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Optimal design of the organizational form of industry-education integration for university-enterprise collaborative innovation in the era of artificial intelligence and its equilibrium computational analysis based on game theory

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Abstract In the era of artificial intelligence, more and more enterprises cooperate with universities to form a collaborative innovation alliance for the integration of industry and education. In this paper, using the evolutionary game theory, we establish the payment matrix of the collaborative innovation game led by the government, led by universities, and participated by enterprises, and carry out the analysis of replicated dynamic equations and stability of equilibrium points to construct the evolutionary game model of the integration of industry and education with the participation of multiple subjects. Through numerical example analysis, the role of different factors on the evolutionary equilibrium and the behavioral strategies of each game subject is explored. The results show that the evolution of industry-industry integration increases with the increase of the willingness of enterprises and universities to participate, and when the willingness to participate is greater than 0.5, the evolution of industry-industry integration tends to be 1. In addition, the enthusiasm of the university and enterprises to participate in the co-construction increases with the increase of the cooperation benefits created by the input resources, and the scientific and reasonable distribution coefficients of the cooperation benefits can help to increase the willingness to cooperate of the main subjects. In the R&D stage and the production and commercialization stage, when the penalty is greater than 6.25~6.5 and 4~6 respectively, it is easy to lead to the deep integration of the university and enterprise sides. In order to ensure the construction of the integration of industry and education, it is recommended to establish a complete information channel, design a good incentive-punishment mechanism, as well as improve the policies and regulations of the integration of industry and education, so as to promote the optimization and development of the organizational form of the integration of industry and education.

Index Terms evolutionary game theory, replication dynamic equation, industry-education integration, collaborative innovation

I. Introduction

With the rapid development of China's economy, the continuous upgrading of industrial structure, the demand for high-quality, application-oriented specialists is also increasing, local universities in this context shoulder the important mission of training application-oriented talents, however, there is a certain disconnect between the traditional education model and the industrial development needs, how to effectively integrate the teaching resources of colleges and universities with the industrial needs, has become one of the current urgent issues [1]-[4]. In such a background, the construction of the ecosystem of industry-teaching integration in local universities has become a new research hotspot.

The integration of industry and education refers to the establishment of a close cooperative relationship between enterprises and colleges and universities to realize the effective integration of teaching resources and industrial demand through win-win cooperation [5], [6]. The integration of industry and education has important significance and value, which is conducive to optimizing the talent cultivation mode, improving the level of scientific research, and promoting the development of local economy [7], [8]. However, at present, the integration of industry and education has shortcomings such as the disconnection between talent cultivation and market demand, and the unsound cooperation mechanism between universities and enterprises, etc. The cooperation mode between universities and enterprises still stays in the traditional stage of school-enterprise cooperation and scientific research cooperation, and the depth and breadth of the cooperation are yet to be improved; moreover, the internal management mechanism of the universities is not perfect, and the internal management of some universities still stays in the traditional academic mode, and lacks the relevant mechanism and policy support for the cooperation with the enterprises. The relevant mechanism and policy support for cooperation [9]-[12]. And in the process of industry-education integration, game and integration is an important theoretical framework. According to game theory, there exists an interest game relationship between colleges and universities and enterprises in the process of industry-education integration [13], [14]. Colleges and universities pursue talent cultivation and scientific research level improvement, while enterprises pursue technological innovation and market competitiveness improvement, in this case, colleges and universities and enterprises need to play a certain game to balance the interests of both sides [15]-[17].

In this paper, we use the evolutionary game theory method to construct a three-party evolutionary game model of industry-teaching integration collaborative innovation involving the government, enterprises and universities, put forward the relevant research assumptions of the three-party subjects, construct the payment matrix under the government's participation and the government's non-participation, and carry out the evolutionary stabilization strategy solution through the expectation function of the benefit, the replication dynamic equation and the stability analysis of the equilibrium point, and systematically discuss the evolutionary strategy solution of the government, enterprises and The decision-making evolution process of universities for collaborative innovation is systematically discussed. On this basis, combined with numerical analysis, the impacts of the initial willingness of universities and enterprises, government incentive subsidies, cooperative income, distribution coefficients based on different income distribution mechanisms and the punishment strength of defaults on the strategic choices of innovation subjects are investigated. By analyzing the evolutionary stabilization strategies of the participants in different contexts, the factors affecting the strategy choice of the participants are identified.

II. Equilibrium calculation analysis of industry-education integration based on game theory

Collaborative innovation between universities and enterprises refers to the full release of the vitality of integrating each other's technology, talents, capital, information and other major innovation elements among innovation subjects such as universities, research institutions and enterprises, so as to effectively integrate and fuse innovation elements and resources, break down barriers between innovation subjects, realize the smooth construction of innovation platforms, and enhance the in-depth cooperation among various subjects of collaborative innovation. In the process of collaborative innovation among the subjects of industry-education integration, how to ensure that the behavior of the participating parties is coordinated and coherent is related to the success or failure of industry-university-research collaborative innovation cooperation. Therefore, a tripartite evolutionary game model of the willingness of the government, universities and enterprises to participate is constructed to analyze the collaborative innovation mechanism of industry-education integration guided by the government, led by universities and participated by enterprises.

