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Research Article

An Innovation Ecosystem Game Study: The Role of Noncontractual Mechanisms

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Innovation ecosystem management is now a new paradigm in innovation management research. Innovation ecosystems are dynamic innovation alliances based on noncontractual governance. In this paper, a traditional cooperative innovation game model and a cooperative innovation game model with noncontractual mechanism are developed and compared. The results show that the cooperation formed only by contractual mechanisms' model is unstable and the system is likely to collapse. The noncontractual mechanism can be used as a supplement to the contractual mechanism to make the game develop towards a stable "cooperation-cooperation" state. The research conclusion of this paper will make the core companies in the innovation ecosystem realize the important role of noncontractual mechanism and help them make decisions.

1. Introduction

Innovation has long been regarded as the main driving force of development. Since the term "innovation" was first put forward in the "Theory of Economic Development" in 1912, innovative activities have been widely carried out, and the forms of innovation have been constantly studied. The forms of innovation activity change from innovation networks to innovation system and now to innovation ecosystem. Hanna and Freeman [1] incorporate the environment in which an enterprise survives and thrives into their study of the enterprise based on ecosystem theory and based on the concept of the business ecosystem proposed by Moore [2], who originally used the concept of the natural ecosystem to explain the competitive and cooperative relationships between interdependent enterprises. Then, Adner [3] introduced technological innovation into ecosystems as well, introducing the concept of innovation ecosystems.

In recent years, many scholars have conducted research on the connotation and development of innovation ecosystems. For example, Kapoor [4] examined the value creation process in innovation ecosystems, put forward that innovation needs to be dependent on changes in the external environment and the participation of ecosystem members. Iansiti and Levien's study [5] identifies the innovation ecosystem as a loose network of suppliers, distributors, outsourcing enterprises, product and service manufacturers, technology providers, and other organizations. Also, coevolution, mentioned by Eisenhardt and Martin in their study [6], is the key feature of innovation ecosystems and the only way to promote effective ecosystems.

By summarizing the existing studies, it can be concluded that the innovation ecosystem is a dynamic organizational structure composed of different participants of innovation activities with competition and cooperation relationship, whose main purpose is to create shared value through collaborative innovation. Since the participants come from different fields, they need the same value proposition, that is, a consensus to share knowledge and resources to achieve a common goal [7]. Unless the participants can work together efficiently and maintain stable collaborative relationships, the innovation ecosystem will face collapse [8].

However, stable cooperative relationships are hard to maintain, especially in innovation ecosystems dominated by core enterprises, where there are both cooperative and competitive relationships. Core enterprises possess key resources such as capital, technology, and markets, which can attract and disadvantage SMEs (small and medium enterprises) and generate core enterprise control [9]. The core company is the key node of the innovation ecosystem and usually has some control over the system because it owns the core heterogeneous resources [10]. In China, innovative SMEs are defined as enterprises that have the capability of technological invention and improvement, new product development, and are small in size [11]. In the process of cooperation between the two parties, there are sensitive issues such as the distribution of benefits, and technology transfer, which have a greater impact on the stability of the system.

Innovation ecosystem emphasizes participants' noncontractual value cocreation and noncontractual governance sharing. Although participants are interdependent, they exist independently of each other [12]. There is a lot of research on how to promote a stable partnership. For example, Faming and Meijuan [13] constructed an evolutionary model of the coordination mechanism of value cocreation behavior in innovation ecosystems, and pointed out that cooperation is mainly influenced by a series of factors, such as the distribution ratio of value cocreation excess benefits, the cost of coordinating cooperation, the benefits of choosing cheating strategies and the benefits of adopting cooperation strategies alone, and the rewards and penalties. Using dynamic game theory, Bao et al. [14] investigated the cooperation mechanisms between grid companies and third-party companies in the energy big data ecosystem in both cases with and without government regulation. Zou et al. [15] constructed an evolutionary game model with three parties: core companies, academic research institutions, and information intermediaries. The study pointed out that incentives can increase the motivation of participants, but excessive incentives may lead to opportunism and free riding, so core companies should implement a punishment mechanism.

As noted above, existing research has focused on finding the role of "hard" institutions such as supporting regulations and contractual content. However, Dondofema and Grobbelaar [16] mentioned that in addition to "hard" institutions, "soft" institutions, such as the culture that governs the rules of interaction, also influence cocreation. Using a partial least squares path model, de Vries et al. [17] analyzed survey data from 70 account managers of a large multinational corporation to explore the impact of contractual and noncontractual characteristics on knowledge sharing behavior among partners. Ren and Zhen [18] designed five elements of noncontractual mechanism and further subdivided them to form a two-level structure of noncontractual elements, which clarified the important role of noncontractual mechanism in R&D (Research and Development) cooperation among innovative SMEs.

