Hindawi
Journal of Mathematics
Volume 2021, Article ID 8038672, 10 pages
https://doi.org/10.1155/2021/8038672

Research Article

Simulation Study on the Evolutionary Game Mechanism of Collaborative Innovation in Supply Chain Enterprises and Its Influencing Elements

Jue-Ping Xie and Huai-Ying Lei

School of Economics and Management, Tiangong University, Tianjin 300387, China

Correspondence should be addressed to Huai-Ying Lei; lhy@tiangong.edu.cn

Received 29 September 2021; Revised 8 November 2021; Accepted 15 November 2021; Published 3 December 2021

Academic Editor: Shaojian Qu

Collaborative innovation between companies is critical for increasing supply chain value. However, as a dynamic game process, the collaboration between manufacturer, provider, and seller in the supply chain is influenced by a range of elements. This paper is set out to investigate the collaborative innovation strategy adopted by manufacturer, supplier, and distributor (the "three players"). To meet this end, an analytical framework was built to study the evolutionary game of collaborative innovation in supply chain enterprises. Based on the analysis, this research further studied the dynamic evolutionary mechanism and influencing elements through four different simulation cases. The research showed the following. (1) When the three players have equal innovative capability, they are more willing to contribute to innovation if the projected revenue is higher reflecting an increasing coefficient of collaborative innovation gains. As a result, the three players are more likely to agree on their cooperation approach. (2) When the three players have different independent and innovative capabilities, they are more willing to innovate if the collaborative innovation gain coefficient increases, but supply chain players with stronger capability are more active to innovate than their peers. In other words, strong innovators attach particular attention to innovation. (3) When any collaborative innovation could generate profits for all players in the supply chain, the player who enjoys the benefit but lacks innovative capability will be unwilling to cooperate with others if additional gains rise. Thus, better maintenance of the stability of the collaborative innovation system requires a strictly implemented coordination mechanism.

1. Introduction

Chinese enterprises have entered a critical stage of transformation and reform, while innovation could be the main source of sustainable development. Some agents may find it difficult to engage in innovation alone due to limited resources. Luckily, the emerging economic model provides more opportunities for innovation linkages and collaboration in the supply chain industry. Facing development, governments should guide enterprises to strengthen collaborative innovation. The aim of this paper has therefore been to review key elements that are decisive to the collaborative innovation strategy for different circumstances, which will serve as a reference to policy-makers. This article explores how environment elements and innovation gains influence the innovation strategies based on simulation analysis of supply chain bodies in the mechanism of game evolution. These findings have laid a theoretical foundation for the government to guide and strengthen collaborative innovation and will greatly improve the overall collaborative innovation capability of the industry.

Innovation has been proposed as the national development strategy as the Chinese public has a stronger awareness of innovation. Meanwhile, more scholars have paid particular attention to this topic. In recent years, there has been an increasing amount of literature on collaborative innovation, particularly its application in the supply chain. To date, there are two primary research objects of collaborative innovation studies.

1.1. The Influencing Elements of Supply Chain Synergy. According to the concept of open innovation proposed by Chesbrough [1], enterprises should integrate internal and external resources in the process of innovation research and development for sharing economy and expand the source to partners and competitors in the industry, thus creating a friendly environment for performing collaborative innovation in the supply chain. In their empirical study on the service industry and manufacturing industry in the United States, Tamer Cavusgil et al. [2] pointed out that the synergy effects between supply chain enterprises are positively correlated with tacit knowledge transformation. In an investigation into the role of trust in the process of supply chain collaboration, Nyaga et al. [3] found that the trust and commitment between supply chain members support collaborative innovation, which generates a higher profit than the cost incurred by the collaboration, leading to better collaborative performance and satisfaction. To analyze how information sharing affects competition and cooperation in the supply chain industry, Albert and Tong [4] addressed two retailing companies receiving symmetrical demand signals. The analysis of Majumder and Srinivasan [5] on competing supply chains discovered that cost network structure and leadership are the two elements affecting the competition status of the supply chain.

Du and Shao [6] established a game model to compare the profits earned by core and supporting enterprises through independent innovation with the profits made by collaborative innovation. The research proved that in the market environment, enterprises would get better innovation results through collaboration than working individually. An empirical study by Trigo and Vence [7] measured the positive correlations between innovation level and collaboration. In 2017, Skippari et al. [8] studied cognitive barriers preventing supply chain players from collaborative innovation and suggested that market players' different viewpoints would affect collaborative innovation activity.

1.2. An Evolutionary Game Model for the Collaborative Innovation by Supply Chain Enterprises. Over the past decade, most research in collaborative innovation has emphasized the use of evolutionary game theory. In 2016, Bai and Sarkis [9] used game theory to study supplier's development situations and analyze how collaborative and noncooperative decisions between manufacturers and suppliers influence the latter's investment directly. To better understand the contract design made in different collaborative situations between manufacturers and suppliers, Friedl and Wagner [10] established a systematic innovation model covering supply chain players, which showed that suppliers would produce the maximum value when receiving cooperative incentives. In another research on collaboration and cooperation, Feng et al. [11] used the evolutionary game to analyze the mechanism between prefabricated component producers under punishment and incentive conditions. When manufacturers and suppliers try to solve problems in a complex collaborative system, the evolutionary game theory helps analyze how the problem scale and handling mechanism impact the decision-making process [12].

In a discussion of profit allocation mechanism, Ma and Wang [13] discussed and modified the Shapley value model with the innovation incentives, which may enhance the competitiveness of the supply chain. In another modified Shapley value model, Li et al. [14] extensively studied innovation resource investment, innovation profits, and potential risks when redistributing the gains from collaborative innovation among supply chain players. In the evolutionary game model of collaborative innovation built by Wu et al. [15], the government plays the guide, the university is the pioneer, while enterprises are the major participant, demonstrating distinct strategic decision-making process of different market players. The evolutionary game model can also be used to depict enterprises' decision behavior. Ji et al. [16] found that enterprises, universities, and research institutes invested resources differently as their preferences towards cooperation fairness, output, and profit allocation ratio diversify.

The above literature has attempted to explain the formation and influencing elements of the collaborative innovation mechanism. In addition, a considerable amount of literature has used the game model to study the dynamic evolution path of collaborative innovation, the profit allocation among the three players in a game, or elements of game strategy choice. However, few studies have researched how collaborative innovation gain, as an influencing element, impacts industrial players' strategic choice of collaborative innovation.