II. A. Establishment of the game model payment matrix

II. A. 1) Basic assumptions of the model

Industry-education integration is the main manifestation of collaborative innovation, but in addition to enterprises and universities, which are the direct participants in collaborative innovation, the government also plays an important role in collaborative innovation. The government, as the party that implements supervision and provides incentives, also receives the tax benefits of the sales revenue paid by the enterprises to develop new products, which can be quantified in the country's tax bureau. During the initial period of collaborative innovation, universities and enterprises clarify their respective rights and obligations in the form of a contract and pay a certain amount of deposit in advance as a guarantee for the execution of the contract. In the real industry-university-research collaborative innovation, the government will regularly assess the operational performance of the collaborative innovation center and the completion of the tasks of each participating subject as the basis for subsequent funding. Based on this, the following assumptions are given:

(1) Participating subjects. In the process of government, industry, academia and research collaborative innovation game, there are three types of participating subjects, namely, the government (G), colleges and universities (S) and enterprises (E). The government is mainly responsible for promoting the collaborative innovation cooperation between enterprises and colleges and universities by providing different incentives to enterprises and colleges and universities, as well as supervising the industry-academia-research collaborative innovation, etc. The government is mainly responsible for providing the resources for collaborative innovation and monitoring the collaborative innovation. Enterprises are mainly responsible for providing co-innovation resources and the transformation of co-innovation results. Universities are mainly responsible for the output of co-innovation knowledge, technology and talents. Moreover, all three parties are finite rational in the game process, and find the optimal strategy through multiple games.

(2) Cooperation strategy. In the game process of collaborative innovation of industry-education integration, the government can choose to provide enterprises and universities with preferential policies for collaborative innovation and supervise the process of collaborative innovation of enterprises and universities, or it can choose not to provide preferential policies and not to supervise the process of collaborative innovation of enterprises and universities, and the set of strategies is (participation, non-participation). Universities and enterprises can choose to engage in co-innovation according to their own needs, or they can choose not to engage in co-innovation, and their choice of strategy set is (synergy, no synergy).

(3) Collaboration cost. Although the government will not be directly involved in the process of collaborative innovation, it will formulate preferential policies for the collaborative innovation of enterprises and colleges and universities and supervise the collaborative innovation process of enterprises and colleges and universities, which generates a total cost of G_1, enterprises and colleges and universities, as the main participant in the collaborative innovation process, are bound to put in a certain amount of manpower, material and financial resources, which generates a total cost of C, and the total cost is C, and the total cost is C, which is reduced by S, when the government chooses to participate in collaborative innovation. When the government chooses to participate in collaborative innovation, the preferential policies provided by the government will make enterprises and universities in the process of collaborative innovation invested in the total cost of C reduced, the reduction of the cost of the amount of S, at this time, the total cost of enterprises and universities to pay for the total cost of $C-S$. Remember that the cost-sharing ratio coefficient of enterprises and universities is t, then the cost paid by enterprises is tC or $t(C-S)$, and the cost paid by universities is $(1-t)C$ or $(1-t)(C-S)$.

(4) Cooperation benefits. Use R_1 to denote the gains obtained when the government chooses the “participation” strategy, and b to denote the gains obtained when the government chooses the “non-participation” strategy as a percentage of the gains obtained when the government chooses the “participation” strategy, and b to denote the gains obtained when the government chooses the “non-participation” strategy as a percentage of the gains obtained by the government. The government's gain from choosing the “non-participation” strategy is bR_1, with b ranging from 0-1. With R_2 and R_3 denote the initial benefit before the enterprise and the university to carry out collaborative innovation, when the enterprise and the university both choose collaborative innovation, the collaborative innovation will bring additional benefit R for the enterprise and the university, and the ratio coefficient of the sharing of this part of the benefit is a, i.e., the enterprise obtains the benefit of the collaborative innovation is aR, and the university obtains the benefit of the collaborative innovation is $(1-a)R$. When the university chooses co-innovation and the enterprise chooses individual R&D, the benefit obtained by the enterprise's individual R&D is L_1, and when the enterprise chooses co-innovation and the university chooses individual R&D, the benefit obtained by the university's individual R&D is L_2. In addition, the government will give financial support G_2 to universities that actively participate in collaborative innovation.

(5) Penalty. Under the supervision of the government, in order to avoid the default of enterprises and universities participating in collaborative innovation, when the enterprise chooses to carry out collaborative innovation and the university chooses not to carry out collaborative innovation, the university needs to pay a certain amount of penalties to the enterprise, which is recorded as W. When the university chooses to carry out co-innovation and the enterprise chooses not to carry out co-innovation, i.e., when the enterprise defaults on the contract, the enterprise needs to pay a certain penalty to the university, which is recorded as K.

II. A. 2) Payment matrix construction

In the model, the government, enterprises and colleges and universities make strategic choices based on their own willingness, assuming that the government's willingness to choose to participate in collaborative innovation, i.e., the probability of participating in collaborative innovation is x, then the government's willingness to choose not to participate in collaborative innovation is $1-x$. The willingness of enterprises to choose to engage in collaborative innovation is then the willingness of enterprises to choose not to engage in collaborative innovation is $1-y$. The willingness of universities to choose to carry out collaborative innovation is z, then the willingness of universities to choose not to carry out collaborative innovation is $1-z$. $x,y,z\in[0,1]$. And according to the above 5-point assumptions, the payment matrix of the collaborative innovation game of industry-education integration is obtained as shown in Table 1 and Table 2. In the table, the participation constraints of enterprises are reflected in the default payment K when defaulting, and the incentive constraints are reflected in the benefit distribution coefficient $1-a$ of the benefits gained from participating in collaborative innovation. The participation constraint of universities is reflected in the liquidated damages W paid in case of default, and the incentive constraint is reflected in the benefit distribution coefficient a of the benefits obtained from participating in collaborative innovation.

