1,0)$, and the evolutionary stability strategy set is (cooperation, noncooperation).

Case 8. When Conditions 2, 4, 5, and 7 are simultaneously established, there is no stable point in the system. Regardless of initial state, the system will not converge, and there is no evolutionary stability strategy for the system.

Case 9. When Conditions 2, 5, 7, and 8 are simultaneously established, there is one stable point $C(1,0)$ in the system. Regardless of initial state, the system converges to the stable point $C(1,0)$, and the evolutionary stability strategy set is (cooperation, noncooperation).

Case 10. When Conditions 1, 2, 4, and 7 are simultaneously established, there is one stable point $B(0,1)$ in the system. Regardless of initial state, the system converges to the stable point $B(0,1)$, and the evolutionary stability strategy set is (noncooperation, cooperation).

Case 11. When Conditions 1, 2, 3, and 4 are simultaneously established, there is one stable point $A(0,0)$ in the system. Regardless of initial state, the system converges to the stable point $A(0,0)$, and the evolutionary stability strategy set is (noncooperation, noncooperation).

Case 12. When Conditions 1, 2, 3, and 8 are simultaneously established, there is one stable point $C(1,0)$ in the system. Regardless of initial state, the system converges to the stable point $C(1,0)$, and the evolutionary stability strategy set is (cooperation, noncooperation).

Case 13. When Conditions 1, 6, 7, and 8 are simultaneously established, there is one stable point $B(0,1)$ in the system. Regardless of initial state, the system converges to the stable point $B(0,1)$, and the evolutionary stability strategy set is (noncooperation, cooperation).

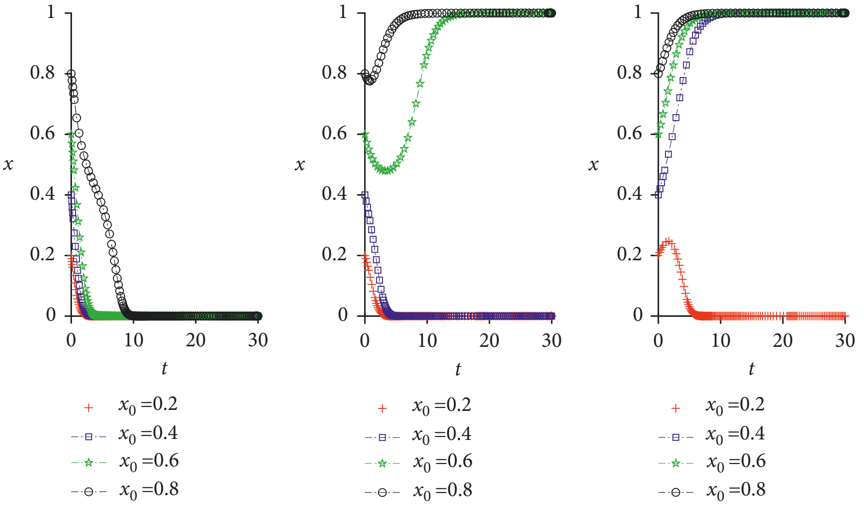
Case 14. When Conditions 1, 4, 6, and 7 are simultaneously established, there is one stable point $B(0,1)$ in the system. Regardless of initial state, the system converges to the stable point $B(0,1)$, and the evolutionary stability strategy set is (noncooperation, cooperation).

Case 15. When Conditions 1, 3, 4, and 6 are simultaneously established, there is one stable point $A(0,0)$ in the system. Regardless of initial state, the system converges to the stable point $A(0,0)$, and the evolutionary stability strategy set is (noncooperation, noncooperation).

Case 16. When Conditions 1, 3, 6, and 8 are simultaneously established, there is no stable point in the system. Regardless of initial state, the system will not converge, and there is no evolutionary stability strategy for the system.

According to Cases 2, 6, 11, and 15, the establishment of Conditions 3 and 4 is the necessary condition for the evolutionary stability strategy set to be (noncooperation, noncooperation). That is, if the system evolves to a stable state in which the two parties both choose the noncooperation strategy, the additional benefit obtained by the service provider is certain to be less than zero when the client chooses the noncooperation strategy and the service provider chooses the cooperation strategy, and the additional benefit obtained by the client is certain to be less than zero when the service provider chooses the noncooperation strategy and the client chooses the cooperation strategy.

According to Cases 1, 10, 13, and 14, the establishment of Conditions 1 and 7 is the necessary condition for the evolutionary stability strategy set to be (noncooperation, cooperation). That is, if the system evolves to a stable state in which the client chooses the noncooperation strategy and the service provider chooses the cooperation strategy, the additional benefit obtained by the client when it chooses the



(a) (b) (c)

FIGURE 2: Impact of the initial probabilities of the two parties choosing the cooperative strategy on system evolution. Comparing (a), (b), and (c), as y_0 (initial probability of the two parties choosing the cooperation strategy) increases, the probability of the system evolving to the ideal state increases. (a) $y_0 = 0.5$; (b) $y_0 = 0.7$; (c) $y_0 = 0.9$.

cooperation strategy is certain to be less than that of choosing the noncooperation strategy when the service provider chooses the cooperation strategy, and the additional benefit obtained by the service provider is certain to be more than zero when the client chooses the noncooperation strategy and the service provider chooses the cooperation strategy.