Inspired by the studies above, noncontractual mechanisms are gradually taking their place in management, possible "gaps" or "oversteps" in traditional contract management can be overcome. However, there is a lot of research on the categorization and development of noncontractual mechanisms, but what role noncontractual mechanisms can play in the traditional management game is yet to be discussed. So, we would like to study the role of some noncontractual management mechanisms in specific mathematical models.

In summary, there is a lack of research on noncontractual mechanisms and quantitative analysis on the role of noncontractual mechanisms in the innovation ecosystem. This paper constructs an evolutionary game model to analyze the evolution laws of core companies and innovative SMEs in the innovation ecosystem. The contributions of this paper can be summarized as follows: (1) the role of contractual and noncontractual mechanisms in the innovation ecosystem is quantitatively discussed, which provides a reference for the innovation ecosystem management approach; (2) the evolutionary mechanism of the strategies of core companies and innovative SMEs in the innovation ecosystem is studied, which helps to solve the barriers to collaborative innovation such as "free riding". The study will help to remove barriers to collaborative innovation like "free riding" and promote cooperation.

The rest of this paper is organized as follows. Section 2 describes in detail about the problem and assumptions of the evolutionary game model. In Section 3, we describe in detail about the evolutionary game model under different mechanisms. In Section 4, the results of the system simulation are presented. Finally, the conclusions of this paper are presented in Section 5.

2. The Problem Description and Research Assumptions

2.1. Problem Description. We build a model based on the background that core companies lead the construction of innovation ecosystems and attract innovative SMEs to participate in innovation cooperation. Innovative SMEs are those whose output indicators of technological innovation activities, such as new product development results, patents, and the number and ratio of technological innovations, are superior to those of average SMEs [19]. However, with the rapid development of science and technology, industrial iterations continue to accelerate. Innovative SMEs need to utilize external resources to improve their own technological innovation capabilities and establish cooperative R&D relationships with strong core companies. Existing studies do not provide a clear definition of core companies. In this paper, core companies refer to industry leaders that master core technologies and have relatively strong knowledge creation and knowledge spillover capabilities [20].

When both sides of the game choose a cooperative strategy, additional benefits can be created and shared. Free-riding behavior occurs when one party chooses to cooperate and the other chooses not to cooperate. Based on their own cost-benefit considerations, core companies may passively share technological resources to gain more additional benefits. Innovative SMEs may choose to passively conduct innovation R&D and instead absorb the technological knowledge of core companies and use their innovation resources.

In this paper, we examine the role of different regulatory mechanisms in promoting collaborative innovation and discouraging free-riding behavior.

2.2. Research Assumptions

Assumption 1. Both core companies and innovative SMEs are finite rational and have strategies of "cooperate" and "betray." The percentage of participation of the core company with "cooperate" strategy is x, the percentage of participation of the innovative SMEs with "cooperate" strategy is y, where $x, y \in [0, 1]$.

Assumption 2. When core companies and innovative SMEs adopt "betray" strategies, they secretly absorb others' technology and convert it into revenue. The knowledge absorption conversion rate of core companies is ω_1, and that of innovative SMEs is ω_2. Assume that $\omega_1 > \omega_2$.

Assumption 3. The cost of innovation for core companies and innovative SMEs is related to the amount of knowledge they invest. The knowledge input $K1$ of core companies is larger than the input $K2$ of innovative SMEs. The cost of innovation coefficient for core companies is $b1$, the cost of innovation coefficient for innovative SMEs is $b2$. Smaller cost of innovation coefficient indicates higher innovation ability, so $b1 < b2$.

Assumption 4. In the same business environment, the reputational loss B is the same for both parties when they choose the "betray" strategy.

Assumption 5. Both the reward coefficient A and the penalty coefficient P are determined by the core companies. In addition, since existing studies do not quantify reputation, we assume that $B < A$.

3. The Evolutionary Game Model and Solution

3.1. The Basic Model. Referring to the results of Yu and Shi [21] and Huainian et al. [22], we developed a game model underlying the cooperative innovation behavior of innovation ecosystems. All the parameters are listed in Table 1.

