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Research Article

Research on Game Industry Cooperation Based on Evolutionary Game Model

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With the arrival of the information age, the growth space of the game industry is expanding, and the interest relationship between game businesses is becoming more sensitive. To alleviate the increasingly fierce competitive pressure, some game businesses will seek cooperation to pursue more profits, but some businesses are unwilling to cooperate. In this paper, we study the interest relationship between competition and cooperation among game businesses by constructing a tripartite evolutionary game model. We first obtain the expected revenue by using the weighted average method and then obtain the replicator dynamic equation. The stability and the sensitivity of the equilibrium strategy combination of the evolutionary game system are discussed. Finally, simulation analysis of the evolutionary model is realized and some suggestions based on the deductive results are put forward. Simulation results show that the system achieves stability at the equilibrium point (0, 1, 1) or (1, 1, 1). The equilibrium point (0, 1, 1) indicates that online game businesses select competition, while web and stand-alone game businesses seek cooperation. The equilibrium point (1, 1, 1) indicates that the tripartite actively seeks cooperation.

1. Introduction

In recent years, the game industry faces a fiercely competitive market and has changed from barbaric growth to a high-quality direction. The relevant favorable policies of the state will further expand the growth space of the industry. According to the China Game Industry Report for the first half of 2022, from January to June 2022, the actual sales revenue of China's game market was 147.789 billion yuan, and the number of game users was about 666 million [1]. The expansion of the game industry is accompanied by the inflow of more businesses. To gain an advantage in the fierce competition, some game businesses will actively seek cooperation, but some dominant businesses are unwilling to cooperate. Therefore, there may be an interest gap in the cooperation between different game merchants, and it is of great significance to study the interest relationship driving the cooperation behavior according to the cooperation phenomenon between game merchants.

The research objects of commercial competition and cooperation mainly include the financial economy [2, 3], enterprise economy [4–6], industrial economy [7–9], and trade economy [10–12]. These works of the literature mainly focus on interest rate marketization, financial products, competitive advantage, innovation performance, commercial credit, and cooperation. In the Internet era, the video game industry has good prospects and potential for development, while the industry competition is also very fierce [13]. Some scholars have used event analysis [14, 15], factor analysis [16, 17], simulation analysis [18], influencing factor analysis, and potential value analysis ([19]) to study the development trend, mechanism, and prospect of the game industry.

Evolutionary game theory is a strategic analysis method to provide maximum benefits for competing agents, which is widely used in economic management [20–22], environmental protection [23–26], game theory [27, 28], network public opinion [29], and other fields. In [30, 31], replication factor dynamics and dual-population replicator dynamics were used to study the unloading optimization problems. Results show that the proposed method has a significant performance improvement and saves a lot of time, energy, and overhead. Qu et al. used the evolutionary game model to analyze the evolutionary relationship among the government, the public, and the game industry and obtained the optimal strategy from the long-term and short-term perspectives [32]. Based on the evolutionary game theory, Chen and Zhang analyzed the choice of independent R&D and agent R&D and provided valuable suggestions for the development of the game industry [33].

The aforementioned kinds of the literature mainly focus on the development of the game industry, and there are few kinds of literature on the internal competition and cooperation of the game industry, and no scholars have used the evolutionary game theory to study it. Therefore, this paper will use the evolutionary game theory to analyze the relationship between cooperation and competition in the game industry. This paper is divided into three parts: firstly, based on the evolutionary game theory, considering online, web, and stand-alone games, a tripartite evolutionary game model is constructed, and the expected revenue and replicator dynamic equation are obtained through the weighted average method. Then, based on the first method of Lyapunov, the stability of the equilibrium point of the replicator dynamic system is analyzed, and the stable equilibrium point is obtained. Finally, MATLAB software is used to simulate and analyze the sensitivity of parameters and the evolution of different initial strategy values.

2. Establishment of the Evolutionary Game Model

2.1. Some Assumptions and Symbol Description. To construct the game model and analyze the stability of the equilibrium point and the sensitivity of each factor, the following assumptions are made:

Assumption 1. Assuming that the three parties of the game are online games, web games, and stand-alone games, and there is an interest relationship among the three parties, and they all have the characteristics of learning ability and bounded rationality.