Table 1: The game payment matrix of the cooperative innovation(Government participation)

		University	
		Synergistic(y)	Not synergistic(1-y)
Enterprise	Synergistic (y)	$R_1 - G_1 - G_2$, $R_2 + aR - t(C - S)$, $R_3 + (1-a)R - (1-t)(C - S) + G_2$	$R_1 - G_1$, $R_2 - t(C - S) + W$, $R_3 - W + L_2$
	Not synergistic (1-y)	$R_1 - G_1 - G_2$, $R_2 + L_1 - K$, $R_3 - (1-t)(C - S) + K + G_2$	$R_1 - G_1$, R_2 , R_3

Table 2: The game payment matrix of the cooperative innovation(No government participation)

		University	
		Synergistic(y)	Not synergistic(1-y)
Enterprise	Synergistic (y)	bR_1 , $R_2 + aR - tC$, $R_3 + (1-a)R - (1-t)C$	bR_1 , $R_2 - tC + W$, $R_3 - W + L_2$
	Not synergistic (1-y)	bR_1 , $R_2 - K + L_1$, $R_3 - (1-t)C + K$	bR_1 , R_2 , R_3

II. B.Analysis of Evolutionary Stabilization Strategies

II. B. 1) Return Expectation Function Construction

From Tables 1 and 2, the expected returns U_{g_1} for the government's choice of participating in the coordination strategy in the process of coordinating the interests of collaborative innovation in industry-industry fusion, the expected returns U_{g_2} for the government's choice of not participating in the coordination strategy, and the average expected returns $\bar{U}_g$, respectively, are:

$$\begin{aligned} U_{g_1} &= yz(R_g + R_{g_0} - C_g - G_e - G_s) + y(1-z)(R_g + R_{g_0} - C_g - G_e) \\ &+(1-y)z(R_g + R_{g_0} - C_g - G_s) + (1-y)(1-z)(R_g + R_{g_0} - C_g) \end{aligned} \tag{1}$$

$$U_{g_2} = yzR_g + y(1-z)R_g + (1-y)zR_g + (1-y)(1-z)R_g \tag{2}$$

$$\overline{U_g} = xU_{g_1} + (1-x)U_{g_2} \tag{3}$$

In the process of coordinating the interests of collaborative innovation in the integration of industry and education, the expected return of agreeing to the coordination strategy U_{e_1} , the expected return of disagreeing with the coordination strategy U_{e_2} and the average expected return $\overline{U_e}$ are respectively:

$$\begin{aligned} U_{e_1} &= xz(R_e + aR + G_e - C_e) + x(1-z)(R_e + G_e + P_{x\to e} - C_e) \\ &+(1-x)z(R_e + R_{go} - C_g - G_s) + (1-x)(1-z)(R_e + R_{s\to e} - C_e) \end{aligned} \tag{4}$$

$$\begin{aligned} U_{e_2} &= xz(R_e + A_e - P_{e\to s}) + x(1-z)R_e + (1-x)z(R_e + A_e - P_{e\to s}) \\ &+(1-y)(1-z)R_e \end{aligned} \tag{5}$$

$$\overline{U_e} = yU_{e_1} + (1-y)U_{e_2} \tag{6}$$

In the process of coordinating the interests of collaborative innovation in the integration of industry and education, the expected benefits of agreeing to the coordination strategy U_{s_1} , the expected benefits of disagreeing with the coordination strategy U_{S_2} and the average expected return $\overline{U_s}$ are respectively:

$$U_{s_1} = xy(R_s + (1-a)R + G_s - C_s) + x(1-y)(R_s + G_s + P_{e\to s} - C_s) \\ +(1-x)y(R_s + (1-a)R - C_s) + (1-x)(1-y)(R_s + P_{e\to s} - C_s) \tag{7}$$

$$U_{s_2} = xy(R_s + A_s - P_{s\to e}) + x(1-y)R_s + (1-x)y(R_s + A_s - P_{s\to e}) \\ +(1-x)(1-y)R_s \tag{8}$$

$$\overline{U_s} = zU_{s_1} + (1-z)U_{s_2} \tag{9}$$

II. B. 2) Replicating the dynamic equations

From the above analysis, the equation for the replication dynamics of the government is obtained as:

$$F(x) = \frac{dx}{dt} = x(U_{g_1} - \overline{U_g}) = x(1-x)(R_{g_0} - C_g - yG_e - zG_s) \tag{10}$$

The equation for the replication dynamics of the firm is:

$$F(y) = \frac{dy}{dt} = y(U_{e_1} - \overline{U_e}) \\ = y(1-y)(P_{s\to e} - C_e - zA_e + xG_e + zP_{e\to s} - zP_{s\to e} + azR) \tag{11}$$

The equation for the replication dynamics in higher education is:

$$F(z) = \frac{dz}{dt} = y(U_{s_1} - \overline{U_s}) \\ = z(1-z)(P_{e\to s} - yA_s + xG_s - yP_{e\to s} + yP_{s\to e} + yR - ayR - C_s) \tag{12}$$

II. B. 3) Stability analysis of equilibrium points

Associating equations (10), (11), and (12) yields a replication dynamics system for government, business, and universities as:

$$\begin{cases} F(x) = x(1-x)(R_{g_0} - C_g - yG_e - zG_s) \\ F(y) = y(1-y)(P_{s\to e} - C_e - zA_e + xG_e + zP_{c\to s} - zP_{s\to c} + azR) \\ F(z) = z(1-z)(P_{e\to s} - yA_s + xG_s - yP_{c\to s} + yP_{s\to c} + yR - ayR - C_s) \end{cases} \tag{13}$$