When both participants choose the strategy of "cooperate," based on the knowledge they input and distribution ratio, core companies and innovative SMEs can, respectively, obtain innovation benefits as $\alpha\gamma(K1 + K2 - Ks)$ and $(1-\alpha)\gamma(K1 + K2 - Ks)$. According to the difference of knowledge input, the innovation costs of core companies and innovative SMEs are respectively $b1K_1^2/2$ and $b2K_2^2/2$. If the core companies choose "betray," it can get profit $\omega1(K2 - Ks)$ by "free riding." Similarly, innovative SMEs will get $\omega2(K1 - Ks)$ if it chose the strategy of "betray." The payoff matrix is shown in Table 2.

The expected benefits $E11$ for core companies choosing the strategy of "cooperate" is

$$E_{11} = y\alpha\gamma(K_1 + K_2 - K_s) + R_1 - \frac{b_1 1 K_1^2}{2}. \quad (1)$$

Table 1: All parameters of basic model.

Parameters	Definition
x	Percentage of participation of core companies choosing to "cooperate"
y	Percentage of participation of innovative SMEs choosing to "cooperate"
R_1	Base earnings of the core companies
R_2	Base earnings of the innovative SMEs
α	Innovation revenue distribution ratio of core companies
γ	Innovation revenue conversion rate
K_1	The amount of knowledge invested by core companies
K_2	The amount of knowledge invested by innovative SMEs
K_s	Repetitive parts of the knowledge that participants' input
ω_1	Knowledge absorption conversion rate of core companies
ω_2	Knowledge absorption conversion rate of innovative SMEs
b_1	Innovation cost coefficient of core companies
b_2	Innovation cost coefficient of innovative SMEs

The expected benefits E_{12} for core companies choosing the strategy of "betray" is

$$E_{12} = y\omega_1(K_2 - K_s) + R_1. \quad (2)$$

The average expected benefits of core companies E_1 is

$$E_1 = xE_{11} + (1-x)E_{12}. \quad (3)$$

The expected benefits E_{21} for innovative SMEs choosing the strategy of "cooperate" is

$$E_{21} = x(1-\alpha)\gamma(K_1 + K_2 - K_s) + R_2 - \frac{b_2 K_2^2}{2}. \quad (4)$$

The expected benefits E_{22} for innovative SMEs choosing the strategy of "betray" is

$$E_{22} = x\omega_2(K_1 - K_s) + R_2. \quad (5)$$

The average expected benefits of innovative SMEs E_2 is

$$E_2 = yE_{21} + (1-y)E_{22}. \quad (6)$$

The replicator dynamics equation of the game system is

$$\begin{cases} \dfrac{dx}{dt} = x(1-x)\left\{y\left[\alpha\gamma(K_1 + K_2 - K_s) - \omega_1(K_2 - K_s)\right] - \dfrac{b_1 K_1^2}{2}\right\}, \\ \dfrac{dy}{dt} = y(1-y)\left\{x\left[(1-\alpha)\gamma(K_1 + K_2 - K_s) - \omega_2(K_1 - K_s)\right] - \dfrac{b_2 K_2^2}{2}\right\}. \end{cases} \quad (7)$$

Table 2: Payoff matrix of basic model.

		Innovative SMEs: Cooperate	Innovative SMEs: Betray
Core companies	Cooperate	$R_1 + \alpha\gamma(K_1 + K_2 - K_s) - b_1K_1^2/2$ $R_2 + (1-\alpha)\gamma(K_1 + K_2 - K_s) - b_2K_2^2/2$	$R_1 - b_1K_1^2/2$ $R_2 + \omega_2(K_1 - K_s)$
	Betray	$R_1 + \omega_1(K_2 - K_s)$ $R_2 - b_2K_2^2/2$	R_1 R_2

The corresponding Jacobi matrix is concluded as

$$J = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}. \quad (8)$$

Notably,

$$\begin{aligned} a_{11} &= (1-2x)\left\{y\left[\alpha\gamma(K_1 + K_2 - K_s) - \omega_1(K_2 - K_s)\right] - \frac{b_1K_1^2}{2}\right\}, \\ a_{12} &= x(1-x)\left[\alpha\gamma(K_1 + K_2 - K_s) - \omega_1(K_2 - K_s)\right], \\ a_{21} &= y(1-y)\left[(1-\alpha)\gamma(K_1 + K_2 - K_s) - \omega_2(K_1 - K_s)\right], \\ a_{22} &= (1-2y)\left\{x\left[(1-\alpha)\gamma(K_1 + K_2 - K_s) - \omega_2(K_1 - K_s)\right] - \frac{b_2K_2^2}{2}\right\}. \end{aligned} \quad (9)$$