According to Cases 1, 7, 9, and 12, the establishment of Conditions 2 and 8 is the necessary condition for the evolutionary stability strategy set to be (cooperation, noncooperation). That is, if the system evolves to a stable state in which the client chooses the cooperation strategy and the service provider chooses the noncooperation strategy, the additional benefit obtained by the service provider when it chooses the cooperation strategy is certain to be less than that of choosing the noncooperation strategy when the client chooses the cooperation strategy, and the additional benefit obtained by the client is certain to be more than zero when the service provider chooses the noncooperation strategy and the client chooses the cooperation strategy.

To simplify the statement, we define the stable state in which the evolutionary stability strategy set is (cooperation, cooperation) as the ideal state and the stable state in which the evolutionary stability strategy set is (noncooperation, noncooperation) as the worst state. The ideal state is the primary concern of this paper, and only Cases 2, 3, 4, and 5, in which the ideal state exists, are analyzed below.

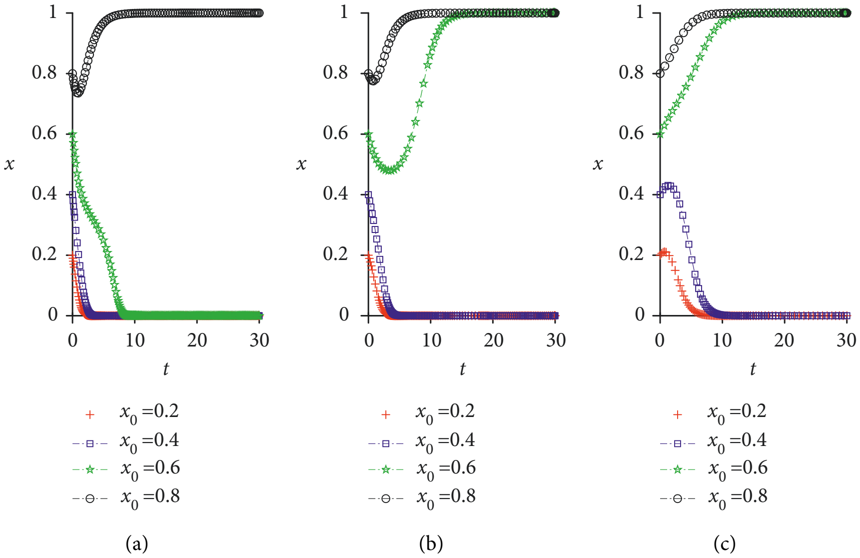
According to Cases 2, 3, 4, and 5, the establishment of Conditions 5 and 6 is the necessary condition for the evolutionary stability strategy set to be (cooperation, cooperation). Under the premise that Conditions 5 and 6 are established, as long as the additional benefit obtained by the client or the service provider when the other party engages in innovation activity independently is more than zero, the system is certain to evolve to a stable state in which the two parties both choose the cooperation strategy, i.e., the ideal state.

That is, the benefits of both the client and service provider when they innovate cooperatively being greater than that when they innovate independently cannot guarantee that the system will certainly evolve to the ideal state. However, as long as the condition that either party gains more than zero when it innovates independently is established along with the preceding state of affairs, the system will certainly evolve to the ideal state.

5. Numerical Simulation under Double Equilibrium

In Cases 3, 4, and 5, the evolutionary stability strategy set is (cooperation, cooperation), and we do not discuss these cases further in this paper. In Case 2, the evolutionary stability strategy set is either (cooperation, cooperation) or (noncooperation, noncooperation), which is a double equilibrium state. We use MATLAB to conduct numerical simulation and analyze the impact of different system parameters on the evolution of the system to generate suggestions on how to improve the probability that both parties choose cooperation strategies in Case 2.

Suppose x_0 and y_0 are the initial probabilities of the client and service provider choosing the cooperation strategy, respectively. The establishment of Conditions 3, 4, 5, and 6 is the prerequisite for the system evolving to the double equilibrium state, in which the evolutionary stability strategy set is either (cooperation, cooperation) or (noncooperation, noncooperation). To satisfy Conditions 3, 4, 5, and 6 (i.e., $(\pi_s' - C_s) + P < 0$; $(\pi_c' - C_c) + P < 0$; $\mu\pi' - \theta C' > \alpha\pi_s' - P$; $(1-\mu)\pi' - (1-\theta)C' > \beta\pi_c' - P$), we suppose that the initial values of the parameters are

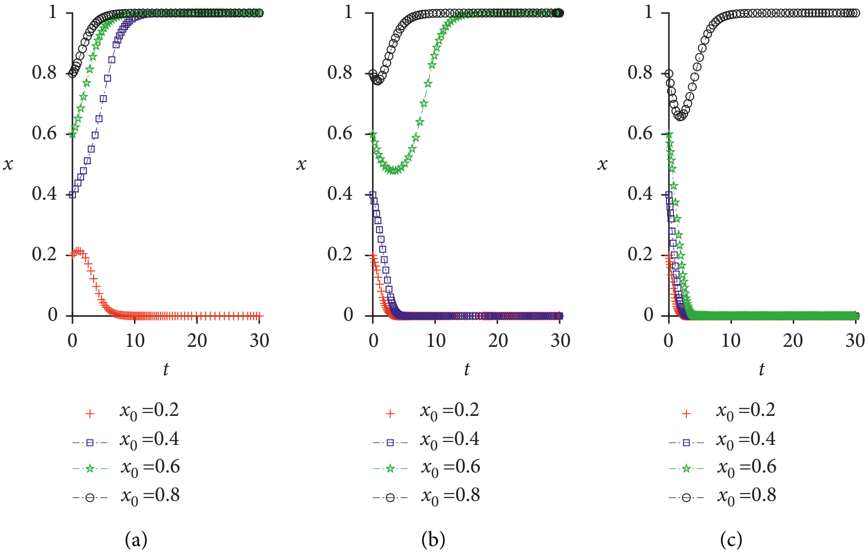


(a)