In order to analyze the asymptotic stability of the equilibrium points of the replicated dynamic equations, it is only necessary to discuss the asymptotic stability of the equilibrium points of the replicated dynamic equations involving the pure strategy, thus, in system (13), let $F(x)=0, F(y)=0, F(z)=0$, the local equilibrium points of the pure strategy can be obtained as $E_1(0,0,0), E_2(0,1,0)$, $E_3(0,0,1), E_4(0,1,1), E_5(1,0,0), E_6(1,1,0), E_7(1,0,1), E_8(1,1,1)$. The evolutionary stabilization strategy of the system can be obtained by analyzing the local stability of the Jacobi matrix of the system of differential equations.According to the theory of evolutionary games, the equilibrium point when all the eigenvalues of the Jacobi matrix are nonpositive is satisfied is the evolutionary stabilization point (ESS) of the system.Therefore, the Jacobi matrix of the system can be obtained from the system (13) as:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} (2x-1)(C_g - R_{g_0} + yG_e + zG_s) & x(x-1)G_e & x(x-1)G_s \\ y(y-1)G_e & (1-2y)F_1 & y(y-1)H_1 \\ z(z-1)G_s & z(z-1)H_2 & F_2(2z-1) \end{bmatrix} \tag{14}$$

Among them:

$$\begin{aligned} H_1 &= A_e - P_{e\to s} + P_{s\to e} - aR \\ H_2 &= A_s + P_{e\to s} - P_{s\to e} - R + aR \\ F_1 &= P_{s\to e} - C_e - zA_e + xG_e + zP_{e\to s} - zP_{s\to e} + azR \\ F_2 &= -(P_{e\to s} - yA_s + xG_s - yP_{e\to s} + yP_{s\to e} + yR - ayR - C_s) \end{aligned} \tag{15}$$

First analyze the case of the equilibrium point $E_1(0,0,0)$, when the Jacobi matrix is:

$$J=\begin{bmatrix} R_{g_0}-C_g & 0 & 0 \\ 0 & P_{s\to e-C_e} & 0 \\ 0 & 0 & P_{e\to s}-C_s \end{bmatrix} \tag{16}$$

The eigenvalues of this Jacobi matrix can be derived as $\lambda_1=R_{g_0}-C_g,\lambda_2=P_{S\to e-C_e},\lambda_3=P_{e\to s}-C_s$, and so on, the eigenvalues of the Jacobi matrices of the eight equilibrium points can be obtained, and the eigenvalues of the Jacobi matrices of each equilibrium point are shown in Table 3. In order to facilitate the analysis of the sign of the eigenvalues and without loss of generality, it is assumed that $R_{g_0}-G_e-G_s-C_g>0$ and that $aR+G_e-C_e>A_e-P_{e\to s},(1-a)R+G_s-C_s>A_s-P_{s\to e}$, i.e., the net benefit of the government's participation in coordination is larger than that of non-participation in coordination, and the net benefit of firms and R&D institutes agreeing to coordination is larger than that of disagreeing to coordination. Observing Table 3, we can see that the equilibrium points E_1,E_2,E_3,E_4,E_6,E_7 all have at least one eigenvalue that is positive, so these equilibrium points are not asymptotically stable, and we only need to study and analyze the equilibrium points E_5 and E_8 in the next step.

Table 3: Eigenvalues of each equilibrium point jacobian matrix

Equilibrium point	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3
$E_1(0,0,0)$	$R_{g_0}-C_g$	$P_{s\to e}-C_e$	$P_{e\to s}-C_s$
$E_2(0,1,0)$	$R_{g_0}-G_e-C_g$	$C_e-P_{s\to e}$	$P_{e\to s}+(1-a)R-C_s-A_s$
$E_3(0,0,1)$	$R_{g_0}-G_s-C_g$	$P_{c\to s}+aR-C_E-A_c$	$C_s-P_{e\to s}$
$E_4(0,1,1)$	$R_{g_0}-G_e-$ G_s-C_g	$C_e+A_e-P_{e\to s}-aR$	$C_s+A_s-P_{e\to s}-(1-a)R$
$E_5(1,0,0)$	$C_g-R_{g_0}$	$G_e-C_e+P_{s\to e}$	$G_s-C_s+P_{e\to s}$
$E_6(1,1,0)$	$G_e+C_g-R_{g_0}$	$C_e-G_e-P_{s\to e}$	$G_s+P_{s\to e}+(1-a)R$ $-C_s-A_s$
$E_7(1,0,1)$	$G_e+C_s-R_{g_0}$	$G_e+P_{e\to s}+aR$ $-C_e-A_e$	$C_s-G_s-P_{e\to s}$
$E_8(1,1,1)$	$G_e+C_g+G_s$ $-R_{g_0}$	$A_E+C_e-G_e$ $-P_{e\to s}-aR$	$A_s+C_s-G_s-P_{s\to e}$ $-(1-a)R$

(1) Asymptotic stability analysis of the equilibrium point $E_5(1,0,0)$

When $\begin{cases} G_e-C_e+P_{s\to e}<0 \\ G_s-C_s+P_{e\to s}<0 \end{cases}$ When $E_5(1,0,0)$ is the asymptotically stable point, i.e., in the case where the government participates in the coordination, the sum of the fines that the university does not agree to coordinate the payment of fines to the enterprise and the government rewards the enterprise for participating in the coordination of the tax revenue is less than the cost of the enterprise to carry out the coordination of interests and the sum of the fines that the enterprise does not agree to coordinate the payment of fines to the university and the government rewards the university for participating in the The sum of the funds paid to the university for coordination is less than the cost to the university of carrying out benefit coordination, at which point the stable evolutionary strategy of the system is (participate, disagree with coordination, disagree with coordination). This evolutionary result may appear in the early stage of the collaborative innovation interest coordination process, at this time, due to the fact that enterprises and universities have just begun to contact each other, each other's interests are not enough to understand each other's demands, and need to pay more resources for negotiation and communication, more time and energy to get along with each other, both sides of the cost of coordinating the interests of both parties are at a high level, which leads to disagreeing to coordinate the best strategy for the common of the two. This, in turn, emphasizes the importance of the government's role in the difficult process of coordinating the interests of collaborative innovation, and the government's supervision and guidance can help the coordinating parties to get through the most difficult initial stage.