The determinant and trace of the matrix, which we specify as DetJ and TrJ, are expressed as

$$\begin{aligned} \text{DetJ} &= a_{11} \cdot a_{22} - a_{12} \cdot a_{21}, \\ \text{TrJ} &= a_{11} + a_{22}. \end{aligned} \quad (10)$$

When $dx/dt = 0, dy/dt = 0$, we can find five local equilibrium points: O (0, 0), A (0, 1), B (1, 0), C (1, 1), and D (x_D, y_D). Among them,

$$\begin{aligned} x_D &= \frac{b_2K_2^2}{2(1-\alpha)\gamma(K_1 + K_2 - K_s) - 2\omega_2(K_1 - K_s)}, \\ y_D &= \frac{b_1K_1^2}{2\alpha\gamma(K_1 + K_2 - K_s) - 2\omega_1(K_2 - K_s)}. \end{aligned} \quad (11)$$

Then, using the Jacobi matrix, we can analyze the stability of five equilibrium points. The value of the matrix determinant and the trace of the matrix from the five equilibrium points are given in Table 3. For the sake of discussion, we assume that

$$\begin{aligned} a &= \alpha\gamma(K_1 + K_2 - K_s) - \omega_1(K_2 - K_s) - \frac{b_1K_1^2}{2}, \\ b &= (1-\alpha)\gamma(K_1 + K_2 - K_s) - \omega_2(K_1 - K_s) - \frac{b_2K_2^2}{2}. \end{aligned} \quad (12)$$

As shown in Table 3, under the situation that $a < 0$ or < 0, there is only ESS point O (0, 0). It is to deal with the situation that both participants choose "betray" strategy. Under the conditions that $a > 0$, $b > 0$, there are two ESS points O (0, 0) and C (1, 1). This indicates that both participants can evolve towards either "cooperate" or "betray"; the specific evolutionary results are determined by the actual situation.

The dynamic evolution processes are shown in Figures 1 and 2. In Figure 2, when the initial state falls in the region OADB, the model will eventually evolve and stabilize at the point O (0, 0). If the initial state falls in the area CADB, the evolutionary stability point is C (1, 1). In addition, as a and b increase, the point D (x_D, y_D) will move toward the point O (0, 0), and the probability of ESS convergence to the state (1, 1) will increase. This indicates that when one of the parties chooses "cooperate," the payoff gap of the other party's different strategies affects its willingness to cooperate.

3.2. The Model with Noncontractual Mechanisms. Based on the study of noncontractual mechanisms [18, 23], we introduce three noncontractual mechanisms in the model, the added parameters are shown in Table 4.

Mechanism 1: Core companies screen partners to join the innovation ecosystem by paying costs C, requiring that the partner has similar common goals and corporate culture, and that the technologies it owns do not conflict with the core company as much as possible. In the model, K_s is set to 0 and the initial y is significantly increased.

Mechanism 2: In the same innovation environment, core companies and innovative SMEs that choose "betray" strategies will receive a reputation loss B.

Mechanism 3: A trust-based and process-based mechanism is added to the model, which rewards innovative

Table 3: The value of the matrix determinant and the trace of the matrix from the five equilibrium points.

(x, y)	Prerequisite	DetJ	TrJ	Results
(0, 0)	—	+	−	ESS point
(0, 1)	$a > 0$	+	+	Unstable point
	$a < 0$	−	Unknown	Saddle point
(1, 0)	$b > 0$	+	+	Unstable point
	$b < 0$	−	Unknown	Saddle point
(1, 1)	$a > 0$, $b > 0$	+	−	ESS point
	$a > 0$, $b < 0$	−	Unknown	Saddle point
	$a < 0$, $b > 0$	−	Unknown	Saddle point
	$a < 0$, $b < 0$	+	+	Unstable point
(x_D, y_D)	—	−	0	Saddle point

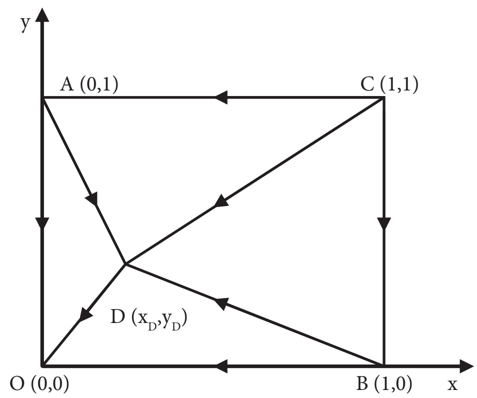

Figure 1: No prerequisite.