(b)

(c)

FIGURE 3: Impact of π_c' on system evolution. Comparing (a), (b), and (c), as π_c' (innovation benefit of the client when it innovates independently) increases, the probability of the system evolving to the ideal state increases. (a) $\pi_c' = 1$; (b) $\pi_c' = 3$; (c) $\pi_c' = 5$.



(a)

(b)

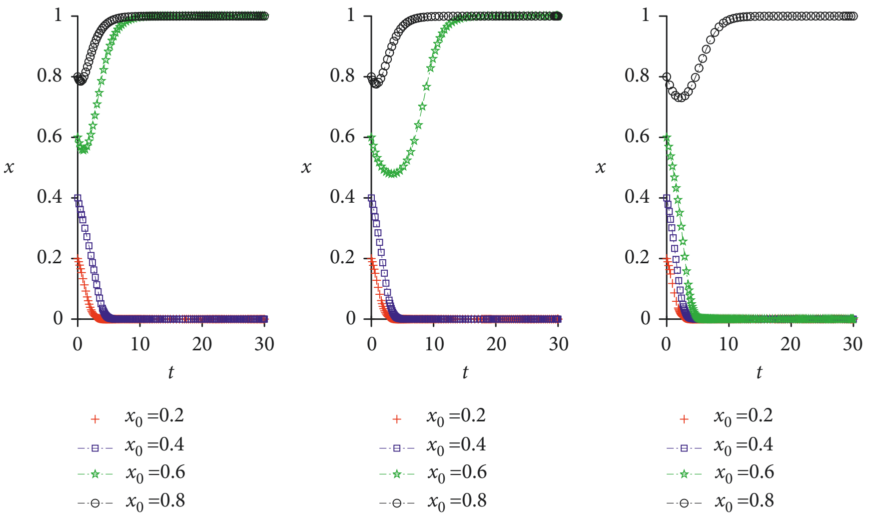
(c)

FIGURE 4: Impact of C_c on system evolution. Comparing (a), (b), and (c), as C_c (cost borne by the client when it innovates independently) decreases, the probability of the system evolving to the ideal state increases. (a) $C_c = 5$; (b) $C_c = 7$; (c) $C_c = 9$.

$\pi_c' = 3, C_c = 5, \beta = 0.4, \pi_s' = 4, C_s = 6, \alpha = 0.45, P = 1, \pi' = 7, \mu = 0.5, C' = 4, \theta = 0.5, y_0 = 0.7$. During the analysis, all parameters are initial values except the value of the target parameter changes. To clearly show the impact of the parameters on system evolution, the system evolution curves when x_0 is taken as 0.2, 0.4, 0.6, and 0.8 are provided in each diagram.

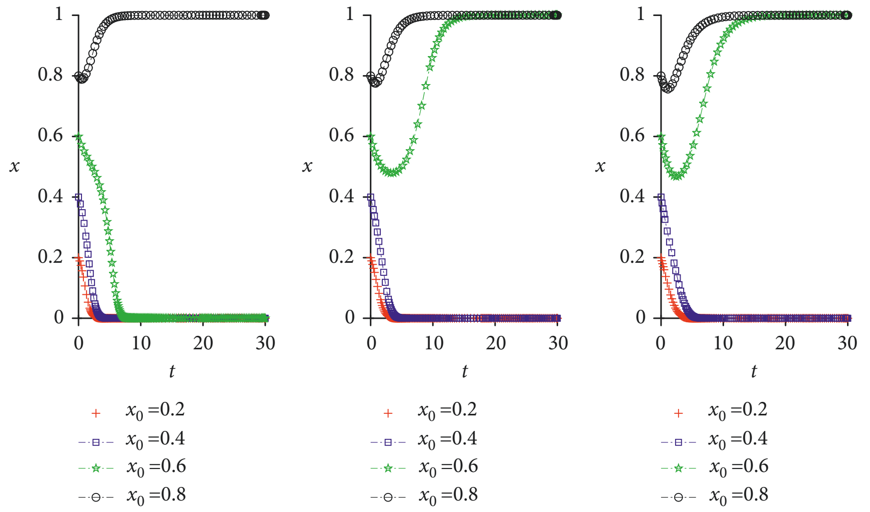
5.1. Impact of the Initial Probabilities of the Two Parties Choosing the Cooperation Strategy on System Evolution. The impact of the initial probabilities of the two parties choosing the cooperation strategy on system evolution is shown in Figure 2. Comparing 2(a)–2(c), one can note that with the increase in the initial probability of the two parties choosing the cooperation strategy the probability of the system evolving to the ideal state increases. It can also be seen from 2(b) or 2(c) that the higher the initial probability of the client choosing the cooperation strategy is, the faster the system converges to the ideal state. Therefore, it can be inferred that enhancing the cooperation willingness of both parties in the early stage is conducive to the evolution of the system to the ideal state.

