Research on Optimization of Industry-University-Research Cooperation Based on Enterprise Incentive

Lu Chen¹, Jie Wu¹, Yongxiang Sheng¹, Jun Hu¹, Qinfen Shi²

¹School of Economic and Management, Jiangsu University of Science and Technology, Zhenjiang 212003, P.R. China
²Suzhou University of Science and Technology, Suzhou 215000, P.R. China

*Corresponding Author: Jie Wu, School of Economic and Management, Jiangsu University of Science and Technology, Zhenjiang 212003, P.R. China; Email: 0511wujie@163.com

Abstract: Enterprise incentive is an important means to stimulate the enthusiasm of university research and development and promote the innovation and development of enterprise. The paper constructs different game models of industry-university-research cooperation and innovation, and analyzes the stability of the models. The paper also analyzes the cooperation process between enterprise and university and the optimal incentive coefficient of enterprise through the example and numerical simulation of industry-university-research cooperation, and studies the optimization effect of enterprise incentive on industry-university-research cooperation. The conclusion is as follows: enterprise incentive has positive influence on industry-university-research cooperation and innovation, and can improve the efficiency of industry-university-research cooperation and innovation. The size of enterprise incentive has an “inverted u-shaped” influence on the innovation of industry-university-research cooperation, and there is a threshold value.

1. Introduction

Innovation-driven development strategy is the fundamental way to promote in-depth integration of industry-university-research cooperation innovation with enterprise as the main body. Industry-university-research cooperation innovation is an important means to open up the innovation chain of enterprise and promote innovation development. The incentive of enterprise has practical significance to optimize the efficiency of industry-university-research cooperation innovation and break down the barriers of industry-university-research cooperation.

At present, many scholars have conducted research on industry-university-research institute cooperative innovation, and most scholars believe that cooperative innovation plays an important role in the development of enterprise. Baykara et al. [¹] found that the complexity of industrial generic technology system research and development makes enterprise have to seek cooperation from university. Bočková et al. [²] think industry-university-institute cooperation such as research and development to improve the level of innovative enterprise performance. In the existing research, it can be found that scholars pay more attention to the influence of industry-university-research cooperation policy, cooperation mechanism, network characteristics and other factors on industry-university-research cooperation innovation. Lin et al. [³] studied the impact of industry-university-research cooperation policies on school-enterprise technical cooperation.
Wang et al. [4] studied the stage evolution characteristics and network attributes of patent industry-university-research cooperation. Previous studies have provided useful references for this paper to study the optimization of industry-university-research cooperation innovation. This article, on the basis of related research, introducing enterprise incentive innovation model of "industry-university-institute" cooperation, builds the enterprise incentive factors of the presence or absence of two kinds of production-study-research cooperation innovation game model, and calculates the stability of the equilibrium results under two kinds of model, through the numerical analysis to compare two kinds of model of production-study-research cooperative innovation efficiency. The threshold value and optimal value of enterprise incentive coefficient are analyzed emphatically.

2. Model Hypothesis
This paper studies the optimization of enterprise incentive on industry-university-research institute cooperative innovation, and makes the following assumptions:

(1) Game Players. There are two kinds of game players in industry-university-research cooperation innovation studied in this paper, which are university and enterprise respectively. If enterprise wants to obtain technological innovation, they need to seek cooperation from university and gather talents, technologies and other resources from university. University can obtain financial support from enterprise through industry-university-research cooperation.

(2) Behavior Selection. In the game of industry-university-research cooperation innovation, enterprise can choose to carry out industry-university-research cooperation innovation according to their needs, or choose not to carry out industry-university-research cooperation innovation. The strategic choice of university is also \{cooperation, noncooperation\}.

(3) Cooperation Benefits. \(\Pi_i\) represents the revenue generated by independent research and development of each subject, \(\Pi_1\) represents the revenue from independent research and development, \(\Pi_2\) represents the revenue from independent research and development. When enterprise and university choose cooperation at the same time, cooperative innovation benefits \(\Pi\) will be generated. Enterprise can obtain the benefits of cooperative innovation \(\theta_1\Pi\), university can obtain the benefits of cooperative innovation \(\theta_2\Pi\), thus, the cooperation income of the enterprise is \((\Pi_1 + \theta_1\Pi)\), and the cooperation income of the university is \((\Pi_2 + \theta_2\Pi)\).

(4) Cooperation Costs. When enterprise chooses cooperation with university, they need to pay certain costs, including human, material, financial and other costs. The cooperation cost incurred by each subject is \(C_i(i = 1,2)\), the cooperation costs of enterprise and university are respectively \(C_1, C_2\) (\(C_1 > C_2\)).