As all the previous collaborative innovation research studies were cross-sectional in design, this article combines the three spiral model with game analysis as a major research methodology to analyze the influencing coefficient of collaborative innovation gain. The simulation analysis focused on the three-layer supply chain body made up of individual manufacturers, suppliers, and distributors and studied the key elements influencing the gain coefficient under three different circumstances. The research results will make a contribution to the theory which governments could refer to when making policies encouraging collaborative innovation.

2. Evolutionary Game Framework for the Analysis of Collaborative Innovation by Supply Chain Enterprises

More than half a century ago, Ansoff [17] formulated his synergy effect theory, centered around how enterprises achieve mutual growth through collaboration and resource sharing. According to Baidu Encyclopedia, collaboration refers to the process of two or more individuals working jointly to achieve their common goal or the capability to do so. Economic slowdown intensified competition between enterprises and even between supply chains. Such competitions are usually reflected in business ecosystems, such as

Alibaba, Tencent, and Baidu. In the Internet economy, more resources are available to share on the World Wide Web, enabling supply chain enterprises (manufacturer, supplier and distributor) to pursuit collaborative innovation at low cooperation cost. Thus, a new development model emerges. Anthony Jnr [18] revealed that the internal and external characteristics influence an enterprise's sustainable innovation capability.

The collaborative innovation in the supply chain is evolved in the game theory framework, leading to the earning equilibrium and rationalization. The three players in the game, among others, are the manufacturer (m) who produces products, supplier (s) who delivers products, and distributor (d) who sells products. The three players form a closed-loop of game theory (Figure 1), enabling enterprises in the supply chain to make the best decisions [19].

(1) *Collaborative Strategy*. In the collaborative innovation in the supply chain, the three players (manufacturer, supplier, and distributor) enjoy equal status, which means they can freely choose strategies according to their gains and losses. The strategy set (engagement and no engagement in collaborative innovation) was denoted as (Y, N).

(2) *Collaborative Cost*. Assuming that there is no enterprise playing the leading role in the collaborative innovation and the government does not control the system with punitive and rewarding regulations, enterprises are allowed to make strategy choices according to the market cycle [20, 21]. The costs paid by manufacturer, supplier, and distributor for collaborative innovation are thus denoted as C_m, C_s, and C_d, respectively.

(3) *Collaborative Gains*. Almost all enterprises are forced to and will inevitably carry out innovative research and development in today's market [22–24]. Assuming that an enterprise has independent innovation capability, the gains thus generated are independent innovation gains. The independent innovation gains obtained by manufacturer, supplier, and distributor are denoted as W_m, W_s, and W_d, respectively. When two of the three players participate in collaborative innovation and share knowledge and technology, their gains will increase. The collaborative innovation gain is denoted as coefficient k_1, representing the increase from the independent innovation gains. The collaborative innovation gain coefficient is k_2 if all the three players participate in collaborative innovation. Based on the scale effect, $k_2 > k_1$, which conforms to the actual situation.

(4) *Additional Gains*. The supply chain players are closely linked in the production cycle. When the player engaging in collaborative innovation shares its technological and knowledge innovations, other external parties may obtain an increase in gains without costs or risks [25].

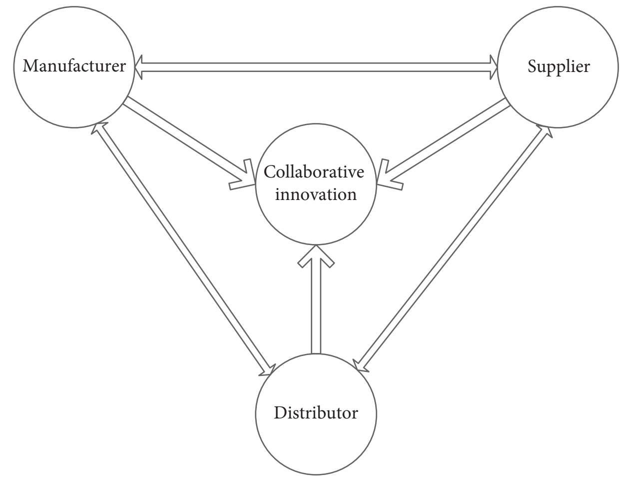

Figure 1: Manufacturer supplier distributor collaborative innovation.

If one of the three players engages in collaborative innovation, while the other two players do not, those who do not innovate may also record gains generated by innovative achievements in the supply chain. The additional gains received by the manufacturer, supplier, and distributor are denoted as $\Delta W_m^+ (\Delta W_m^+ \geq 0)$, $\Delta W_s^+ (\Delta W_s^+ \geq 0)$, and ΔW_d^+ $(\Delta W_d^+ \geq 0)$, respectively. When two of the three parties engage in collaborative innovation, the other party (be the manufacturer, the supplier, or the distributor) would also enjoy additional gains. The additional gains of the three players in this condition are denoted as $\Delta W_m^{++} (\Delta W_m^{++} \geq 0)$, $\Delta W_s^{++} (\Delta W_s^{++} \geq 0)$, and $\Delta W_d^{++} (\Delta W_d^{++} \geq 0)$, respectively.

3. Analysis of the Evolution Mechanism of Collaborative Innovation Game of Supply Chain Enterprises

3.1. The Payoff Matrix in the Game. According to the game theory, supply chain enterprises adjust their game strategy according to their gains. We assume that the probability of a manufacturer's engagement in collaborative innovation is x $(0 \leq x \leq 1)$ and no engagement is $1 - x$; the probabilities of a supplier's engagement and not engagement are y $(0 \leq y \leq 1)$ and $1 - y$, respectively; and the probabilities of the distributor are z $(0 \leq z \leq 1)$ and $1 - z$, respectively.

The manufacturer (m), supplier (s), and distributor (d) have two strategic choices, i.e., engagement and no engagement in collaborative innovation. Table 1 demonstrates the game payoff matrix of eight strategy combinations.

3.2. Analysis on the System of Replicator Dynamic Equation and Stability of Collaborative Innovation. The manufacturer, supplier, and distributor are determined to engage in collaborative innovation based on the results of multiple games. The system of replicator dynamic equation represents the dynamic evolution of their decision-making process.