5.2. Impact of π_c' on System Evolution. The impact of π_c' on system evolution is shown in Figure 3. One can note that with the increase in π_c' the probability of system evolution to the ideal state increases, and the convergence speed accelerates.



(a) (b) (c)

Figure 5: Impact of β on system evolution. Comparing (a), (b), and (c), as β (client's spillover coefficient) increases, the probability of the system evolving to the ideal state decreases. (a) $\beta = 0.2$; (b) $\beta = 0.4$; (c) $\beta = 0.6$.



(a) (b) (c)

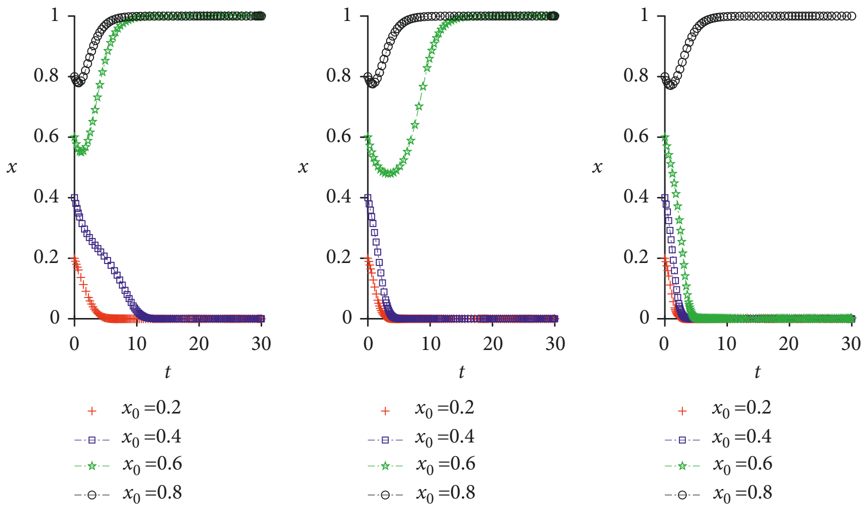
Figure 6: Impact of π_s' on system evolution. Comparing (a), (b), and (c), as π_s' (innovation benefit of the service provider when it innovates independently) increases, the probability of the system evolving to the ideal state increases. (a) $\pi_s' = 3.6$; (b) $\pi_s' = 4$; (c) $\pi_s' = 4.4$.

In Case 2, $\Pi_{cn}^c < 0$. When π_c' increases, the client's benefit Π_{cn}^c increases. When π_c' increases to a certain value, $\Pi_{cn}^c > 0$, the system changes from Case 2 to 3, in which the system is certain to evolve to the ideal state.

Therefore, increasing the innovation benefit of the client when it innovates independently always increases the probability of the system evolving to the ideal stable state. Moreover, when the above benefit is large enough, the system is certain to evolve to the ideal state, in which the two parties both adopt a cooperation strategy.

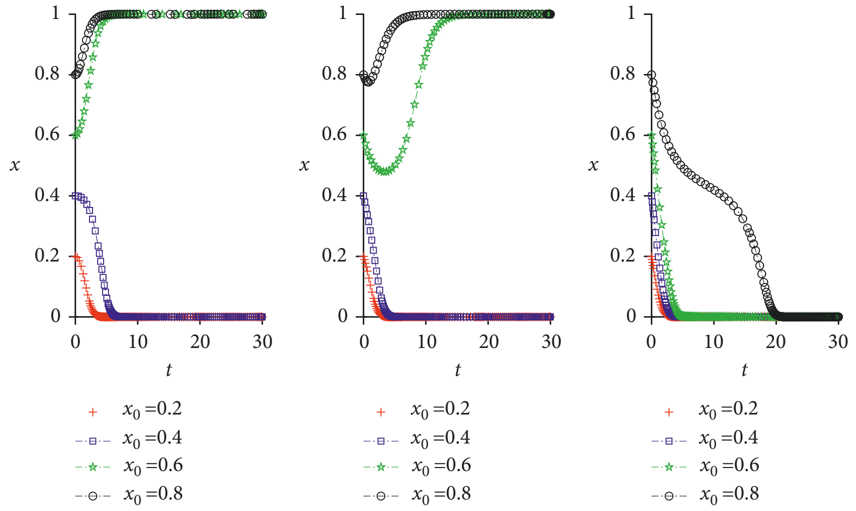
5.3. Impact of C_c on System Evolution. The impact of C_c on system evolution is shown in Figure 4. It can be found that, with the increase in C_c, the probability of system evolution to the ideal state decreases, and the convergence speed slows. The greater the cost borne by the client when it innovates independently is, the less the benefit the client obtains and the more reluctant it is to adopt the cooperation strategy. Therefore, decreasing the cost borne by the client when it innovates independently increases the probability of the system evolving to the ideal state.

5.4. Impact of β on System Evolution. The impact of β on system evolution is shown in Figure 5. One can note that with the increase in β the probability of the system evolving to the ideal state decreases, and the convergence speed slows. The larger the spillover coefficient, the greater the additional benefit and total benefit obtained by the service provider



(a) (b) (c)

Figure 7: Impact of C_s on system evolution. Comparing (a), (b), and (c), as C_s (cost borne by the service provider when it innovates independently) decreases, the probability of the system evolving to the ideal state increases. (a) $C_s = 5.4$; (b) $C_s = 6$; (c) $C_s = 6.6$.