(2) Analysis of the asymptotic stability of the equilibrium point $E_8(1,1.1)$

When the assumptions above are satisfied, $E_8(1,1,1)$ is the point of asymptotic stability, i.e., under government participation, the benefits obtained by the government from participating in coordination are greater than the sum of the costs of .participating in coordination and the tax relief for enterprises and the funds rewarded to universities as a result of the enterprises and universities agreeing to coordinate, and the sum of the additional benefits obtained by enterprises from agreeing to participate in coordination and the tax relief from the government, minus the costs of coordination is greater than the difference between the benefits obtained by the firms from not agreeing to coordinate and the fines imposed on them for not agreeing to coordinate, and the sum of the additional benefits obtained by the universities from agreeing to participate in the coordination and the government subsidies minus the cost of coordination is greater than the difference between the benefits obtained by the universities from not agreeing to coordinate and the fines imposed on them for not agreeing to coordinate, and then the system's stabilizing evolutionary strategy is (Participate, Agree to Coordinate, Agree to coordination). Under the government's efforts, enterprises and universities, through continuous communication and integration, have increased their willingness to participate in the coordination of interests, and the process of coordination of interests is on the right track of mutual promotion, and eventually converges to the stable equilibrium of both agreeing to coordinate, and each obtains the optimal net benefit of coordination of interests.

III. Analysis of numerical example tests

In this chapter, some typical parameters are selected to analyze and discuss the evolution process of choosing the strategy of industry-education integration through numerical arithmetic examples to verify the system stability results.

III. A. Influence of initial willingness of school enterprises

The initial value of the school-enterprise two-party strategy (y,z) takes the values of (0.2,0.2),(0.5,0.5),(0.8,0.8), and the system evolution process under the initial willingness of the different school-enterprises is shown in Figure 1. As can be seen from the figure, whether the integration of production and education can be successfully promoted by the initial willingness of the school and enterprises has a significant impact, when (y,z) takes the value of (0.2,0.2), the evolution of the integration of production and education tends to converge to 0 with the passage of time, and the lower initial willingness of the two sides will reveal the negative tendency to co-construction and invest fewer resources for co-construction, and the demand for access to their own resources can not be met, which will ultimately lead to the failure of the co-construction. Failure of co-construction. In contrast, when (y,z) takes the value of (0.8,0.8), the evolution of the integration of industry and education tends to be close to 1 over time and is faster than that when (y,z) takes the value of (0.5,0.5), and the higher initial willingness of the two sides will prompt the two sides to put in more advantageous resources to reach a good interactive relationship, which will lead to the co-built mechanism can run smoothly at the initial stage.

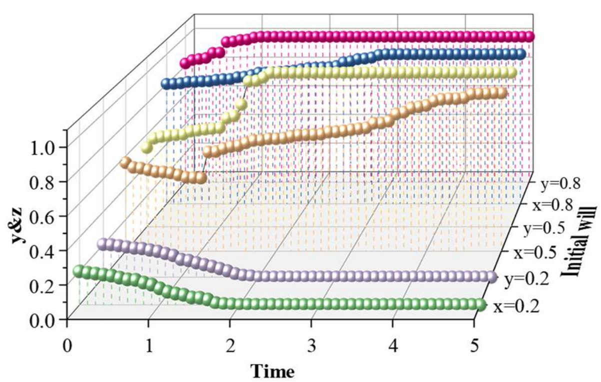


Figure 1: The system evolution process of the different initial will of the school and enterprise

III. B. Impact of government incentive subsidies

Assuming that the value of government subsidy G is 0.5, 1, 1.5, according to the past cooperation of the integration of industry and education, it can be seen that in the beginning stage of the actual construction, the subject's participation in the enthusiasm is not high, and most of them are guided by the government's policy to reach cooperation, so both sides of the initial willingness to (y,z) to take (0.5,0.5), the change of G to influence on the evolution results are shown in Figure 2. When G takes 0.5, the evolution result of the integration of industry and education is (0,0). When G takes 1 and 1.5, with the increase of G the final evolution result is (1,1), the input cost of both sides of the construction is partially shared by the government, both for the enterprise and the university, the reduction of the amount of resource input means that more resource interaction benefits can be obtained through cooperation, and therefore it will tend to cooperate actively to create more economic and social value.

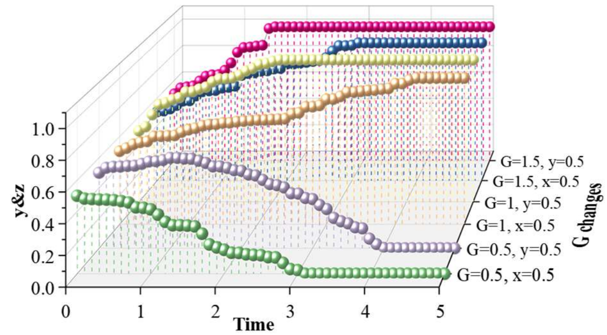


Figure 2: The influence of G changes on evolution results

III. C. Impact of the benefits of cooperation

Assuming that the cooperation gains R are 15, 25, and 35, the cooperation gains under the active strategy are analyzed for their impact on the strategy evolution process, and the effect of the change in R on the evolutionary outcome is shown in Fig. 3. The state of the evolutionary system gradually evolves from the stable point (0,0) to (1,1). The higher the gain of active cooperation between the two parties, the faster the two parties choose the active cooperation strategy. At this time, through co-construction both parties can obtain more external resources to meet their own development needs. At the same time, active cooperation can also obtain the government side to provide incentives to hold resources. In order to continue to obtain more co-build benefits, both parties tend to actively cooperate and invest construction resources to maximize the benefits.