(5) Punishment. When enterprise choose cooperation and university choose noncooperation, enterprise will punish university \(S_1\). When university choose cooperation and enterprise choose noncooperation, university will punish enterprise \(S_2\).

(6) Willingness to Cooperate. In the game model, enterprise and university choose strategies according to their own cooperation willingness, and enterprise' cooperation willingness is \(x\), Unwillingness to cooperate is \(1-x\). University ' cooperation willingness is \(y\), Unwillingness to cooperate is \(1-y\), and \(x,y \in [0,1]\).

3. Evolutionary Game Model
3.1 Cooperative Game Model between Enterprise and University
According to the model hypothesis, the payment matrix of cooperative game between enterprise and university in industry-university-research cooperation innovation is obtained as shown in table 1.
Table 1 Cooperative game payment matrix between enterprise and university

| University | cooperation (y) | noncooperation (1-y) |
|------------|----------------|----------------------|
| cooperation (x) | \(\Pi_1 + \theta_1\Pi - C_1\) | \(\Pi_1 - C_1 + S_2\) |
| \(\Pi_2 + \theta_2\Pi - C_2\) | \(\Pi_2 - S_2\) |
| noncooperation (1-x) | \(\Pi_1 - S_1\) | \(\Pi_1\) |
| \(\Pi_2 - C_2 + S_1\) | \(\Pi_1\) |

According to the payment matrix, the evolutionary stability strategies of enterprise and university are solved.

When enterprise chooses cooperation, the expected revenue is:

\[ E_{11} = y(\Pi_1 + \theta_1\Pi - C_1) + (1-y)(\Pi_1 - C_1 + S_2) = y\theta_1\Pi + \Pi_1 - C_1 + (1-y)S_2. \]

When enterprise chooses noncooperation, the expected revenue is:

\[ E_{12} = y(\Pi_1 - S_1) + (1-y)\Pi_1 = \Pi_1 - yS_1. \]

Average earnings of enterprise:

\[ \bar{E}_i = xE_{11} + (1-x)E_{12} = x(y\theta_1\Pi - C_1 + yS_1 + (1-y)S_2) + \Pi_1 - yS_1. \]

Construct the replication dynamic equation of industry-university-research cooperation:

\[ F(x) = \frac{dx}{dt} = x(E_{11} - \bar{E}_i) \]

Similarly, the replication dynamic equation of industry-university-research cooperation in university can be constructed as follows:

\[ F(y) = \frac{dy}{dt} = y(E_{12} - \bar{E}_i) = y(1-y)(x\theta_2\Pi - C_2 + (1-x)S_1 + xS_2) \]

Thus, the evolution of cooperation between enterprise and university can be described by a system composed of two differential equations. According to \( F(x) = 0 \) and \( F(y) = 0 \), five local equilibrium points can be obtained, which are respectively: \( E_1(0,0), E_2(1,0), E_3(0,1), E_4(1,1), E_5 \frac{C_1 - S_2}{\theta_1\Pi - S_1 + S_2} = \frac{C_1 - S_2}{\theta_1\Pi + S_1 - S_2}. \)

The partial derivatives with respect to \( x, y \) of the differential equations \( F(x) \) and \( F(y) \) are calculated successively to get:

\[ J = \begin{pmatrix}
(1-2x)(y\theta_1\Pi - C_1 + yS_1 + (1-y)S_2) & x(1-x)(\theta_1\Pi + S_1 - S_2) \\
(1-y)(x\theta_2\Pi - C_2 + (1-x)S_1 + xS_2) & (2-2y)(x\theta_2\Pi - C_2 + (1-x)S_1 + xS_2)
\end{pmatrix} \]

When an equilibrium point makes the determinant of the Jacobian matrix \( \det(J) > 0 \) and the trace of the Jacobian matrix \( \text{tr}(J) < 0 \), it can be judged that the equilibrium point is in a locally asymptotically stable state, which is the evolutionary stability strategy. The results are shown in Table 2.