(a) (b) (c)

Figure 8: Impact of α on system evolution. Comparing (a), (b), and (c), as α (service provider's spillover coefficient) decreases, the probability of the system evolving to the ideal state increases. (a) $\alpha = 0.3$; (b) $\alpha = 0.45$; (c) $\alpha = 0.6$.

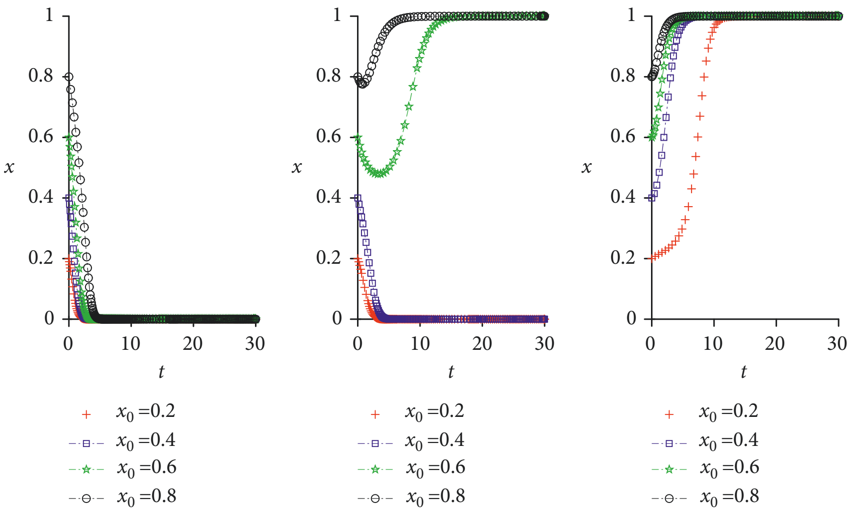
when it adopts a noncooperation strategy, the more inclined it is to be a "free rider" and adopt the noncooperation strategy, and the higher the probability of the system evolving to the worst state. Therefore, decreasing the client's spillover coefficient decreases the benefit of the service provider but increases the probability of the two parties both adopting the cooperation strategy.

5.5. Impact of π_s' on System Evolution. The impact of π_s' on system evolution is shown in Figure 6. One can note that with the increase in π_s' the probability of the system evolving to the ideal state increases, and the convergence speed accelerates.

In Case 2, $\Pi_{nc}^{s} < 0$. When π_s' increases, the client's benefit Π_{nc}^{s} increases. When π_s' increases to a certain value, $\Pi_{nc}^{s} > 0$, the system changes from Case 2 to 4, in which the system is certain to evolve to the ideal state.

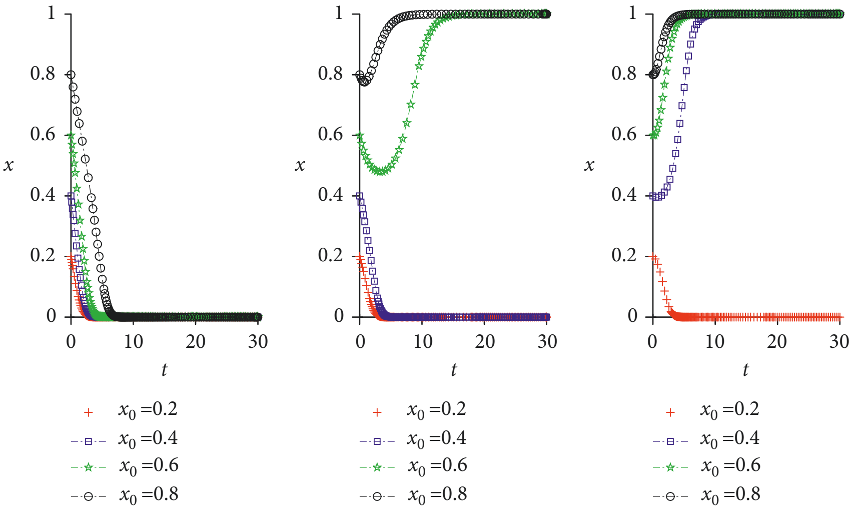
Therefore, increasing the innovation benefit of the service provider when it innovates independently always increases the probability of the system evolving to the ideal stable state. Moreover, when the above innovation benefit is large enough, the system is certain to evolve to the ideal state, in which the two parties both adopt a cooperation strategy.

5.6. Impact of C_s on System Evolution. The impact of C_s on system evolution is shown in Figure 7. One can note that



(a) (b) (c)

FIGURE 9: Impact of P on system evolution. Comparing (a), (b), and (c), as P (the fine to the party that adopts a noncooperation strategy) increases, the probability of the system evolving to the ideal state increases. (a) $P = 0.5$; (b) $P = 1$; (c) $P = 1.5$.



(a) (b) (c)

FIGURE 10: Impact of π' on system evolution. Comparing (a), (b), and (c), as π' (innovation benefit when both parties choose the cooperation strategy) increases, the probability of the system evolving to the ideal state increases. (a) $\pi' = 6$; (b) $\pi' = 7$; (c) $\pi' = 8$.

with the increase in C_s the probability of system evolution to the ideal state decreases, and the convergence speed slows. The greater the cost borne by the service provider when it innovates independently is, the less the benefit it obtains and the more reluctant it is to adopt the cooperation strategy. Therefore, decreasing the cost borne by the service provider when it innovates independently will increase the probability of the system evolving to an ideal state.