Table 1: The payoff matrix of supply chain players.

Strategy combination	Manufacturer (m)	Supplier (s)	Distributor (d)
(N, N, N)	W_m	W_s	W_d
(N, Y, N)	$W_m + \Delta W_m^+$	$W_s - C_s$	$W_d + \Delta W_d^+$
(N, N, Y)	$W_m + \Delta W_m^+$	$W_s + \Delta W_s^+$	$W_d - C_d$
(N, Y, Y)	$W_m + \Delta W_m^{++}$	$W_s(1+k_1) - C_s$	$W_d(1+k_1) - C_d$
(Y, N, N)	$W_m - C_m$	$W_s + \Delta W_s^+$	$W_d + \Delta W_d^+$
(Y, Y, N)	$W_m(1+k_1) - C_m$	$W_s(1+k_1) - C_s$	$W_d + \Delta W_d^{++}$
(Y, N, Y)	$W_m(1+k_1) - C_m$	$W_s + \Delta W_s^{++}$	$W_d(1+k_1) - C_d$
(Y, Y, Y)	$W_m(1+k_2) - C_m$	$W_s(1+k_2) - C_s$	$W_d(1+k_2) - C_d$

The manufacturer's (m) expected gains for engagement in collaborative innovation are E_m^H, while the expected gains for not engaging in collaborative innovation are E_m^L, and the average expected gains are $\overline{E}_m$; therefore,

$$\begin{cases} E_m^H = (1-y)(1-x)(W_m - C_m) + y(1-z)[W_m(1+k_1) - C_m] + (1-y)z+ \\ (1-y)z[W_m(1+k_1) - C_m] + yz[W_m(1+k_2) - C_m], \\ E_m^L = (1-y)(1-x)W_m + y(1-z)(W_m + \Delta W_m^+) \\ +(1-y)z(W_m + \Delta W_m^+) + yz(W_m + \Delta W_m^{++}) \\ \overline{E}_m = xE_m^H + (1-x)E_m^l. \end{cases} \tag{1}$$

The supplier's (s) expected gains for engagement in collaborative innovation are denoted as E_s^H, while the expected gains for not engaging in collaborative innovation are denoted as E_s^L, and the average expected gains are denoted as $\overline{E}_s$; therefore,

$$\begin{cases} E_s^H = (1-x)(1-z)(W_s - C_s) + (1-x)z[W_s(1+k_1) - C_s]+ \\ x(1-z)[W_s(1+k_1) - C_s] + xz[W_s(1+k_2) - C_s], \\ E_s^L = (1-x)(1-z)W_s + (1-x)z(W_p + \Delta W_p^+)+ \\ x(1-z)(W_s + \Delta W_s^+) + xz(W_s + \Delta W_s^{++}), \\ \overline{E}_s = yE_s^H + (1-y)E_s^L. \end{cases} \tag{2}$$

The distributor's (d) expected gains for engagement in collaborative innovation are denoted as E_d^H, while the expected gains for not engaging in collaborative innovation are denoted as E_d^L, and the average expected gains are denoted as $\overline{E}_d$; therefore,

$$\begin{cases} E_d^H = (1-x)(1-y)(W_d - C_d) + (1-x)y[W_d(1+k_1) - C_d]+ \\ x(1-y)[W_d(1+k_1) - C_s] + xy[W_d(1+k_2) - C_d], \\ E_d^L = (1-x)(1-y)W_d + (1-x)y(W_d + \Delta W_d^+)+ \\ x(1-y)(W_d + \Delta W_d^+) + xy(W_d + \Delta W_d^{++}), \\ \overline{E}_d = zE_d^H + (1-z)E_d^L. \end{cases} \tag{3}$$

In the evolutionary game theory, we reach the imitation dynamic equations of the manufacturer (m), supplier (s), and distributor (d) according to the imitation dynamic equation:

$$\begin{cases} f(x) = \dfrac{\mathrm{d}x}{\mathrm{d}t} = x\left(E_m^H - \overline{E}_m\right) = x(1-x)\left(E_m^H - E_m^L\right), \\ f(y) = \dfrac{\mathrm{d}y}{\mathrm{d}t} = y\left(E_s^H - \overline{E}_s\right) = y(1-y)\left(E_s^H - E_s^L\right), \\ f(z) = \dfrac{\mathrm{d}z}{\mathrm{d}t} = z\left(E_d^H - \overline{E}_d\right) = z(1-z)\left(E_d^H - E_d^L\right). \end{cases} \tag{4}$$

If $f(x)$, $f(y)$, and $f(z)$ are 0, the equilibrium points of the three replicator dynamic equations are (0,0,0), (0,1,0), (0,0,1), (0,1,1), (1,0,0), (1,1,0), (1,0,1), and (1,1,1), respectively. Based on the three replicator dynamic equations, we made the Jacobian matrix as follows:

$$J = \begin{bmatrix} \dfrac{\partial f(x)}{\partial x} & \dfrac{\partial f(x)}{\partial y} & \dfrac{\partial f(x)}{\partial z} \\ \dfrac{\partial f(y)}{\partial x} & \dfrac{\partial f(y)}{\partial y} & \dfrac{\partial f(y)}{\partial z} \\ \dfrac{\partial f(z)}{\partial x} & \dfrac{\partial f(z)}{\partial y} & \dfrac{\partial f(z)}{\partial z} \end{bmatrix}. \tag{5}$$

By placing the eight equilibrium points into the Jacobian matrix, respectively, their eigenvalues are as shown in Table 2.

Through the local analysis on the Jacobian matrix, we obtain the evolutionarily stable strategy of the system of replicator dynamic equations. The point would be stable only when the eigenvalues are all nonpositive.

4. Simulation Analysis on the Influencing Factors of Collaborative Strategy

The equilibrium points (0,0,0), (0,1,1), (1,1,0), (1,0,1), and (1,1,1) could be stable points with the change of undetermined parameters of the 3D helical model. This paper only discussed how the coefficient of collaborative innovation gain affects the evolution of collaborative innovation game. To this end, other parameters have to be determined before observing the changes in the coefficient of collaborative innovation gains.

Table 2: Eigenvalues of the Jacobian matrix.