Assumption 2. The strategy selection of the game agent mainly depends on the profit and loss of the selected strategy, and constantly adjusts the strategy by comparing the profit and loss under different strategies, to gradually achieve the optimal result over time.

Assumption 3. The strategy space of the network game is (cooperation α_1, competition α_2), we select α_1 with probability x and select α_2 with probability $(1-x)$, $x\in[0, 1]$. The strategy space of the web game is (cooperation β_1, competition β_2), we select β_1 with probability y and select β_2 with probability $(1-y)$, $y\in[0, 1]$. The strategy space of the stand-alone game is (cooperation γ_1, competition γ_2), we select γ_1 with probability z and select γ_2 with probability $(1-z)$, $z\in[0, 1]$.

Assumption 4. The game industry is divided into three categories: online games, web games, and stand-alone games. And different types of games have different consumption modes and operation methods. In this paper, the revenue equations are established according to the type of game and construct a three-way evolutionary game model combined with the revenue equation of the three parties to analyze the game relationship of the game industry.

Assumption 5. Online games and web games gain revenue through the sale of game equipment, and stand-alone games gain revenue through the sale of game copyright. Suppose that the three parties gain revenue from each unit of market share through their respective marketing means as A_1, A_1, and A_2. When the other two game merchants cooperate and maintain their competitive behavior, their side will lose a certain market share, and the sales of game equipment lost by online games and web games are B_1 and B_2, respectively. Players of stand-alone games have purchased the game copyright, and there is no other consumption potential, so stand-alone games will not cause losses due to the loss of the original players.

Assumption 6. After the successful cooperation of the game merchants, discount promotion activities will be carried out. The old players of the online game can buy at a discount price. Therefore, the online game will lose the price difference that the old players buy at the original price. Suppose that the price difference loss is C; web games have the characteristics of "spending money is invincible," and the players' comparative consumption will not be reduced, so there is no price difference loss in web games.

Assumption 7. Web games require constant advertising, endorsements, and other ways to promote the game and attract players. When web games cooperate with other game industries, they play a certain role in publicity, so they can save part of the publicity costs. Suppose that the publicity costs saved by cooperation between web games and the game industry are F.

Assumption 8. When the other two game industries maintain competition, one's cooperation request will be rejected, so the reputation will be lost. Let the reputation loss be H.

Assumption 9. Stand-alone games can obtain secondary revenue by embedding advertisements, peripheral products, and product copyrights. And the revenue is related to the number of people who know about the game. The cooperation between a stand-alone game and its game industry can make more people know about the game, thus increasing the secondary revenue. Suppose that the secondary revenue increased by the cooperation between a single game and a game industry is D.

Assumption 10. Web games do not need to be downloaded, the computer configuration requirements are low, and there is no operability. Online games and stand-alone games need to be downloaded first and require higher technology and computer configuration. It can be seen that the starting rate of different games is different, so the inflow of players between mutually cooperative games is also different. Assuming that cooperation is formed between each other, the number of players flowing into web games from online games and stand-alone games is 1 unit, the number of players flowing into online games from web games and stand-alone games is 0.5 units and 0.8 units, respectively, and the numbers of users flowing into stand-alone games from online games and web games are 0.7 units and 0.2 units, respectively.

2.2. Model Establishment. According to the abovementioned assumptions, the mixed strategy game matrix constructed by online games, web games, and stand-alone games is listed in Table 1.

2.3. Revenue Expectation and Replicator Dynamics. Revenue expectation refers to the expected revenue that can be predicted in the future based on known information under ideal circumstances. Usually, the future uncertain return is expressed in terms of a variety of possible values and their corresponding probabilities, and the weighted average is revenue expectation. In evolutionary game theory, the replicated dynamic equation is often established based on the revenue expectation. Therefore, we begin with the revenue expectations of online, web, and stand-alone games.