Table 2 results of cooperative local stability analysis

| Equation | det(J) (symbol) | tr(J) (symbol) | Result |
|----------|----------------|---------------|--------|
| \(E_1(0,0)\) | \((S_2 - C_1)(S_1 - C_2)\) | \(S_2 - C_1 + S_1 - C_2\) | (+) \(\Pi_1\) | (-) \(\Pi_1\) | ESS |
| \(E_2(1,0)\) | \((C_1 - S_2)(\theta_1\Pi - C_1 + S_2)\) | \(\theta_1\Pi + C_1 - C_2\) | (+) \(\Pi_1\) | (-) \(\Pi_1\) | instability |
| \(E_3(0,1)\) | \((\theta_1\Pi - C_1 + S_1)(C_2 - S_2)\) | \(\theta_1\Pi - C_1 + C_2\) | (+) \(\Pi_1\) | (-) \(\Pi_1\) | instability |
| \(E_4(1,1)\) | \((\theta_1\Pi - C_1 + S_1)(\theta_2\Pi - C_2 + S_2)\) | \(\theta_1\Pi - C_1 + S_1 + \theta_2\Pi_1 - C_2 + S_2\) | (+) \(\Pi_1\) | (-) \(\Pi_1\) | ESS |
The judging conditions of equilibrium points in table 2 are $S_i < C_i$ and $\theta_i \Pi > C_i$. Table 2 shows that the local equilibrium points of cooperation $E_i(0,0)$ and $E_4(1,1)$ are locally asymptotically stable point (ESS). In addition, there are two stable equilibrium points and a saddle point in the cooperative game system.

3.2 Cooperative Game Model between Enterprise and University under Enterprise Incentives

In industry-university-research cooperation and innovation cooperation, colleges and university have less income and less willingness to cooperate, so it takes a long time for enterprise to reach cooperation with colleges and university. In order to encourage colleges and university to participate in industry-university-research cooperation, enterprise take part of their cooperative earnings to encourage colleges and university, and the incentive ratio is $\delta (\delta \in [0,1])$. The payment matrix of cooperation between enterprise and university under enterprise incentives is shown in table 3.

### Table 3 Payment matrix of cooperative game between enterprise and university under incentive of enterprise

| University | cooperation (1) | noncooperation (0) |
|------------|----------------|--------------------|
| cooperation (x) | $(\Pi_1 + \theta_i \Pi - C_i) + (1 - \delta)(\Pi_1 - C_i + S_i)$ | $\Pi_1 - C_i + S_i$ |
| noncooperation (1) | $\Pi_1 - S_i$ | $\Pi_1 - S_i$ |

According to table 3, the evolutionary stability strategies of enterprise and university are solved. When enterprise choose cooperation, the expected revenue is: $E_{11}' = y((1 - \delta)(\Pi_1 + \theta_i \Pi - C_i)) + (1 - y)(\Pi_1 - C_i + S_i) = (1 - \delta)y\theta_i \Pi + (1 - y\delta)(\Pi_1 - C_i) + (1 - y)S_i$. When enterprise choose noncooperation, the expected revenue is: $E_{12}' = y(\Pi_1 - S_i) + (1 - y)\Pi_1 = \Pi_1 - yS_i$. Average earnings of enterprise is: $\bar{E}_i = xE_{11}' + (1 - x)E_{12}' = (1 - \delta)x\theta_i \Pi - xy\delta\Pi_i + xy\delta C_i - xC_i + x(1 - y)S_i - (1 - x)yS_i + \Pi_1$. Construct the replication dynamic equation of enterprise industry-university-research cooperation:

$$F(x)' = \frac{dx}{dt} = x(E_{11}' - \bar{E}_i') = x((1 - \delta)y\theta_i \Pi - y\delta\Pi_1 + y\delta C_i - C_i + (1 - y)S_i + yS_i).$$

Similarly, the replication dynamic equation of production-university-research cooperation in university can be constructed as follows:

$$F(y)' = \frac{dy}{dt} = y(E_{21}' - \bar{E}_i') = y((1 - \delta)x\theta_i \Pi + x\delta\Pi_1 + x\delta C_i - C_i - (1 - x)S_i + xS_i).$$

According to $F(x)' = 0$ and $F(y)' = 0$, five local equilibrium points can be obtained, which are respectively: $E_1'(0,0)$, $E_2'(1,0)$, $E_3'(0,1)$, $E_4'(1,1)$, $E_5'(\theta_i \Pi + \delta\Pi_1 - \delta C_i - S_i + S_2, (1 - \delta)\theta_i \Pi - \delta\Pi_1 + \delta C_i + S_i - S_2)$. The partial derivatives with respect to $x, y$ of the differential equations $F(x)'$ and $F(y)'$ are calculated successively to get:
By judging the determinant \( \det(J') > 0 \) and trace \( tr(J') < 0 \) of the Jacobian matrix, the evolutionary stability strategy can be obtained, as shown in table 4.