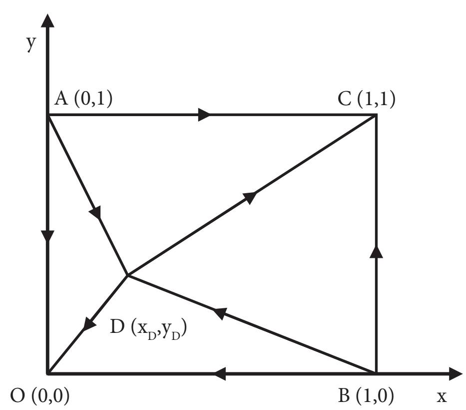

Figure 2: $a > 0$, $b > 0$.

Table 4: New parameters in the model noncontractual mechanisms.

Parameters	Definition
C	Costs used by core companies to screen partners
B	Loss of reputation
A	Trust-based reward coefficient
P	Trust-based penalty coefficient

SMEs for their good will to cooperate, and penalizes them based on their percentage of participation that choosing "betray." When both parties choose "cooperate" strategy, core companies reward innovative SMEs with Ay. When core companies choose "cooperate" strategy and innovative SMEs choose "betray" strategy, core companies impose a penalty of $P(1-y)$ on innovative SMEs.

The new payoff matrix is shown in Table 5.

Similarly, there are five local equilibrium points in this model: $O(0, 0)$, $A(0, 1)$, $B(1, 0)$, $C(1, 1)$, and $D(x_D, y_D)$. The Jacobi matrix is

$$J = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}. \tag{13}$$

Notably,

$$\begin{aligned} b_{11} &= (1-2x)\left[y\alpha\gamma(K_1+K_2) - Ay^2 - y\omega_1 K_2 \right.\\ &\quad \left. + P(1-y)^2 + B - \frac{b_1 K_1^2}{2}\right],\\ b_{12} &= x(1-x)\left[\alpha\gamma(K_1+K_2) - 2Ay - \omega_1 K_2 - 2P(1-y)\right],\\ b_{21} &= y(1-y)\left[(1-\alpha)\gamma(K_1+K_2) + Ay - \omega_2 K_1 + P(1-y)\right],\\ b_{22} &= (1-2y)\left[x(1-\alpha)\gamma(K_1+K_2) + Axy - x\omega_2 K_1 \right.\\ &\quad \left. + Px(1-y) + B - \frac{b_2 K_2^2}{2}\right] + xy(1-y)(A-P). \end{aligned} \tag{14}$$

The determinant DetJ and trace TrJ of the Jacobi matrix J are, respectively,

$$\begin{aligned} \mathrm{DetJ} &= b_{11}\cdot b_{22} - b_{12}\cdot b_{22},\\ \mathrm{TrJ} &= b_{11} + b_{22}. \end{aligned} \tag{15}$$

For the sake of discussion, we assume that

$$\begin{aligned} a &= \alpha\gamma(K_1+K_2) - A - \omega_1 K_2 + B - \frac{b_1 K_1^2}{2},\\ b &= (1-\alpha)\gamma(K_1+K_2) - \omega_2 K_1 + P + B - \frac{b_2 K_2^2}{2},\\ c &= (1-\alpha)\gamma(K_1+K_2) - \omega_2 K_1 + A + B - \frac{b_2 K_2^2}{2}. \end{aligned} \tag{16}$$

The evolutionary stability of local equilibrium points in the new model is analyzed as shown in Table 6.

When $b < 0$, the ESS point of the model is (1, 0). This is to deal with the situation that core companies choose "cooperate" and innovative SMEs choose "betray." When $a > 0, c > 0$, the model converges to the state (1, 1), which means both participants choose "cooperate" strategy. Due to the parameter setting $b > c$, so these two ESS cannot exist at the same time.

4. System Simulation Analysis

In order to intuitively observe the dynamic evolution process of the strategy selected between the core companies and the innovative SMEs, the MATLAB system simulation

TABLE 5: Payoff matrix of the model with noncontractual mechanisms.

		Innovative SMEs	
		Cooperate	Betray
Core comanpies	Cooperate	$R_1 + \alpha\gamma(K_1 + K_2) - b_1K_1^2/2 - Ay - C$ $R_2 + (1-\alpha)\gamma(K_1 + K_2) - b_2K_2^2/2 + Ay$	$R_1 - b_1K_1^2/2 + P(1-y) - C$ $R_2 + \omega_2K_1 - P(1-y) - B$
	Betray	$R_1 + \omega_1K_2 - B - C$ $R_2 - b_2K_2^2/2$	$R_1 - B - C$ $R_2 - B$

TABLE 6: The evolutionary stability of local equilibrium points in the new model.