2.3.1. Revenue Expectation of Online Games. From Table 1, when online game businesses select cooperation, the revenue expectation is

$$\begin{aligned}E_{11} = {} & y(1-z)(0.5A_1 - C) + (1-y)z(0.8A_1 - C) \\ & + (1-y)(1-z)H + yz(1.3A_1 - C).\end{aligned} \tag{1}$$

Correspondingly, when online game businesses select competition, the revenue expectation is

$$E_{12} = -B_1 yz. \tag{2}$$

By adopting the weighted average method, we can obtain the average revenue expectation of online games

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

2.3.2. Revenue Expectation of Web Games. From Table 1, when web game businesses select cooperation, the revenue expectation is

$$\begin{aligned}E_{21} = {} & 2A_2xz + x(1-z)(A_2 - F) + (1-x)z(A_2 - F) \\ & + (1-x)(1-z)(-H - 2F).\end{aligned} \tag{4}$$

Correspondingly, when web game businesses select competition, the revenue expectation is

$$\begin{aligned}E_{22} = {} & xz(-B_2 - 2F) - 2(1-x)(1-z)F \\ & - 2x(1-z)F - 2(1-x)zF.\end{aligned} \tag{5}$$

By adopting the weighted average method, we can obtain the average revenue expectation of web games:

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

2.3.3. Revenue Expectation of Stand-Alone Games. From Table 1, when stand-alone game businesses select cooperation, the revenue expectation is

$$\begin{aligned}E_{31} = {} & xy(0.9A_3 + 2D) + x(1-y)(0.7A_3 + D) \\ & + (1-x)y(0.2A_3 + D).\end{aligned} \tag{7}$$

Correspondingly, when stand-alone game businesses select competition, the revenue expectation is

$$E_{32} = 0. \tag{8}$$

By adopting the weighted average method, we can obtain the average revenue expectation of stand-alone games:

$$E_3 = zE_{31} + (1-z)E_{32}. \tag{9}$$

2.3.4. Replicated Dynamic Equation. The evolutionary game with bounded rationality is a dynamic selection and adjustment process and finally reaches certain equilibrium. The dynamic change rate of game players' strategies is the core of the analysis of bounded rational games, and the dynamic change rate of game models can be reflected by differential equations [34]. The replicator dynamic equation can ensure that the evolutionary stability strategy (ESS) is evolutionary equilibrium. Generally speaking, there are two methods to derivate the replicated dynamic equation: the first is the Malthusianism population growth model [35] and the second is the strategy shift based on revenue deviation [36].

According to the theory of the strategy shift based on revenue deviation, the replicator dynamic equations of online games, web games, and stand-alone games are

$$\begin{aligned}F(x)\frac{\mathrm{d}x}{\mathrm{d}t} &= x(E_{11} - E_1), \\ F(y)\frac{\mathrm{d}y}{\mathrm{d}t} &= y(E_{21} - E_2), \\ F(z)\frac{\mathrm{d}z}{\mathrm{d}t} &= z(E_{31} - E_3).\end{aligned} \tag{10}$$

By substituting these revenue expectations into $F(x)$, $F(y)$, and $F(z)$, we can obtain the replicator dynamic equations of the strategy selection behaviors:

Table 1: Payment matrix under different strategy choices.

	Web games		Stand-alone games	
			Cooperation (z)	Competition ($1-z$)
Online games	Cooperation (x)	Cooperation (y)	$1.3A_1 - C, 2A_2, 0.9A_3 + 2D$	$0.5A_1 - C, A_2, F, 0$
		Competition ($1-y$)	$0.8A_1 - C, -B_2 - 2F, 0.7A_3 + D$	$-H, -2F, 0$
	Competition ($1-x$)	Cooperation (y)	$-B_1, A_2 - F, 0.2A_3 + D$	$0, -H - 2F, 0$
		Competition ($1-y$)	$0, -2F, 0$	$0, -2F, 0$

$$\begin{aligned} F(x) &= -x(x-1)\left(-Cy - Cz + Cyz - Hy - Hz + H + Hyz + 0.5A_1 y + 0.8A_1 z + B_1 yz\right),\\ F(y) &= -y(y-1)\left(-H + Hx + Hz - Hxz + Fx + Fz + A_2 x + A_2 z + B_2 xz\right),\\ F(z) &= -z(z-1)\left(Dx + Dy + 0.7A_3 x + 0.2A_3 y\right). \end{aligned} \tag{11}$$

3. Stability Analysis of the Evolutionary Game System

3.1. Equilibrium Point and Eigenvalues. By solving the system of equations

$$\begin{cases} F(x) = 0,\\ F(y) = 0,\\ F(z) = 0, \end{cases} \tag{12}$$

we can obtain 8 equilibrium points, which are listed in Table 2.