Equilibrium point	Eigenvalue T_1	Eigenvalue T_2	Eigenvalue T_3
$E_1\,(0,0,0)$	$-C_m$	$-C_s$	$-C_d$
$E_2\,(0,1,0)$	$k_1W_m - C_m - \Delta W_m^+$	C_s	$k_1W_d - C_d - \Delta W_d^+$
$E_3\,(0,0,1)$	$k_1W_m - C_m - \Delta W_m^+$	$k_1W_s - C_s - \Delta W_s^+$	C_d
$E_4\,(0,1,1)$	$k_2W_m - C_m - \Delta W_m^{++}$	$-(k_1W_s - C_s - \Delta W_s^+)$	$-(k_1W_d - C_d - \Delta W_d^+)$
$E_5\,(1,0,0)$	C_m	$k_1W_s - C_s - \Delta W_s^+$	$k_1W_d - C_d - \Delta W_d^+$
$E_6\,(1,1,0)$	$-(k_1W_m - C_m - \Delta W_m^+)$	$-(k_1W_s - C_s - \Delta W_s^+)$	$k_2W_d - C_d - \Delta W_d^{++}$
$E_7\,(1,0,1)$	$-(k_1W_m - C_m - \Delta W_m^+)$	$k_2W_s - C_s - \Delta W_s^{++}$	$-(k_1W_d - C_d - \Delta W_d^+)$
$E_8\,(1,1,1)$	$-(k_2W_m - C_m - \Delta W_m^{++})$	$-(k_2W_s - C_s - \Delta W_s^{++})$	$-(k_2W_d - C_d - \Delta W_d^{++})$

4.1. Influence of Collaborative Innovation Gain Coefficient on the Evolution Process of Collaborative Innovation Strategy. In the changing economy, enterprises' economic scale and innovation ability in the supply chain are thus different. We studied how the coefficient of collaborative innovation gains influences the strategic evolution from the perspective of the independent innovation gains, collaborative innovation costs, and additional gains of the manufacturer, supplier, and distributor [26].

Situation 1. Where the manufacturer, supplier, and distributor engaging in collaborative innovation have similar economic scale, gains, and costs, we observe how the coefficient of collaborative innovation gains impacts its strategic evolution when the three players have the same level of willingness. The parameters' setting is as follows: $W_m = W_s = W_d = 30$, $W_m^+ = W_s^+ = W_d^+ = 5$, $W_m^{++} = W_s^{++} = W_d^{++} = 6$, $C_m = C_s = C_d = 8$, and $x = y = z = 0.5$.

According to the simulation by Matlab software (Figure 2), the three players' strategies follow the same evolving paths due to their similarities in economic scale. The line in Figure 2 represents the evolution of collaborative innovation strategy of the three players. As shown in Figure 2, as k_1 and k_2 increase by the same ratio, the strategies of the three players gradually changed from (N, N, N) to (Y, Y, Y). Simulation results showed that the manufacturer, supplier, and distributor would choose similar strategies when they have an equal economic scale and enjoy a relatively fair allocation of collaborative innovation gains. Moreover, as the coefficient of collaborative innovation gains grows, they are more willing to engage in collaborative innovation. Finally, the three players would also devote themselves to collaborative innovation driven by the market margin. The evolution of collaborative innovation strategy aligns with the market law of enterprises' nature of "profit-seeking."

Situation 2. We suppose the independent innovation gains recorded by the three players are different, but their costs for collaborative innovation and additional gains are the same. When the three players have the same level of initial willingness to engage in collaborative innovation, we observe the influence of the coefficient of collaborative innovation gains on the evolutionary game of collaborative innovation strategy. The parameters' setting is as follows: $W_m = 30$, $W_s = 40, W_d = 50, W_m^+ = W_s^+ = W_d^+ = 5, W_m^{++} = W_s^{++} = W_d^+$ $+ = 6, C_m = C_s = C_d = 8$, and $x = y = z = 0.5$.

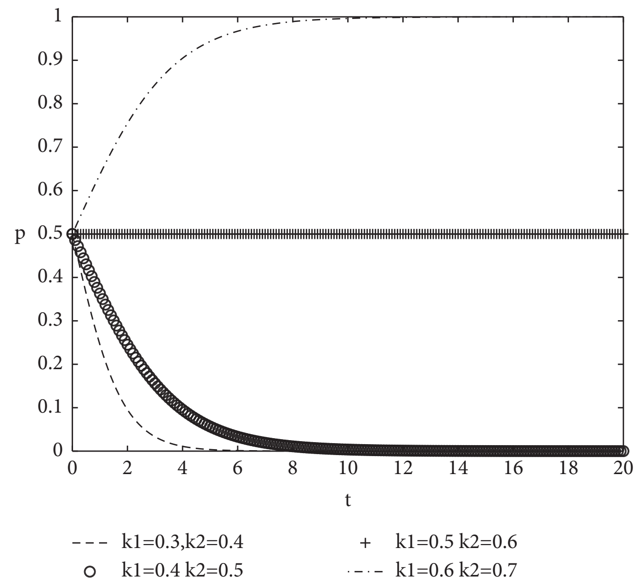

Figure 2: Strategy evolution paths under different gain coefficients.

Matlab software simulated the model and produced the results, as shown in Figures 3–5. The strategies of the three players follow different evolving paths as they have inconsistent independent innovation gains. According to Figures 3–5, the strategy of the three parties gradually changed from (N, N, N) to (Y, Y, Y) as k_1 and k_2 increase. Simulation results showed that the three players are inclined to choose the same strategy when the collaborative innovation gains are fairly distributed despite their different independent innovation gains. However, the entity with greater independent innovation gains is more likely to make better achievements in collaborative innovation, and the player with stronger independent innovation capability would be more willing to engage in collaborative innovation as the coefficient of collaborative innovation gains rises. The bottom line is that enterprises with stronger independent innovation capability are likely to leverage and transform the production means of other market players to enhance their productivity through collaborative innovation.

The enterprises with greater independent innovation gains arouse other market players' enthusiasm for collaborative innovation. In the actual economic environment, the "Internet + traditional enterprise" have been driving the transformation of traditional enterprises and promoting the traditional enterprises to pursue innovation, which is consistent with the simulation results [27].