(x, y)	Prerequisite	DetJ	TrJ	Results
(0, 0)	—	+	+	Unstable point
(0, 1)	$a > 0$	+	+	Unstable point
	$a < 0$	−	Unknown	Saddle point
(1, 0)	$b > 0$	−	Unknown	Saddle point
	$b < 0$	+	−	ESS point
(1, 1)	$a > 0, c > 0$	+	−	ESS point
	$a > 0, c < 0$	−	Unknown	Saddle point
	$a < 0, c > 0$	−	Unknown	Saddle point
	$a < 0, c < 0$	+	+	Unstable point
(x_D, y_D)	—	−	−	Saddle point

TABLE 7: Parameter settings of basic model.

	Initial x	Initial y	α	γ	K_1	K_2	K_s	ω_1	ω_2	b_1	b_2
Case 1	0.8	0.7	0.8	5	10	5	2	2	1	0.5	0.7
Case 2	0.8	0.7	0.7	5	10	5	2	2	1	0.5	0.7
Case 3	0.8	0.6	0.7	5	10	5	2	2	1	0.5	0.7

TABLE 8: Parameter settings of the model with noncontractual mechanisms.

	Initial x	Initial y	α	γ	K_1	K_2	ω_1	ω_2	b_1	b_2	B	A	P
Case 4	0.8	0.7	0.9	5	5	5	2	1	0.5	0.7	1	2	7
Case 5	0.8	0.7	0.7	5	10	5	2	1	0.5	0.7	1	2	25
Case 6	0.8	0.3	0.7	5	10	5	2	1	0.5	0.7	1	2	25

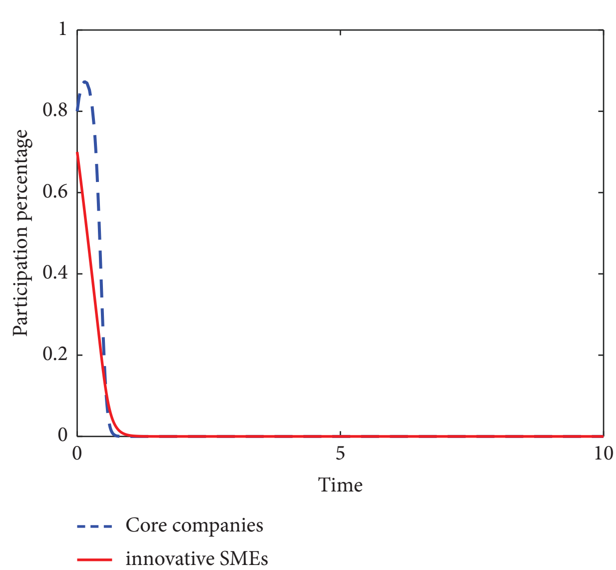

FIGURE 3: Case 1 $(x = 0.8, y = 0.7, \alpha = 0.8)$.

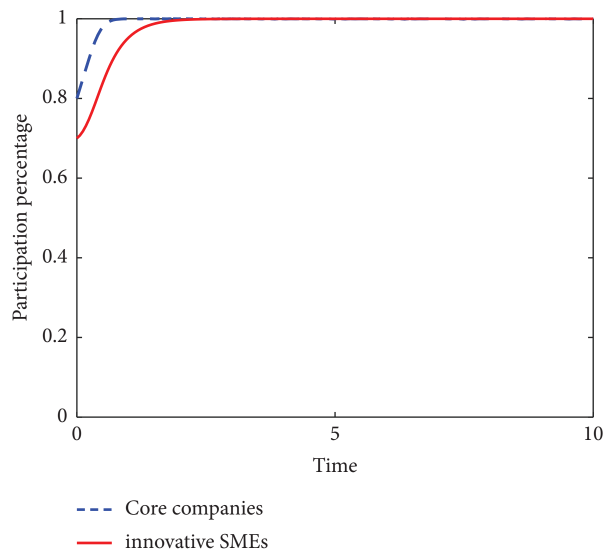

Figure 4: Case 2 ($x = 0.8, y = 0.7, \alpha = 0.7$).