In the evolutionary stable strategy, the Jacobian matrix is often used to judge whether these equilibrium points achieve ESS. By calculating the partial derivatives of $F(x)$, $F(y)$, and $F(z)$, we can obtain the Jacobian matrix of the three-way evolutionary game:

$$J = \begin{bmatrix} \dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y} & \dfrac{\partial F(x)}{\partial z}\\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y} & \dfrac{\partial F(y)}{\partial z}\\ \dfrac{\partial F(z)}{\partial x} & \dfrac{\partial F(z)}{\partial y} & \dfrac{\partial F(z)}{\partial z} \end{bmatrix}. \tag{13}$$

To analyze the stability of the eight equilibrium points, we respectively substitute these equilibrium points into (13) and obtain 8 Jacobian matrices. Then, we can calculate the eigenvalues of the Jacobian matrices, which are listed in Table 3.

3.2. Stability Analysis. According to Lyapunov's first method [37], if all eigenvalues of the Jacobian matrix in Table 3 have negative real parts, the equilibrium point is asymptotically stable, and if there are one or more eigenvalues with positive real parts at the equilibrium point, then the equilibrium point is unstable. Therefore, we can obtain the stability analysis of the equilibrium points, which are listed in Table 4.

3.3. Conclusions of Stability Analysis. According to Table 4, we have the following conclusions.

Conclusion 1. There are only two equilibrium points that can be stabilized, i.e., $E_3(0,1,1)$ and $E_8(1,1,1)$. As we can see from the coordinates of E_3 and E_8, the y-axis and z-axis are always 1 whether the x-axis is 0 or 1. This indicates that both web and stand-alone game businesses are not affected by online games and are inclined to cooperate. This can be explained as web games can get income from the inflow of players and save the cost of publicity after choosing cooperation, and stand-alone games can get more copyright sales income and secondary income by choosing cooperation, rather than losing this income, even consuming part of the funds to make up for the loss if they choose not to cooperate. Therefore, if game businesses want to keep long-term stability, they should seek beneficial and harmless cooperation.

Conclusion 2. From Table 4, when$C > 1.3A_1 + B_1$, $E_3(0,1,1)$ achieves stability and when$C < 1.3A_1 + B_1$, $E_8(1,1,1)$ achieves stability, the behavior strategy choice of online games is affected by discount losses, player churn losses, and gains. When the sum of the benefits brought by cooperation and the losses caused by noncooperation is smaller than the discounted losses of cooperation, the final evolution of online games will tend to be competitive. When popular online game businesses cooperate with other unpopular game businesses, the inflow of new players will decrease, and discount promotions reduce the consumption of older players. In such cases, online game businesses will be more inclined to compete. On the contrary, unpopular online game businesses need the inflow of new players, and they are more likely to cooperate to obtain an inflow of new players and profits. Therefore, it is recommended that the discount promotion issued by popular and powerful online games at the time of cooperation be changed to the activity of receiving newcomer discounts through the partner's game account, which can play a better inflow effect and avoid the loss of reduced consumption of old players. The number of unpopular online games is not many old players, and the discount will produce fewer losses, so the unpopular online games can implement discount promotions when

Table 2: Equilibrium points and their coordinates.

Equilibrium points	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8
Coordinates	(0, 0, 0)	(0, 1, 0)	(0, 1, 1)	(0, 0, 1)	(1, 0, 1)	(1, 1, 0)	(1, 0, 0)	(1, 1, 1)

Table 3: Eigenvalues of the Jacobian matrices.

Equilibrium point	λ_1	λ_2	λ_3
$E_1\,(0,0,0)$	0	H	$-H$
$E_2\,(0,1,0)$	H	$D+0.2A_3$	$0.5A_1-C$
$E_3\,(0,1,1)$	$-D-0.2A_3$	$-F-A_2$	$1.3A_1-C+B_1$
$E_4\,(0,0,1)$	0	$F+A_2$	$0.8A_1-C$
$E_5\,(1,0,1)$	$C-0.8A_1$	$-D-0.7A_3$	$2F+2A_2+B_2$
$E_6\,(1,1,0)$	$C-0.5A_1$	$2D+0.9A_3$	$-F-A_2$
$E_7\,(1,0,0)$	$F+A_2$	$D+0.7A_3$	$-H$
$E_8\,(1,1,1)$	$-2D-0.9A_3$	$C-1.3A_1-B_1$	$-2F-2A_2-B_2$

Table 4: Stability analysis of equilibrium points.