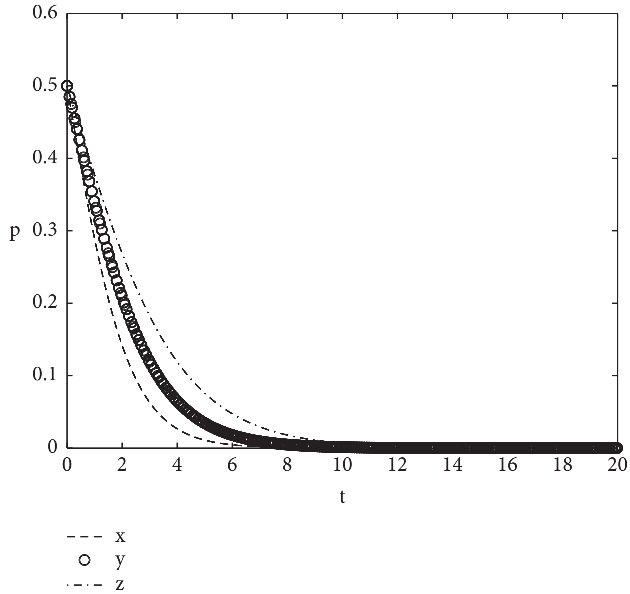

Figure 3: $k_1 = 0.3$ and $k_2 = 0.4$.

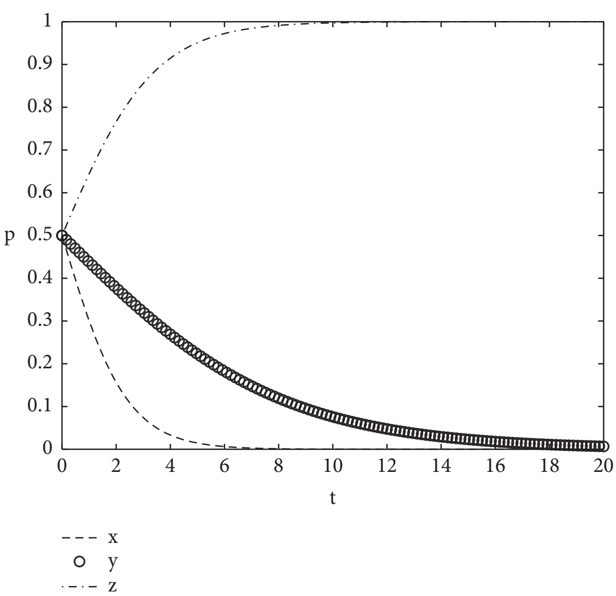

Figure 4: $k_1 = 0.35$ and $k_2 = 0.45$.

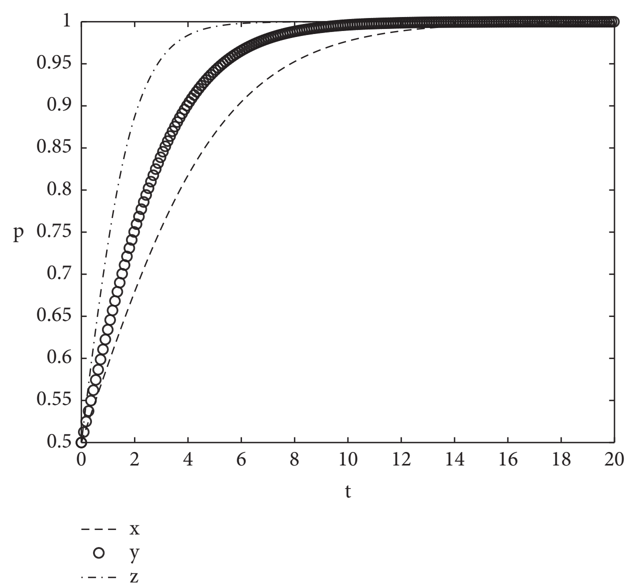

Figure 5: $k_1 = 0.5$ and $k_2 = 0.6$.

Situation 3. We suppose the additional gains of the three parties are different. There are few areas in the real economic environment for market players to carry out collaborative innovation activities because they are not complementary to each other. Therefore, players refusing to engage in collaborative innovation may gain additional gains from those engaging in collaborative innovation. The parameters' setting is as follows: $W_m = 30, W_s = 30, W_d = 30, W_m^+ = 10, W_s^+ = 8, W_d^+ = 6, W_m^{++} = W_s^{++} = W_d^{++} = 6, C_m = C_s = C_d = 8$, and $x = y = z = 0.5$.

Figures 6–9 show the Matlab software simulation results. The strategies of the three players follow different evolving paths due to differences in additional gains. As shown in Figure 6, the strategies selected by the three players are not hugely different in terms of the evolving paths when the coefficient of collaborative innovation gains is small. As a result, enterprises are generally unwilling to engage in collaborative innovation when the benefits of collaborative innovation are not apparent.

In Figure 7, as the coefficient of collaborative innovation gains increases, the effect of collaborative innovation becomes more apparent. However, the player receiving greater additional gains is less willing to engage in collaborative innovation than the party with lower additional gains. Additional gains attenuated enterprises' willingness to benefit from other players' innovative achievements though such additional gains gained without costs reduce the risk that the loss of the player exceeds its gains.

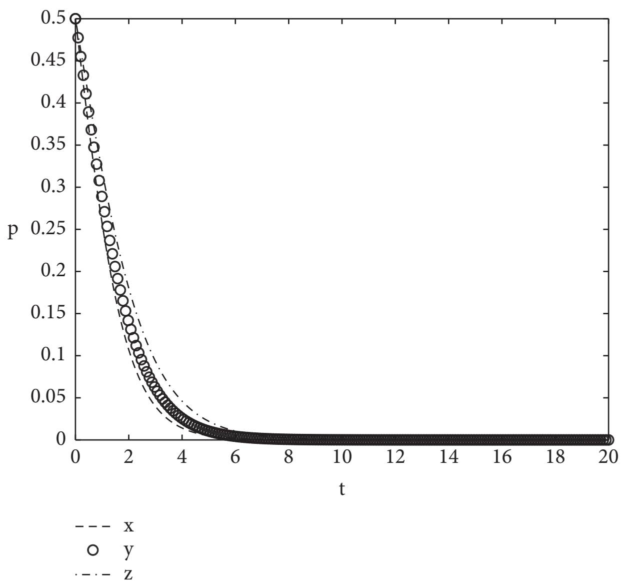

Figure 6: k_1 = 0.3 and k_2 = 0.4.