### Table 4 Analysis results of local stability of cooperation under enterprise incentives

| Equation | \( \det(J') \) (symbol) | \( tr(J') \) (symbol) | Result |
|----------|--------------------------|------------------------|-------|
| \( E_1' \) \((0,0)\) | \((S_2 - C_1)(S_1 - C_2)\) | \(-\) | ESS |
| \( E_2' \) \((1,0)\) | \((C_1 - S_2)(\delta \theta_1 \Pi + \delta \Pi_1 - \delta C_1 - C_2 + S_2)\) | \(+\) | instability |
| \( E_3' \) \((0,1)\) | \((-\delta \theta_1 \Pi - \delta \Pi_1 + \delta C_1 - C_2 + S_1)(C_2 - S_2)\) | \(+\) | instability |
| \( E_4' \) \((1,1)\) | \((\delta \theta_1 \Pi + \delta \Pi_1 - \delta C_1 - C_2 + S_2)\) | \(-\) | ESS |
| \( E_s' \) | \(\theta_1 \Pi + \delta \theta_1 \Pi + \delta \Pi_1 - \delta C_1 - S_1 + S_2, \theta_1 \Pi - \delta \theta_1 \Pi - \delta \Pi_1 + \delta C_1 + S_1 - S_2\) | \(\) | |

The judging conditions of equilibrium points in table 4 are \( S_i < C_i \) and \( \theta_1 \Pi > C_i \). As can be seen from table 4, the local equilibrium points \( E_1'(0,0) \) and \( E_4'(1,1) \) under the incentive of enterprise are local progressive stability points (ESS), which correspond to the cooperative strategies adopted by enterprise and university and the non-cooperative strategies adopted by them respectively.

### 3.3 Evolutionary Phase Diagram

![Fig.1 Cooperation evolution between enterprise and university](image)

There are two locally asymptotically stable points (ESS) in both cooperative game models, namely (cooperation, cooperation) and (noncooperation, noncooperation), but the saddle points of the two systems are different. It can be seen from figure 1 that equilibrium point \( E_s' \) and polyline \( E_s'E_s'E_s' \) are critical points and borderlines of different states of cooperative evolutionary game respectively, while equilibrium point \( E_s \) and polyline \( E_s'E_s'E_s' \) are critical points and borderlines of different states of cooperative evolutionary game under enterprise incentive respectively. The size of critical point determines the movement direction of the critical point. The larger the value of critical point \( E_s \),
and \( E_E \) is, the more the critical point \( E_E'E_E \) and \( E_E'E_E' \) move upward to the right, and the larger the area of region \( E_E'E_E'E_E \) and \( E_E'E_E'E_E' \) is, indicating the lower the probability of enterprise and university choosing "cooperation" strategy.

4. Numerical Analysis

In this paper, the case of industry-university-research cooperation innovation between CSCL and Jiangsu University of Science and Technology is selected for numerical analysis. According to the cooperation agreement, the two sides will intensify cooperation in collaborative innovation, capital operation and other aspects, further enhance scientific research cooperation and technical exchanges at all levels between CSSD and just, and jointly conduct scientific research projects and report results by affiliated enterprise, research institutes and university.

This paper does not discuss the role of punishment, assuming that the punishment of enterprise not participating in cooperation with university is equal to that of university not participating in cooperation with enterprise \( S_1 = S_2 \). According to the cooperation between CSSC and just, the numerical analysis values of each parameter are obtained, as shown in Table 5.

| parameter | \( \theta_1 \) | \( \theta_2 \) | \( S_1 \) | \( S_2 \) | \( C_1 \) | \( C_2 \) |
|-----------|----------------|----------------|---------|---------|---------|---------|
| implication | Income distribution | coefficient of cooperative innovation | punishment | Cost of cooperation |
| numerical value | 0.8 | 0.2 | 60 | 60 | 120 | 70 |

| parameter | \( \Pi \) | \( \Pi_1 \) | \( \delta \) | \( x \) | \( y \) |
|-----------|---------|---------|---------|---------|
| implication | Benefits of cooperative innovation | Enterprise independent research and development income | Enterprise incentive coefficient | Initial willingness to cooperate |
| numerical value | 300 | 80 | 0.2 | 0.5 | 0.3 |

4.1 Comparison of Evolution Results of the Two Systems

Figure 2 is a comparison of the evolution results of the two systems. As can be seen from figure 2, in the system without enterprise incentive, enterprise and university reach cooperation at point \( A \). However, in the system of enterprise incentive, the cooperation time between enterprise and university reached at point \( A' \) is shorter. This is because although encouraging colleges and university will cause enterprise to lose some profits, and enterprise' willingness to cooperate will be slightly reduced at the beginning, appropriate incentives of enterprise will promote the growth of cooperation willingness of colleges and university, and the growth rate of cooperation willingness of colleges and university is faster than the decline rate of cooperation willingness of enterprise. Therefore, in the system of enterprise incentive, the time for enterprise and university to reach
industry-university-research cooperation is shorter. From the perspective of long-term development of industry-university-research cooperation, faster cooperation in industry-university-research cooperation and innovation can generate more benefits. In order to achieve its own long-term development, CSTC should give certain incentives to just to promote faster cooperation between industrial parties and university-research parties.