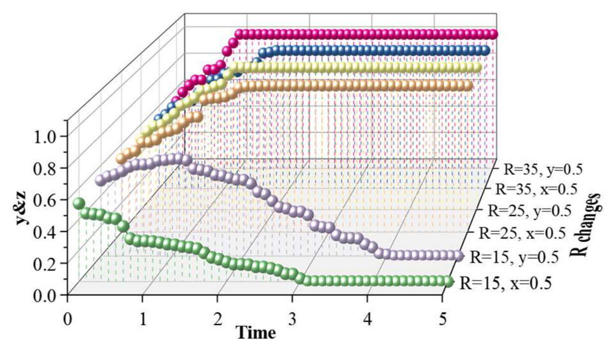
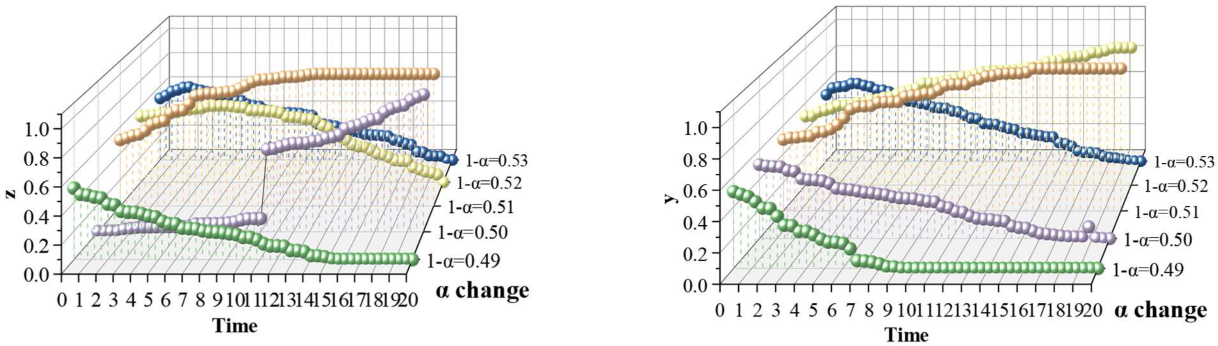


Figure 3: The influence of R changes on evolution results

III. D. Impact of different distributions of benefits

III. D. 1) Research and development phase

Figure 4 shows the simulation of the impact of the ratio of the benefits distribution between universities and enterprises in the R&D stage α on the participation of both parties in the deep integration of industry, academia, and research, where the benefits include the innovation income and financial subsidies in the R&D stage, while other parameters remain unchanged. For universities, α has two critical values, one of which is located at 0.49~0.50, and the other at 0.51~0.52. For enterprises, 1-α has two critical values, one of which is located at 0.50~0.51, and the second at 0.52~0.53. z converges to 0 when α ≤0.49, and converges to 0 when 0.50≤α ≤0.51, z converges to 1. When 1-α ≤0.50, y converges to 0. When 0.51≤1-α ≤0.52, y converges to 1. This indicates that they are willing to continue to participate in the integration of industry and education when both sides match their payoffs and rewards, otherwise they will default on their development alone halfway through the integration, and The benefit distribution ratio of enterprises willing to continue to participate in the integration of industry and education is slightly higher than that of the university side, firstly, it is because the cost paid by enterprises is usually higher than that of the university side, so the required return is relatively higher. The second is that enterprises are more sensitive to benefits than the university side. When α ≥ 0.52, z converges to 0, and when 1-α ≥ 0.53, y converges to 0. The main reason for this phenomenon is that the benefits of both parties include a part of the government's financial subsidies, due to the government's over-intervention produces an inhibitory effect, which in turn leads to a reduction in the benefits of both parties and ultimately chooses to breach the contract halfway through the process.



(a)To universities (b)To enterprises

Figure 4: The impact of the R&D stage income distribution system

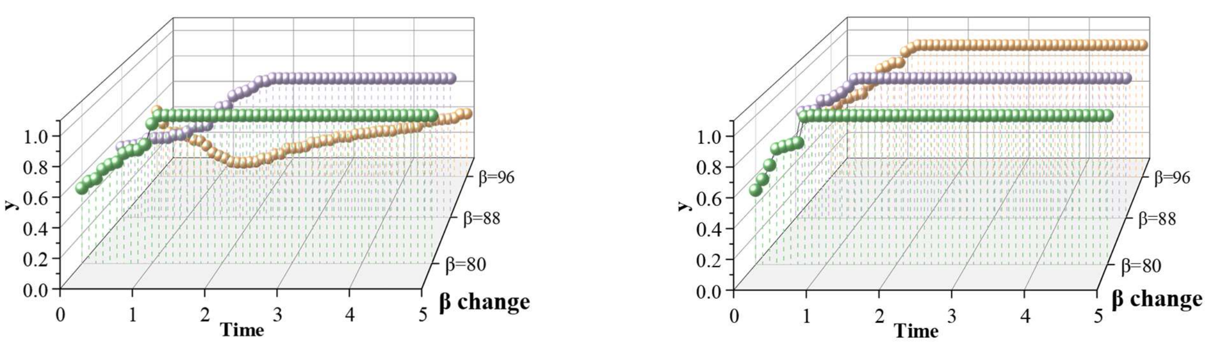
III. D. 2) Production and Commercialization Stages

Figure 5 shows the simulation of the impact of the allocation coefficients in the production and commercialization stages on the participation of private and state-owned enterprises in the integration of industry and education, based on different revenue allocation mechanisms, while other parameters remain unchanged.