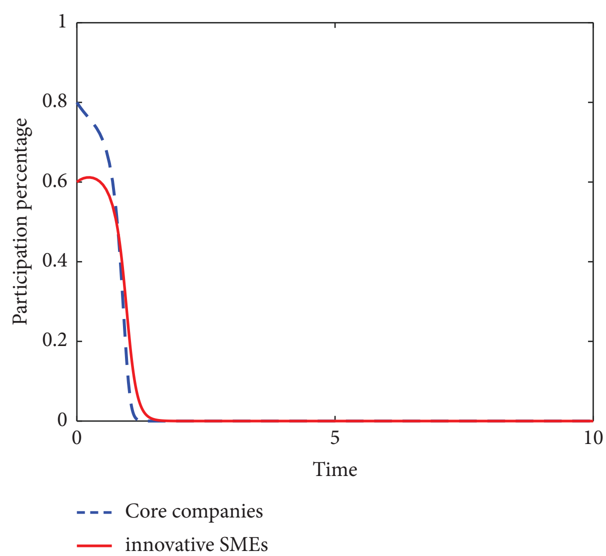

Figure 5: Case 3 ($x = 0.8, y = 0.6, \alpha = 0.7$).

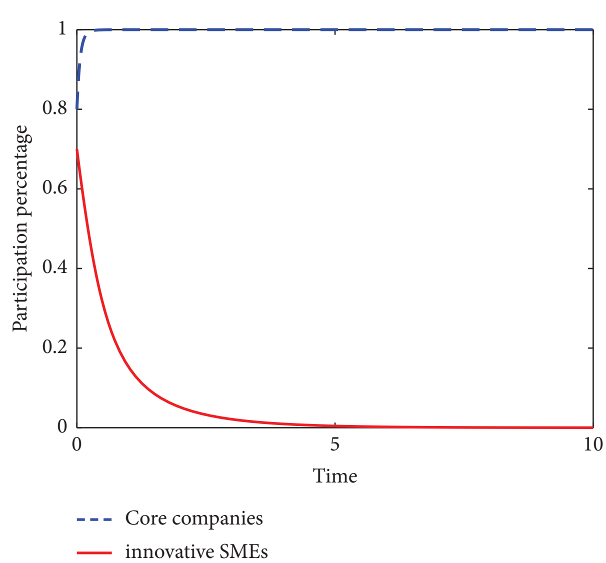

Figure 6: Case 4 ($x = 0.8, y = 0.7, \alpha = 0.9$).

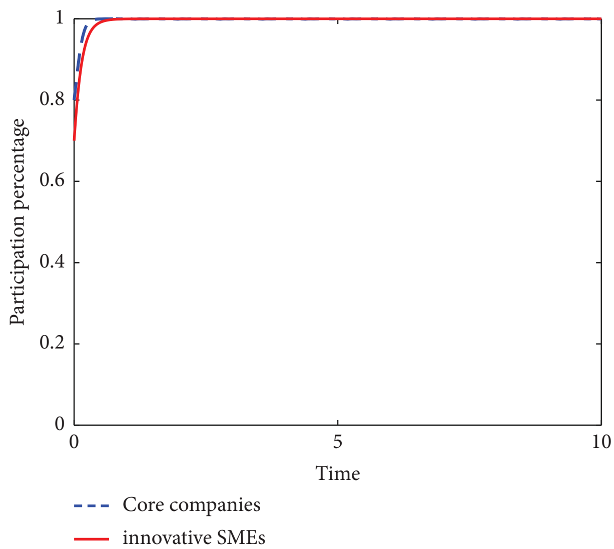

Figure 7: Case 5 $(x = 0.8, y = 0.7, \alpha = 0.7)$.

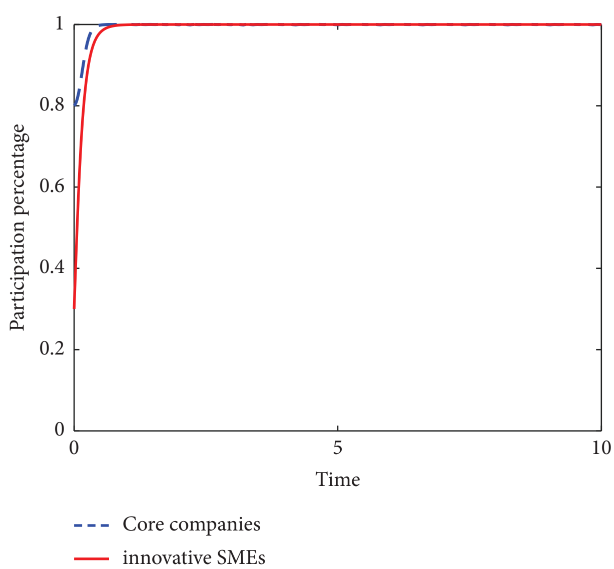

Figure 8: Case 6 $(x = 0.8, y = 0.3, \alpha = 0.7)$.

tool is used under the three cases. The assumed values of the parameters under the three cases are shown in Tables 7 and 8.