4.2 Influence of Enterprise Incentive Coefficient $\delta$ on Evolution Results

Figure 3 (a) and figure 3 (b) show the influence of the change of enterprise incentive coefficient $\delta$ on the cooperation results between enterprise and university. According to Fig. 3 (a), when the incentive coefficient $\delta$ of the enterprise is 0.1, the enterprise and the university reach cooperation at point $B$. When $\delta$ is 0.2, the enterprise and the university reach cooperation at point $B'$. When $\delta$ is 0.3, enterprise and university reach cooperation in point $B''$. That is, when $\delta$ is 0.2, the cooperation time between enterprise and university is the shortest. When $\delta$ is less than 0.2, enterprise has a higher willingness to cooperate, but university are less motivated and less willing to cooperate. However, when $\delta$ is greater than 0.2, although colleges and university are greatly stimulated and their willingness to cooperate increases, their willingness to cooperate decreases as enterprise pay more incentives, and the time for the system to finally reach cooperation becomes longer. According to figure 3 (b), when the incentive coefficient $\delta$ of the enterprise is 0.5, the enterprise and the university reach cooperation at the point $C$. When the incentive coefficient $\delta$ of the enterprise is 0.55, the enterprise and the university reach cooperation at the point $C'$. When the incentive coefficient $\delta$ of the enterprise is 0.6 and 0.65, the enterprise and university converge to 0, and the final equilibrium point tends to (0,0). When the value is less than the threshold, the enterprise and the university converge to $\delta$, and the final equilibrium point tends to (1,1). At this time, the decrease of $\delta$ makes the system tend to cooperate faster.

It indicates that the incentive coefficient of the enterprise has an "inverted u-shape" effect on the cooperation effect. When the incentive coefficient of the enterprise is 0.2, the cooperation effect is the best. The incentive coefficient of an enterprise has a threshold value, and when the incentive coefficient of an enterprise is greater than the threshold value, the system tends to be uncooperative. In the process of industry-university-research cooperation innovation, CSCC power needs to motivate just at a reasonable proportion to accelerate the industry-university-research cooperation.

5. Conclusion

This paper studies the influence of enterprise incentive factors on industry-university-research cooperation innovation, constructs two game models of industry-university-research cooperation
innovation based on the existence of enterprise incentive factors, and obtains the stable equilibrium solution of each model. By studying the example of the Industry-University-Research cooperation between CSCC and Jiangsu University of Science and Technology, the following conclusions are as follows:

1. Enterprise incentive has a positive impact on industry-university-research cooperation innovation and can improve the efficiency of industry-university-research cooperation innovation. In the cooperative innovation between enterprise, university and colleges, enterprise give certain incentives, improve the enthusiasm of innovation and research, and speed up the cooperation process between enterprise and colleges.

2. The size of enterprise incentive has an "inverted U-shaped" influence on industry-university-research cooperation innovation, and there is a threshold value. When the enterprise incentive is small, the university research and development innovation enthusiasm is not strong, and the enterprise incentive doesn’t reach the expected effect, so the gain outweighs the loss; when the enterprise incentive is large, although the innovation and research enthusiasm of colleges and university is high, the enterprise will choose not to cooperate due to the decrease of its own income due to the high incentive.

Acknowledgements
The research presented in this paper was supported by the National Natural Science Foundation of China No. 71471091; the National Natural Science Foundation of China No. 71771161; Graduate Research Innovation Program of Jiangsu Province No. KYCX18_2298.

References
[1] Baykara T, Özbek S, Ceranoğlu A N. A generic transformation of advanced materials technologies: Towards more integrated multi-materials systems via customized R&D and Innovation[J]. Journal of High Technology Management Research, 2015, 26(1):77-87.
[2] Bočková N, Meluzín T. Electronics Industry: R&D Investments as Possible Factors of Firms Competitiveness[J]. Procedia - Social and Behavioral Sciences, 2016, 220:51-61.
[3] Lin Qingfan, Dai Yongwu. Research on the impact of industry-university-research cooperation policies on school-enterprise technical cooperation performance [J]. China higher education research, 2017(12):71-76.
[4] Feng Haiyan. Innovation of cooperation mechanism between university and enterprise [J]. China higher education research, 2014(8):74-78.