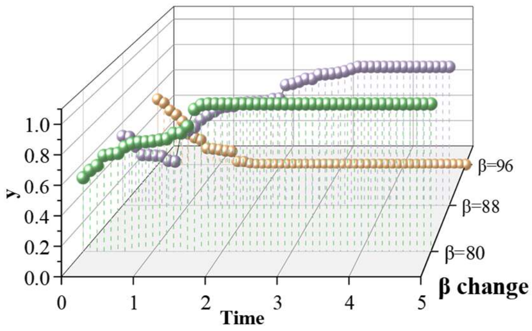
Fig. 5(a) and Fig. 5(d) are the evolutionary simulations based on the relative risk-sharing revenue allocation mechanism, for both private and state-owned enterprises, the revenue allocation mechanism based on relative risk-sharing can better reflect their input and risk-tolerance ability. Therefore, under this mechanism, both parties insist on choosing to continue to participate in the deep integration of industry and education when there are greater risks in the production and commercialization stages.

Figure 5(b) and Figure 5(e) are the evolutionary simulation based on the average distribution of revenue allocation mechanism, it can be seen that for private enterprises, when there is a greater risk in the production and commercialization stage, they still choose to continue to participate in the deep integration of industry-academia-research, but the state-owned enterprises in the risk cost of the critical value is located in the range of 88~96, when the risk cost β is greater than the critical value, y converges to 0, that is, the choice of the midway default because the higher input share of SOEs is ignored under the average allocation mechanism.

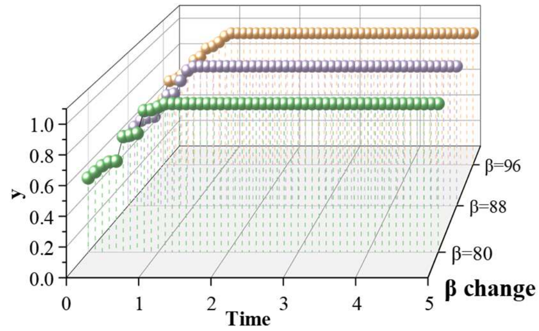
Figure 5(c) and Figure 5(f) are the evolutionary simulation based on the cost-sharing benefit allocation mechanism, it can be seen that for state-owned enterprises, when there is a greater risk in the production and commercialization stage, they still choose to continue to participate in the deep integration of industry, academia, and research, but the critical value of the cost of the risk of the private enterprise is located in 88~96, when the cost of risk β is greater than the critical value, z converges to 0, i.e., chooses to default halfway through default, as the risk element is not taken into account in this benefit distribution mechanism.



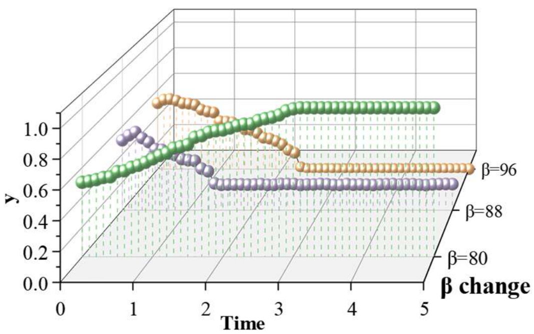
(a)Relative risk sharing(Private enterprise) (b)Average distribution(Private enterprise)



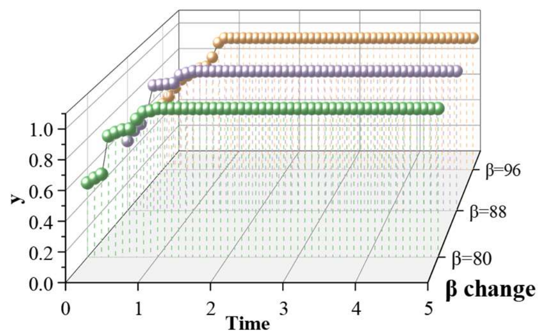
(c)Cost sharing(Private enterprise)



(d)Relative risk sharing(State-owned enterprise)



(e)Average distribution(State-owned enterprise)



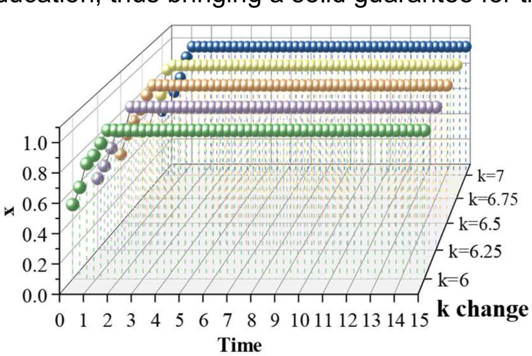
(f)Cost sharing(State-owned enterprise)

Figure 5: The impact of different distributions in production and commercialization

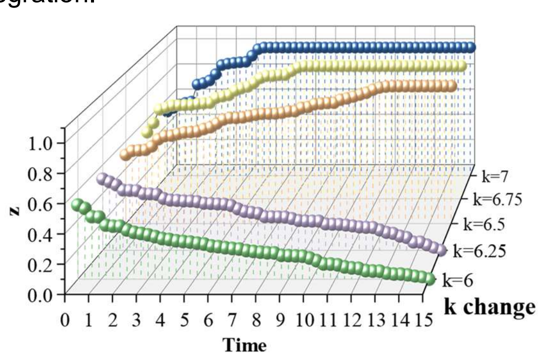
III. E. Impact of the level of penalties