5.7. Impact of α on System Evolution. The impact of α on system evolution is shown in Figure 8. One can note that with the increase in α the probability of the system evolving to the ideal state decreases, and the convergence speed slows. The larger the spillover coefficient, the greater the additional benefit and total benefit obtained by the client when it adopts the noncooperation strategy, the more inclined it is to be a “free rider” and adopt the noncooperation strategy, and the higher the probability of the system evolving to the worst state. Therefore, decreasing the service provider’s spillover coefficient will decrease the benefit of the client but increase the probability of the two parties both adopting the cooperation strategy.

5.8. Impact of P on System Evolution. The impact of P on system evolution is shown in Figure 9. One can note that with the increase in P the probability of the system evolving to an ideal stable state increases, and the convergence rate accelerates. When P is larger than a certain value, the system

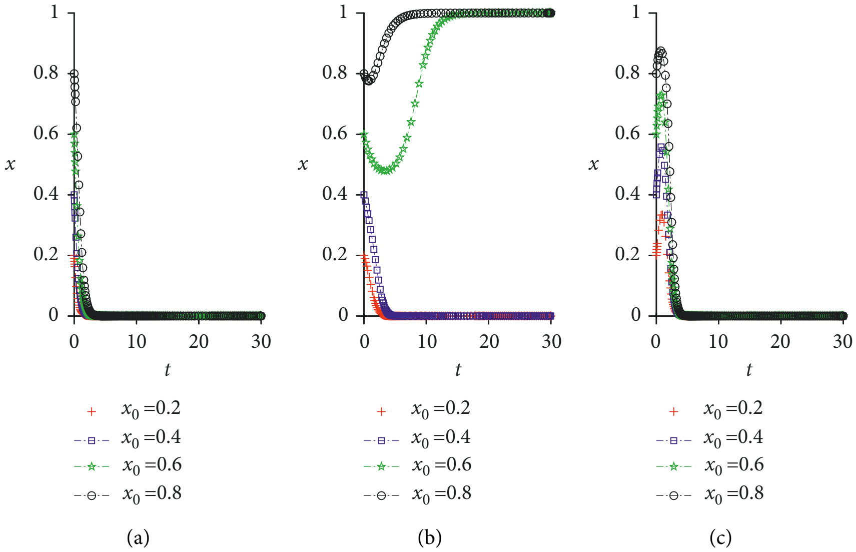


Figure 11: Impact of μ on system evolution. According to (b), when the benefit distribution proportions of the two parties are equal, the system may evolve to the ideal or worst state, while according to (a) and (c), when one party's benefit distribution proportion is much smaller than that of the other, the system will evolve to the worst state. (a) $\mu = 0.1$; (b) $\mu = 0.5$; (c) $\mu = 0.9$.

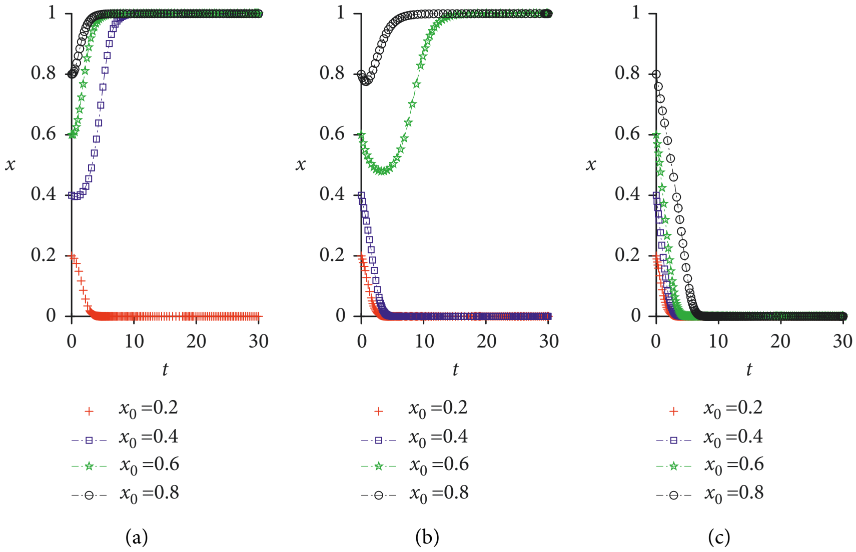


Figure 12: Impact of C' on system evolution. Comparing (a), (b), and (c), as C' (innovation cost when the two parties both choose the cooperation strategy) decreases, the probability of the system evolving to the ideal state increases. (a) $C' = 3$; (b) $C' = 4$; (c) $C' = 5$.