Equilibrium point	Stability conclusion	A condition or cause
$E_1\,(0,0,0)$	Unstable point	There is a positive real part
$E_2\,(0,1,0)$	Unstable point	There is a positive real part
$E_3\,(0,1,1)$	ESS	$C>1.3A_1+B_1$
$E_4\,(0,0,1)$	Unstable point	There is a positive real part
$E_5\,(1,0,1)$	Unstable point	There is a positive real part
$E_6\,(1,1,0)$	Unstable point	There is a positive real part
$E_7\,(1,0,0)$	Unstable point	There is a positive real part
$E_8\,(1,1,1)$	ESS	$C<1.3A_1+B_1$

cooperating, which plays a role in retaining old players while introducing new players, which is more conducive to long-term development.

4. Sensitivity Analysis and Simulation

We in this section analyzed the sensitivity of H, A_1, A_2, and A_3. The dynamic evolutions were carried out by using MATLAB. Under the condition of $C>1.3A_1+B_1$, we set $A_1=20$, $A_2=10$, $A_3=10$, $B_1=5$, $B_2=5$, $C=5$, $D=5$, $F=5$, and $H=5$ and took (0.2, 0.2, 0.2) as the initial point. In our simulations, we first discussed the evolution process and results with various values of H, A_1, A_2, and A_3, then we analyzed the evolution process and results with different initial strategy combinations.

4.1. Sensitivity Analysis of H. By setting H to 5, 13, and 15, respectively, we performed 50 evolutions of the replicated dynamic equations and displayed the simulation results in Figure 1. It is evident from Figure 1 that the increase in reputation losses will reduce the evolutionary rate of cooperation between online and web game businesses, and online and web game businesses will always be competitive when reputation loss reaches a threshold.

At the initial stage, the willingness of the three parties to cooperate is relatively low. To prevent reputation losses, online and web game businesses choose to maintain a competitive state. However, as stand-alone game businesses do not have reputational losses, they are more inclined to cooperate. When the success rate of tripartite cooperation increases, the willingness to cooperate also increases. Therefore, the tripartite cooperation relationship will be more stable based on ensuring the success rate of cooperation. On the contrary, when the reputation loss is large, online and web game businesses cannot bear the influence of reputation loss and will quickly stabilize in the competition. Therefore, game businesses should maintain positive attitudes toward cooperation and enhance their confidence in the success of the cooperation to achieve a win-win situation for cooperation.

4.2. Sensitivity Analysis of A_1, A_2, and A_3. By setting $A_1=15$, 20, and 25; $A_2=5$, 10, and 25; and $A_3=5$, 10, and 15, respectively, we carried out the evolution of the replicated dynamic equation 50 times. The evolution results are shown in Figure 2. As shown in Figure 2, better revenue per unit stabilizes the game players in the cooperative state more quickly. This is because the inflow of players is limited in the case of cooperation, so the higher the revenue per unit, the more the total profits. Therefore, it is suggested that online and web game businesses should introduce growth fund consumption, and stand-alone games should introduce games that can be modified or enhanced. In this way, the

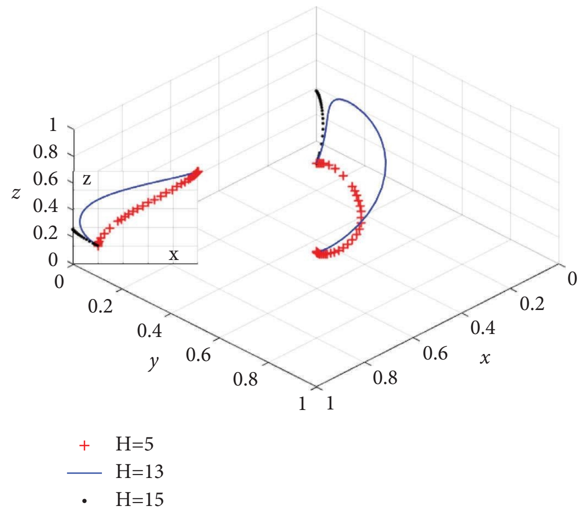

Figure 1: Sensitivity analysis of H.