In Figures 3 and 4, the effect of the profit distribution ratio on ESS points was verified by simulation. As shown in Figures 3 and 4, when $\alpha = 0.8$, the ESS of the model will converge to the state (0, 0). But when $\alpha = 0.7$, the ESS of the model will converge to the state (1, 1). This means that the percentage of innovation benefits that core companies and innovative SMEs negotiate and decide before collaboration can affect the final ESS. An unreasonable percentage of innovation benefits can lead to the collapse of the innovation ecosystem.

In Figure 5, the initial participation of innovative SMEs decreases from 0.7 to 0.6, and the ESS changes from state (1, 1) to state (0, 0), which shows that the initial willingness of participants to participate is important for the stability of the system.

As shown in Figure 6, Case 4 corresponds to the case where ESS is state (1, 0), which means that in special cases, innovative SMEs choose to "cooperate" that is less profitable than the profits they absorb by free-riding on knowledge from core companies. In this case, innovative SMEs choose to "betray" even if they suffer penalties and loss of reputation.

As shown in Figure 7, this case is the same as Case 2, the model converges to the state (1, 1). But the comparison shows that the ESS is reached faster after adding the noncontractual mechanism.

Also, in Figure 8, the initial participation of innovative SMEs is even smaller than Case 3, the difference being that the final evolutionary stabilization strategy of this model is (1, 1). This suggests that with the help of a set of noncontractual mechanisms, the innovation ecosystem, which would otherwise collapse, can become stable.

5. Conclusions

If no noncontractual constraints are introduced, the game evolves in the direction that both parties choose the strategy of "betray" or both parties choose the strategy of "cooperate." The most important factor affecting the ESS of the model is the innovation revenue distribution ratio α. If α is too large, the ESS of the model falls into the (0, 0) state. When α is reasonable, the stable state of the system is related to the initial participation of both participants, and the model will stabilize in the state (1, 1) only when the initial participation of both participants reaches a certain level. If one of the parties has insufficient initial participation, the model will still converge to state (0, 0).

From the above results, it can be seen that the unreasonable proportion of innovation benefits distribution is an important reason why the innovation ecosystem cannot maintain stability. The initial willingness of innovative SMEs to cooperate is another important factor influencing the success of the innovation ecosystem. In general, under this contractual mechanism, the innovation ecosystem organized by the core companies is unstable and the system is likely to collapse.

With the inclusion of noncontractual mechanisms, the model's ESS is associated with the distribution of innovation benefits, trust-based rewards and penalties, and consideration of one's reputation. Because of the cost of rewards and the potential penalties for trust-based rewards and penalties, the ultimate evolutionary stabilization strategy of core companies is "cooperation." When the penalty coefficient is small, innovative SMEs will choose the "betray" strategy when faced with an unreasonable revenue distribution factor, even if they accept fines and loss of reputation. When there is a reasonable distribution of innovation benefits, innovative SMEs develop a stable strategy of "cooperate" after taking into account trust-based penalties and incentives. The evolutionary stability of the model is not affected by the initial participation of innovative SMEs.

From this, we can conclude that contractual mechanisms are the basis for innovative cooperation among firms. The noncontractual mechanism, as a complement, can make innovation cooperation more stable.

In this paper, we analyze the main factors affecting innovation cooperation through evolutionary game theory by constructing an innovation ecosystem game model. A new game model is also constructed and compared by introducing noncontractual mechanisms, and it is quantitatively concluded that noncontractual mechanisms can help contractual mechanisms maintain the stability of the innovation ecosystem.

There are several areas where the research in this paper could be improved:

(1) The interaction between core companies and innovative SMEs has not been presented comprehensively, and in reality, there should be more details in the innovation cooperation contract.

(2) Except for core companies and SMEs, the roles such as consumers, competitive companies, and governments also participate in innovation ecosystem. The complex interactions between different participants need to take into consideration.

(3) The values used in the simulation must be obtained from actual statistical surveys. How firms perceive the importance of their reputation needs to be systematically studied and hierarchically delineated.

The authors of this paper will conduct a more in-depth analysis in follow-up research.

Data Availability

The simulated data used in the article are available from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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