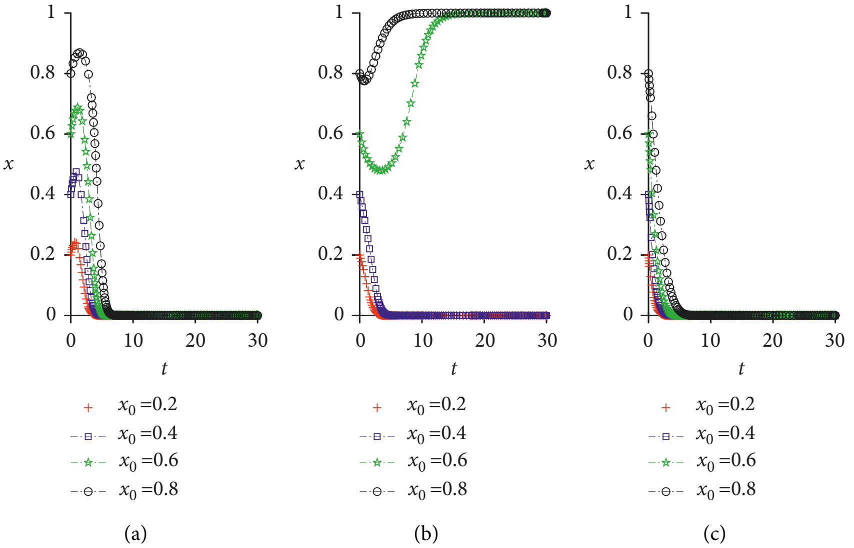
is certain to evolve to the ideal state. With the increase in P, the benefit of the party that adopts the noncooperation strategy decreases. When P is large enough, the benefit of the party that adopts the noncooperation strategy becomes negative. Thus, the party that adopts a noncooperation strategy tends to change its strategy to a cooperation strategy when the other party chooses a cooperation strategy. Therefore, increasing the fine to the party that adopts a noncooperation strategy is conducive to the system evolving to the ideal state.

5.9. Impact of π' on System Evolution.

The impact of π' on system evolution is shown in Figure 10. One can note that with the increase in π' the probability of the system evolving to the ideal state increases, and the convergence speed accelerates. When π' increases, the benefit obtained by the two parties increases, and they are more inclined to choose the cooperation strategy. Therefore, increasing the innovation benefit when both parties choose the cooperation strategy is conducive to the system evolving to the ideal state.

5.10. Impact of μ on System Evolution.

The impact of μ on system evolution is shown in Figure 11. Figure 11(b) shows that when the benefit distribution proportions of the two parties are equal the system may evolve to the ideal state or the worst state. As shown in Figures 11(a) and 11(c), when one party's benefit distribution proportion is much smaller than that of the other party, the



(a)

(b)

(c)

Figure 13: Impact of θ on system evolution. According to (b), when the cost sharing proportions of the two parties are equal, the system may evolve to the ideal state or the worst state, while according to (a) and (c), when one party's cost sharing proportion is much smaller than that of the other party, the system will evolve to the worst state. (a) $\theta = 0.1$; (b) $\theta = 0.5$; (c) $\theta = 0.9$.

system will evolve to the worst state. This is because the party with a smaller benefit distribution proportion obtains less additional benefit, or its total benefit may even be negative, and it is more inclined to choose the noncooperation strategy, which eventually leads the system to evolve to the worst state. Therefore, a reasonable benefit distribution proportion should be set to prevent the system from evolving to the worst state.

5.11. Impact of C' on System Evolution. The impact of C' on system evolution is shown in Figure 12. One can note that with the increase in C' the probability of the system evolving to the ideal state decreases, the convergence speed slows.

When C' increases, the benefits obtained by the two parties decrease, and they are more inclined to choose the noncooperation strategy. Therefore, decreasing the innovation cost when the two parties both choose the cooperation strategy is conducive to the system evolving to the ideal state.

5.12. Impact of θ on System Evolution. The impact of θ on system evolution is shown in Figure 13. Figure 13(b) shows that when the cost sharing proportions of the two parties are equal, the system may evolve to the ideal state or the worst state. As shown in Figures 13(a) and 13(c), when one party's share of the cost is much larger than that of the other party, the system will evolve to the worst state. This is because the party with a larger share of the cost bears more innovation costs, or its total benefit is even negative, and it is more inclined to choose the noncooperation strategy, which eventually leads the system to evolve to the worst state. Therefore, a reasonable cost sharing proportion should be set to prevent the system from evolving to the worst state.

6. Conclusion

Although cooperative innovation between clients and service providers has many benefits, the two parties do not necessarily establish a cooperative innovation relationship. Based on evolutionary game theory, this paper investigates the decision-making mechanism of cooperative innovation between clients and service providers and then analyzes how to promote the cooperative innovation between the two parties.

Based on evolutionary game theory, we assume the process of cooperative innovation is a long-term and dynamic evolution one. In the evolution system, the client and service provider are rational "economic entities," they constantly adjust their strategies of cooperating or not, and their cooperative innovation behavior dynamically evolves over the course of a long-term game.

We analyze the properties of the equilibrium points and obtain the evolution paths in 16 different cases of the evolution system. We find that the benefits of both the client and service provider when they innovate cooperatively being greater than that when they innovate independently cannot guarantee that the system will certainly evolve to a stable state in which both parties adopt a cooperation strategy. However, as long as the condition that either party gains more than zero when it innovates independently is established in addition to the preceding condition, the system is certain to evolve to a stable state in which both parties adopt the cooperative strategy.

We conduct numerical simulation to study the effects of cooperation benefits, spillover effects, and other parameters on the stability of the system evolution process. We find that the increase of the following factors is helpful for the system to evolve to the ideal state: the initial probabilities of the two parties choosing the cooperative strategy, the innovation benefit when one party innovates independently, the penalty when one party cooperates and the other party does not, and the excess benefit when the two parties both cooperate. In addition, the following measures can be taken to promote client-service provider cooperation: reducing the innovation cost and spillover coefficient when one party innovates independently, decreasing the innovation cost when the two parties both choose the cooperation strategy, and setting reasonable benefit distribution and cost sharing proportions.