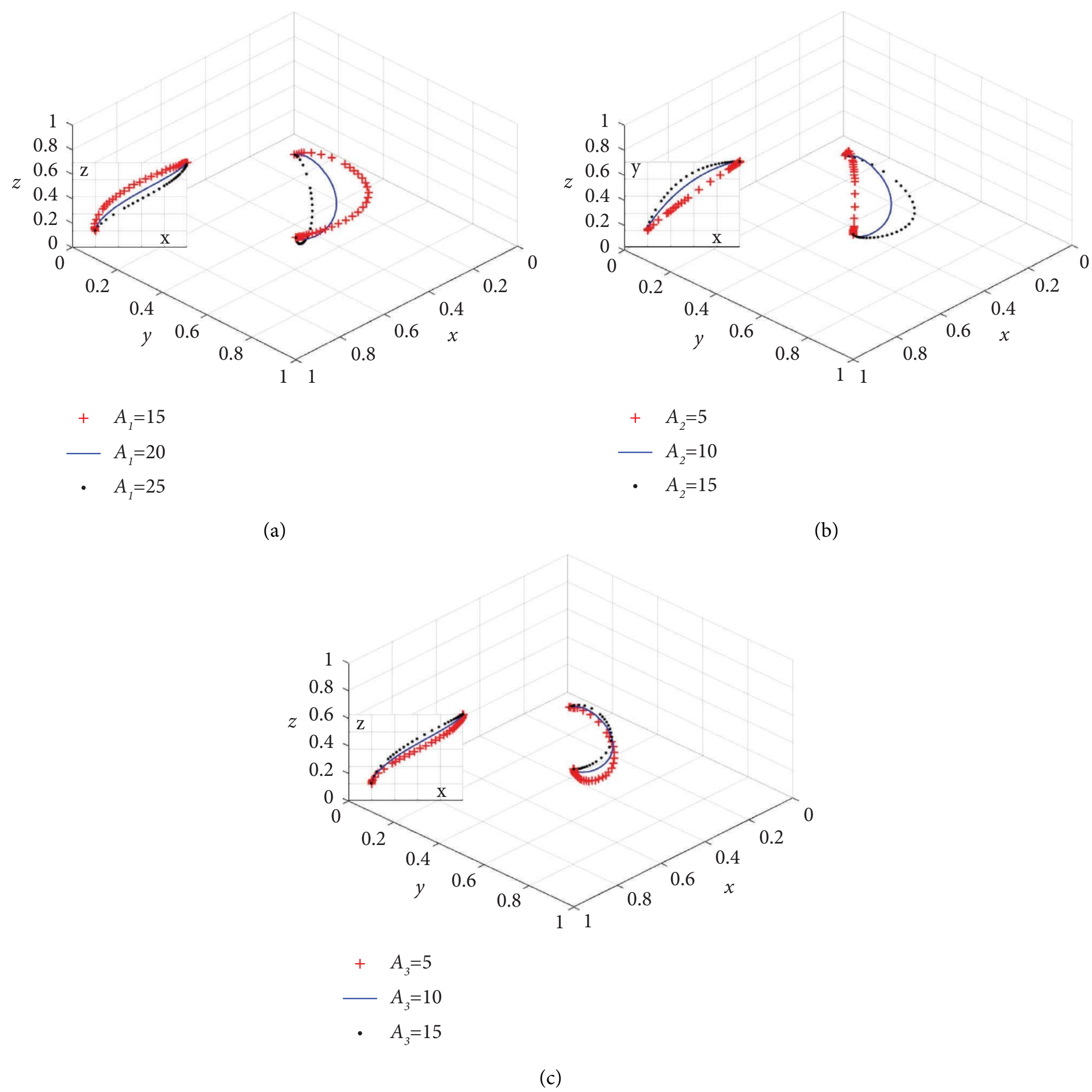

Figure 2: Sensitivity analysis of (a) A_1, (b) A_2 and (c) A_3.