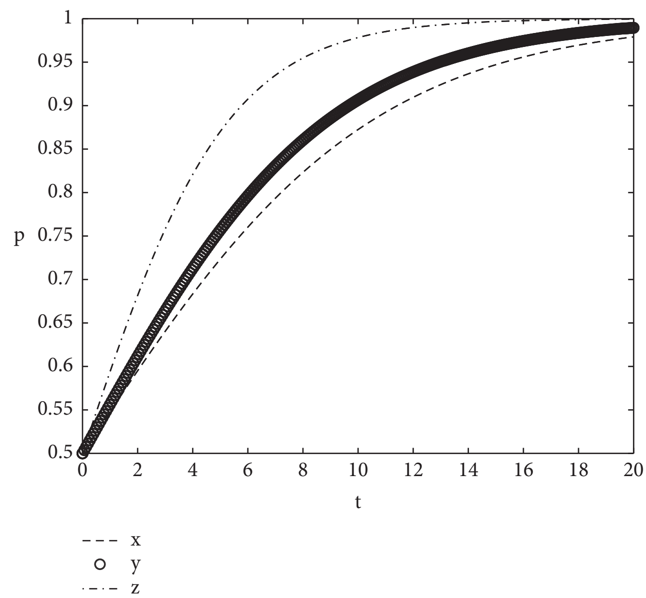

Figure 8: k_1 = 0.6 and k_2 = 0.7.

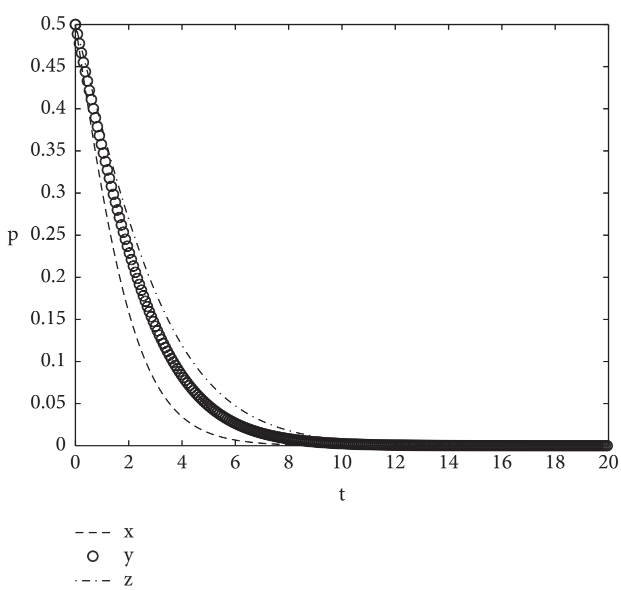

Figure 7: k_1 = 0.5 and k_2 = 0.6.

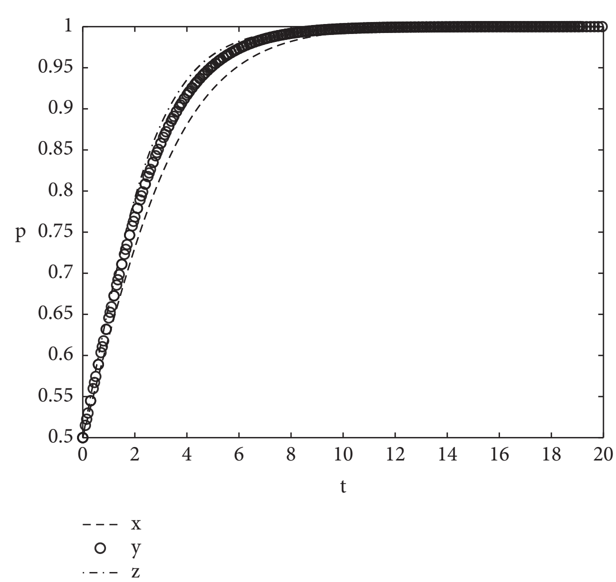

Figure 9: k_1 = 0.7 and k_2 = 0.8.

As shown in Figures 8 and 9, as the coefficient of the collaborative innovation earning grows higher, collaborative innovation shows a noticeable effect. The weakening effect of additional gains on enterprises' willingness to engage in collaborative innovation is waning. When the collaborative innovation earning coefficient increases to a certain level, the evolving paths of the three players converge. In general, the enterprise will choose to engage in collaborative innovation when the effect of collaborative innovation is favorable to self-development.

Situation 4. We suppose that the three players record different additional gains. Players not engaging in collaborative innovation may receive different additional gains from those engaging in collaborative innovation. The parameters' setting is as follows: $W_m = 30, W_s = 30, W_d = 30, W_m^+ = 5, W_s^+ = 5, W_d^+ = 5, W_m^{++} = 10, W_s^{++} = 8, W_d^{++} = 6, C_m = C_s = C_d = 8$, and $x = y = z = 0.5$.

Figures 10–13 show the Matlab software simulation results. The strategies of the three players follow different evolving paths due to different additional gains.

As shown in Figures 10–13, additional gains may attenuate the enterprises' willingness to engage in collaborative innovation, a similar result to Situation 3. By comparing the coefficients of consistent collaborative innovation gains in Situations 3 and 4, double shares of additional gains have a more substantial impact on enterprises' willingness to engage in collaborative innovation than a single share of additional gains. In the real situation, if more enterprises participate in

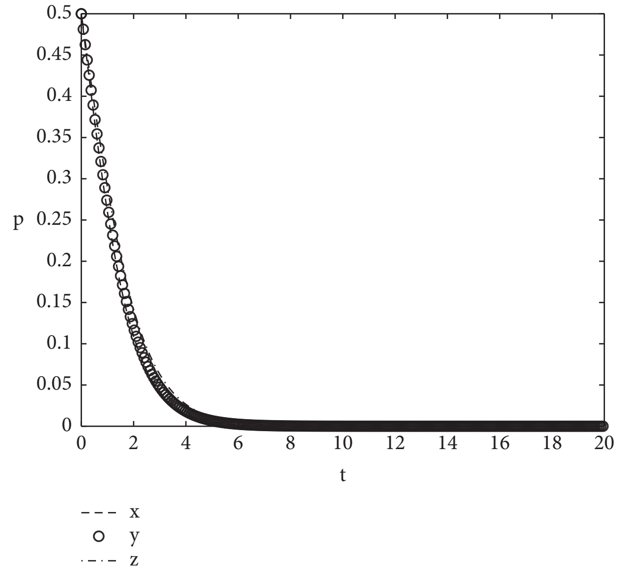

Figure 10: $k_1 = 0.3$ and $k_2 = 0.4$.