Based on the preceding conclusions, management suggestions are provided regarding how to promote cooperative innovation between clients and service providers:

(1) For the client, employing a performance-based outsourcing contract, which is helpful in creating an independent innovation space for service providers, and setting up innovation funds are effective ways to encourage service providers to innovate. Service providers can actively tap the potential needs of clients and integrate clients into the innovation process. In addition, communication mechanisms, such as "innovation days," through which the two parties regularly discuss innovation opportunities, could also be established to create good internal and external innovation environments for improving the enthusiasm for cooperative innovation.

(2) The party that chooses the cooperation strategy should "keep an eye on" its innovation achievements and prevent their possible spillover. Establishing an informal contract [47] and incorporating noncooperation penalty clauses in it are effective ways to restrict noncooperation behavior. The relevant authorities are suggested to strengthen guidance, supervision, and management and improve the intellectual property protection system to prevent the "free riding" phenomenon.

(3) In the process of cooperative innovation, to increase the excess benefit generated by cooperative innovation, clients can proactively clarify their pain points and needs and share knowledge resources, such as business processes and internal information, while service providers can mobilize more professional resources, such as innovative technologies and specialists. In addition, the two parties should reduce the cooperative innovation cost as much as possible by, e.g., adopting advanced technical means, clarifying role division, and maintaining work consistency.

In the field of cooperative innovation between clients and service providers, the previous research mainly examines the implementation process of cooperative innovation, including analyzing the impact of important factors on the implementation process and introducing specific guidance frameworks and implementation methods, as well as the benefit of cooperative innovation. Our research focuses on the decision-making mechanism of the cooperative innovation behavior and how to form a stable cooperative innovation relationship, making up for the lack of research on the topic in the previous literature.

Our study enriches the relevant research fields of cooperative innovation between clients and service providers and evolutionary game theory. In addition, the conclusion obtained not only provides a theoretical basis for the clients and service providers to make the best decision, but also offers practical guidance on how to promote client-service provider cooperation in the process of service innovation.

This paper suffers from several limitations. Although the spillover effect, which occurs when one party innovates independently, and the synergy effect, which occurs when both parties innovate cooperatively, are considered, these two effects do not reflect the interaction between the two parties. In fact, there is a coupling effect between the two parties in the process of cooperative innovation [48]; that is, the two parties interact and influence one another when making cooperation decisions. Therefore, future research could focus on how the coupling effect affects the evolution of the client and service provider's cooperative behavior.

Appendix

A. Source Code

The authors employ MATLAB to conduct numerical simulation by two stages. At the first stage, the authors define the differential equation function according to the duplicate dynamic equation in Section 3 and set the initial values of the parameters in the differential equation function.

The corresponding source code is as follows:

```
Function dxdt = differential 1_21(t, x)
a = 0.5;
b = 7;
c = 0.5;
d = 4;
e = 0.45;
f = 4;
g = 3;
h = 9;
i = 0.4;
j = 6;
p = 1;
dxdt = [x(1) ∗ (1 − x(1)) ∗ (x(2) ∗ (a ∗ b − c ∗ d − e ∗
f − g + h) + g − h + p); x(2) ∗ (1 − x(2)) ∗ (x(1) ∗
((1 − a) ∗ b − (1 − c) ∗ d − i ∗ g − f + j)+f − j + p)];
End
```

At the second stage, we solve the differential equation and plot the diagram of the system evolution curves. The corresponding source code is as follows:

```
i = 0.2
j = 0.7
[T, Y] = ode45 (‘differential 1_21’, [0 30], [i j]);
Figure (2)
```

```
Plot (T, Y(:, 1), ‘+r’);
Hold on
i = 0.4
j = 0.7
[T, Y] = ode45 (‘differential 1_21’, [0 30], [i j]);
Figure (2)
Plot (T, Y(:, 1), ‘b-.square’);
Hold on
i = 0.6
j = 0.7
[T, Y] = ode45 (‘differential 1_21’, [0 30], [i j]);
Figure (2)
Plot (T, Y(:, 1), ‘g-.pentagram’);
Hold on
i = 0.8
j = 0.7
[T, Y] = ode45 (‘differential 1_21’, [0 30], [i j]);
Figure (2)
Plot (T, Y(:, 1), ‘k-.o’);
Hold on
h = legend({‘\itx_0 = \rm0.2’,‘\itx_0 = \rm0.4’,
‘\itx_0 = \rm0.6’,‘\itx_0 = \rm0.8’,},‘Location’,
‘northeast’)
Set (h, ‘box’, ‘off’)
Set (gca, ‘Font Size’, 18)
Set (gca, ‘Font name’, ‘Times New Roman’)
x label (‘\itt’, ‘Font name’, ‘Times New Roman’, ‘Font
Size’, 20)
y label (‘\itx’, ‘Font name’, ‘Times New Roman’, ‘Font
Size’, 20)
box off
y lim([0 1])
```

Note that the above source codes with given parameter values only generate one diagram, i.e., Figure 4(b). The authors get the other diagrams in Section 4 by adjusting the corresponding parameter(s).

Data Availability

The corresponding data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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