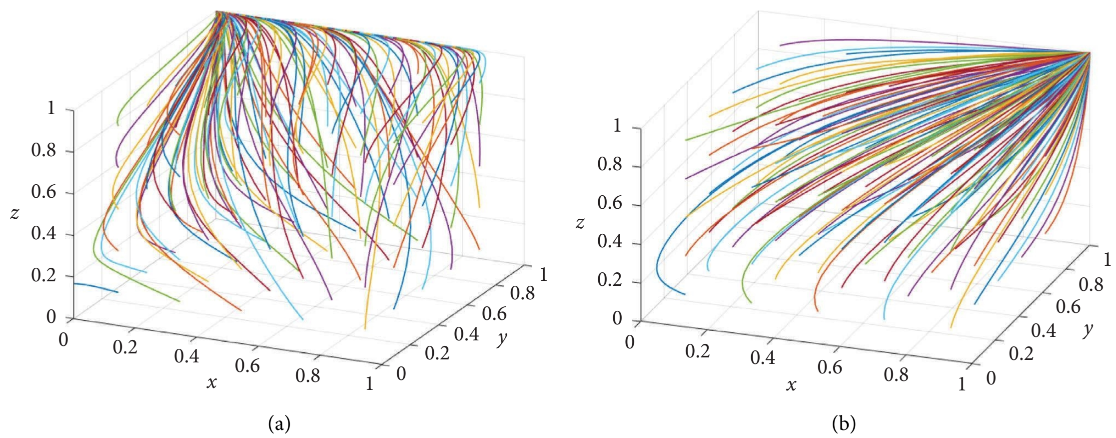

Figure 3: Evolution results with different initial strategy combinations: (a) equilibrium point (0, 1, 1) and (b) equilibrium point (1, 1, 1).

revenue per unit will increase, and the stickiness of players will improve, thus the game businesses will create more revenue.

4.3. Evolution Results with Different Initial Strategy Combinations. Under the condition of $C < 1.3A_1 + B_1$, we set $A_1 = 10$, $A_2 = 10$, $A_3 = 11$, $B_1 = 5$, $B_2 = 5$, $C = 20$, $D = 5$, $F = 5$, and $H = 5$. We carried out the evolutions with two equilibrium points, i.e., (0, 1, 1) and (1, 1, 1). We performed the two situations with 100 evolutions and displayed in Figure 3 the evolution results. The evolution results of equilibrium points (0, 1, 1) and (1, 1, 1) are shown in Figures 3(a) and 3(b), respectively. The evolution results shown in Figure 3 coincide with Conclusion 2. Whether online game businesses choose to cooperate requires comprehensive data analysis. Web and stand-alone game businesses need to seize every opportunity for cooperation.

The conclusion of the simulation analysis is consistent with that of the strategic stability analysis of all parties, which ensures the reliability and availability of the conclusions. Thus, the conclusion provides a certain reference value for game businesses to create a win-win situation for cooperation.

5. Conclusion

To study the cooperative relationship between different game businesses, in this paper we deductively analyzed the three main bodies of online, web, and stand-alone games businesses by establishing an evolutionary game model. Evolution results show that either online game businesses select competition or the tripartite select cooperation, the results eventually tend to stabilize. According to the evolution results, we give some recommendations as follows:

Conclusion 1 shows that the model achieves stability at the equilibrium point $E_3(0, 1, 1)$ or $E_8(1, 1, 1)$, which indicates that web and stand-alone games businesses tend to maintain long-term cooperation because they will lose revenue without cooperation.

Conclusion 2 shows that the relationship between C and $1.3A_1 + B_1$ determines which equilibrium point is stable, and C has strong controllability. This indicates that for popular online games, businesses should replace discount promotions with newcomer discounts. This can not only attract more players, but also avoid the loss caused by the reduction of the consumption of old players.

Sensitivity analysis indicates the greater the reputation loss, the more difficult it is for businesses to achieve cooperation. Once a business inclines to cooperate, the success rate of another business is guaranteed. And maintaining a positive and cooperative attitude is more conducive to achieving a win-win environment for cooperation. Besides, the amount of revenue also affects the rate that approaches stability, but the customer flow is limited. Therefore, with the inflow of limited players, game businesses can create more revenue through consumption innovation or game innovation.

In this paper, we study the strategic evolution relationship between different game businesses based on the rational state. While in practice, more factors should be taken into account, such as political factors, age factors, and so on. The government can be joined as the main body of the fourth-party evolution game in our further work. Besides, players of different ages have different enthusiasm for games. In the future, we can analyze the influence of players' age on the model by the big data analysis, so that the result of the evolutionary game is closer to reality and more convincing. In this way, the results of the evolutionary game will be closer to reality and more convincing.

Data Availability

The 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.

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