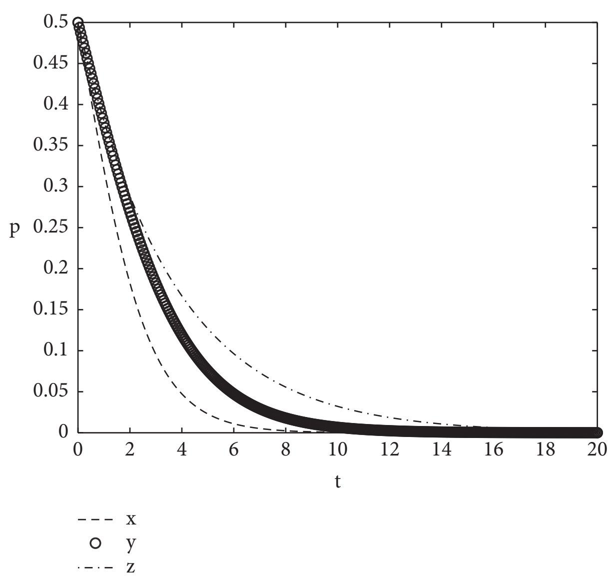

Figure 11: $k_1 = 0.5$ and $k_2 = 0.6$.

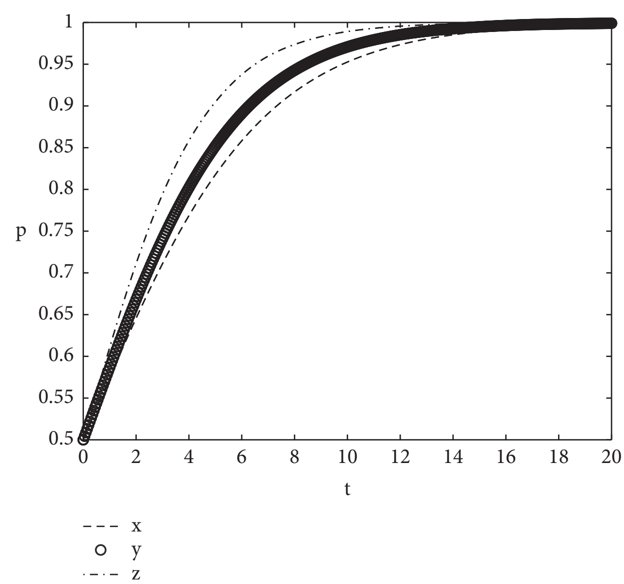

Figure 12: $k_1 = 0.6$ and $k_2 = 0.7$.

collaborative innovation, those who do not engage in collaborative innovation are less willing to do so when they enjoy higher additional gains. China has found it challenging to encourage the conventional manufacturing industry to innovate. Moreover, long-time dependence on innovation achievements owned by foreign companies also undermines Chinese companies' innovation vitality since such dependence on European and American peers has brought in high profits at the cost of losing innovation willpower. The fierce China-US trade frictions create an opportunity for domestic enterprises to pursue innovation and development despite the adverse influences.

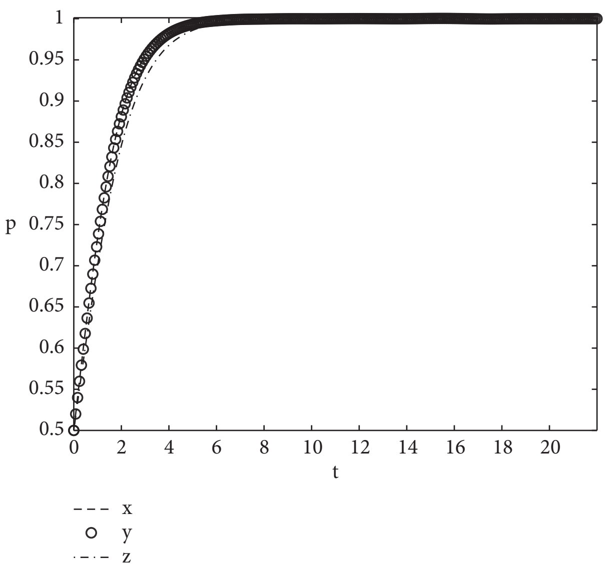

Figure 13: $k_1 = 0.7$ and $k_2 = 0.8$.

5. Conclusion

This paper established a simple supply chain model simulating the innovation behaviors of manufacturer, supplier, and distributor. To simulate the real situation, the model used simplified parameters of collaborative innovation gains to be distributed among the three players. Based the simulation results, this paper discussed the effect of collaborative innovation gains under different economic conditions and analyzed how different economic conditions influence the collaborative innovation strategy based on evolutionary game theory. The research has showed the following. (1) For manufacturer, supplier, and distributor who have the same level of initial willingness, if they have the same independent innovation capability, they are more willing to innovate and more likely to agree on cooperation approach as the coefficient of collaborative innovation gain increases and higher gains are created from collaborative innovation. (2) For manufacturer, supplier, and distributor with different independent innovation capabilities, if the coefficient of collaborative innovation gains is higher, they are more willing to cooperate, but supply chain players with stronger innovation capability are more active than their peers, indicating that stronger innovators are more likely contribute more into innovation and also in a collaborative way. Therefore, governments should cultivate and encourage innovative pioneers in the supply chain of different industries, thus driving the healthy development of the business ecosystem. (3) If all players in the supply chain could enjoy gains generated by any collaborative innovation activities, the three players are more likely to work collaboratively for innovation. As the gains increase, the willingness to cooperate grows stronger. In conclusion, as more gains are shared in the supply chain, market players are more willing to engage in collaborative innovation, accelerating the cooperation between enterprises for innovation.

Overall, the evolutionary game simulation of the collaborative innovation strategy in this paper provides insights for collaborative innovation management in the supply chain. However, these findings are limited by the simplicity of the model, the uncertainties in the actual economy, and the complex and changing government policies. In the future, it will be important to introduce policy guidance into this model of collaborative innovation in the supply chain.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

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

Acknowledgments

This study was supported by the National Social Science Project: Research on the Statistical Measure of Collaborative Innovation and Its Effect Evaluation (project number: 18BTJ015).

References

[1] H. Chesbrough, *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School Press, Boston, 2003.

[2] S. Tamer Cavusgil, R. J. Calantone, and Y. Zhao, "Tacit knowledge transfer and firm innovation capability," *Journal of Business & Industrial Marketing*, vol. 18, no. 1, pp. 6–21, 2003.

[3] G. N. Nyaga, J. M. Whipple, and D. F. Lynch, "Examining supply chain relationships: do buyer and supplier perspectives on collaborative relationships differ?" *Journal of Operations Management*, vol. 28, no. 2, pp. 101–114, 2010.

[4] Y. H. Albert and S. L. Tong, "Contracting and information sharing under supply chain competition," *Management Science*, vol. 54, no. 4, pp. 701–715, 2013.

[5] P. Majumder and A. Srinivasan, "Leadership and competition in network supply chains," *Management Science*, vol. 54, no. 6, pp. iv–1211, 2008.

[6] X. Du and Y. F. Shao, "Game analysis of collaborative innovation between cluster core enterprises and supporting enterprises and adjustment of revenue distribution," *Chinese Journal of Management Science*, vol. 21, no. 11, pp. 745–750, 2013.

[7] A. Trigo and X. Vence, "Scope and patterns of innovation cooperation in Spanish service enterprises," *Research Policy*, vol. 41, no. 3, pp. 602–613, 2012.

[8] M. Skippari, M. Laukkanen, and J. Salo, "Cognitive barriers to collaborative innovation generation in supply chain relationships," *Industrial Marketing Management*, vol. 62, pp. 108–117, 2017.

[9] C. Bai and J. Sarkis, "Supplier development investment strategies: a game theoretic evaluation," *Annals of Operations Research*, vol. 240, no. 2, pp. 583–615, 2016.

[10] G. Friedl and S. M. Wagner, "Supplier development investments in a triadic setting," *IEEE Transactions on Engineering Management*, vol. 63, no. 2, pp. 136–150, 2016.

[11] T. Feng, S. Tai, C. Sun, and Q. Man, "Study on cooperative mechanism of prefabricated producers based on evolutionary

game theory," *Mathematical Problems in Engineering*, vol. 2017, Article ID 1676045, 6 pages, 2017.

[12] M. Zhang, J. Zhu, P. Kumaraswamy, and H. Wang, "Evolutionary game analysis of the effects of problem size and the problem proposing mechanism on the problem processing mechanism in a new main manufacturer-supplier collaborative system," *Mathematics*, vol. 7, no. 7, p. 588, 2019.

[13] S. H. Ma and P. Wang, "The study of profit allocation among partners in supply chain based on the shapley value," *Industrial Engineering and Management*, vol. 3, no. 4, pp. 43–45, 2006.

[14] J. Li, X. Q. Zhu, and X. L. Yao, "The benefit distribution strategy of collaborative innovation of supply chain enterprises is based on shapley's improved model," *Technological Economy*, vol. 35, no. 9, pp. 122–126, 2016.

[15] J. Wu, X. J. Che, and Y. X. Sheng, "Collaborative innovation mechanism of government-industry-university-research Institute based on tripartite Evolutionary Game," *Chinese Journal of Management Science*, vol. 27, no. 1, pp. 162–173, 2019.

[16] L. Y. Ji, Q. F. Meng, and C. H. Zhang, "A study on the evolution of resource input behavior of industry-university-research cooperation considering equity preference," *Business Management*, vol. 14, pp. 177–181, 2018.

[17] I. H. Ansoff, "Strategies for diversification," *Harvard Business Review*, vol. 35, no. 5, pp. 113–124, 1957.

[18] B. Anthony Jnr, "Examining the role of green IT/IS innovation in collaborative enterprise-implications in an emerging economy," *Technology in Society*, vol. 62, Article ID 101301, 2020.

[19] M. M. Huang, "Evolutionary game analysis of cooperation mechanism for collaborative product development in supply chain," *Chinese Journal of Management Science*, vol. 18, no. 6, pp. 155–162, 2010.

[20] Y. Zhou, Y. Zhang, and M. Goh, "Choice of pricing and advertising schemes for a two-sided platform," *Managerial and Decision Economics*, vol. 42, no. 7, pp. 1865–1885, 1865.

[21] M. Y. Wang, L. J. Xiao, and L. Wan, "Research on technology remote collaborative sharing incentive mechanism of strategic emerging industries on the basis of evolutionary game," *Journal of Industrial Engineering and Engineering Management*, vol. 32, no. 3, pp. 206–213, 2018.

[22] S. Yeniyurt, J. W. Henke, and G. Yalcinkaya, "A longitudinal analysis of supplier involvement in buyers' new product development: working relations, inter-dependence, co-innovation, and performance outcomes," *Journal of the Academy of Marketing Science*, vol. 42, no. 3, pp. 291–308, 2014.

[23] M. Y. C. Chew, C. Watanabc, and Y. Tou, "The challenges in Singapore NEWater development: Co-evolutionary development for innovation and industry evolution," *Technology in Society*, vol. 33, no. 3, pp. 200–211, 2011.

[24] Y. Zhou, Y. Zhang, and M. I. M. Wahab, "Optimal pricing and choice of platform advertising schemes considering across-side network effect," *Managerial and Decision Economics*, no. 8, 2021.

[25] K. Yongjae, "The effect of process management on different types of innovations: an analytical modeling approach," *European Journal of Operational Research*, vol. 262, no. 2, pp. 771–779, 2016.

[26] Q. D. John and N. Jork, "Information technology and external search in the open innovation age :new findings from Germany," *Technological Forecasting and Social Change*, vol. 120, no. 7, pp. 223–231, 2017.

[27] M. S. Graca, S. Chris, and F. L. Luis, "Break through innovation in international business: the impact of tech-innovation and market-innovation on performance," *International Business Review*, vol. 26, no. 2, pp. 391–404, 2017.