III. E. 1) Research and development phase

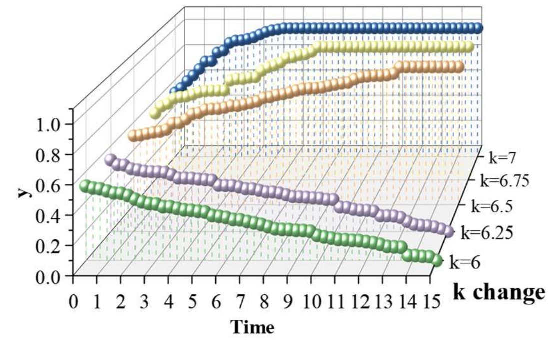
Figures 6 and 7 show the simulation of the impact of the penalty k, v for defaulting in the middle of the R&D stage for universities and enterprises on the participation of both parties in the deep integration of industry and education, respectively, when other parameters are unchanged. For both parties, the critical value of k, v is located at 6.25~6.5, and when k, v is smaller than this critical value, y, z converge to 0, and the final equilibrium point tends to (1, 0, 0). When k, v is greater than this critical value, y, z both converge to 1, and the final equilibrium point tends to (1, 1, 1). In the case of university default in the middle, the convergence speed of the university is higher than that of the enterprise, and in the case of enterprise default in the middle, the convergence speed of the enterprise is faster than that of the university, indicating that the innovation subject cares more about the reduction of its own interests due to the payment of the default penalty than to keep the continued participation to get the default penalty of the other party in the case of the other party's default. It can be seen that increasing the penalty for breach of contract can accelerate the convergence speed of both parties to continue to participate in the deep integration of industry and education, thus bringing a solid guarantee for the deep integration.



(a)To the government

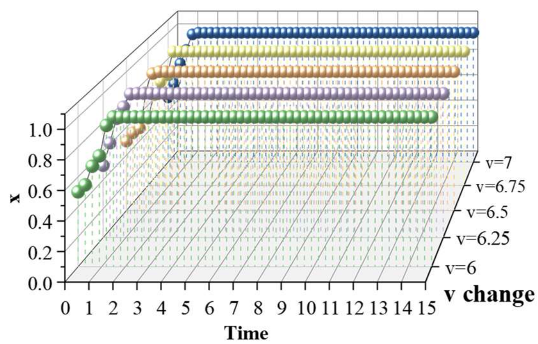


(b)To universities

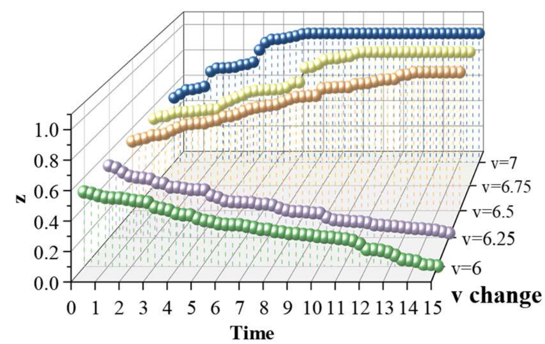


(c)To enterprises

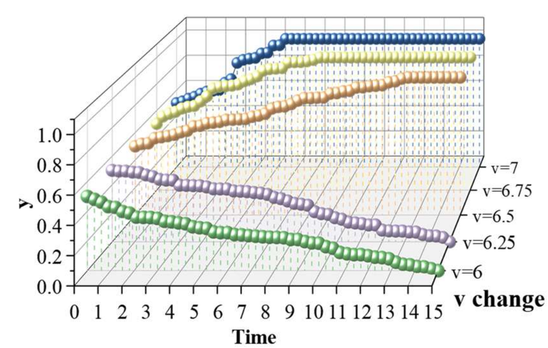
Figure 6: The impact of the university defaults in R&D stage



(a)To the government



(b)To universities

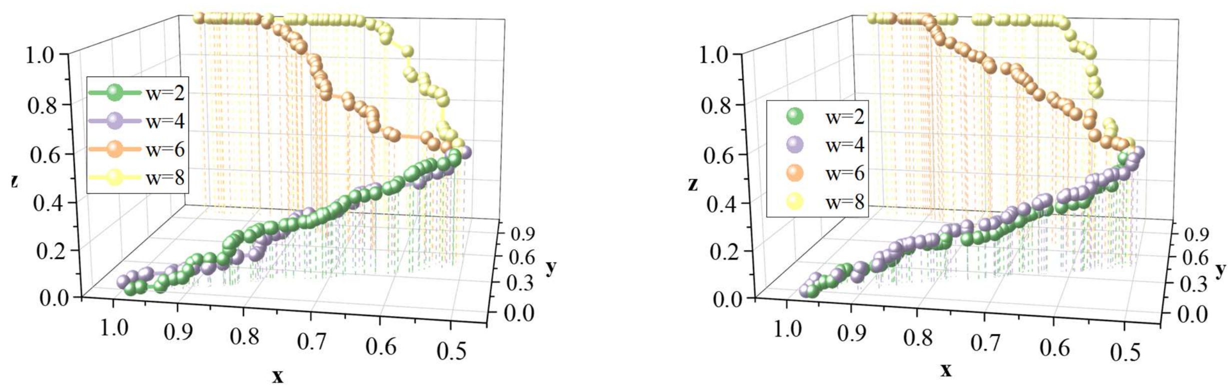


(c)To enterprises

Figure 7: The impact of enterprises defaults in R&D stage

III. E. 2) Production and Commercialization Stages

Fig. 8 shows the simulation of the impact of the penalty w and m for the default of private and state-owned enterprises in the production and commercialization stages in the middle of the production and commercialization stages on the participation of both parties in the depth of convergence, while other parameters remain constant. As can be seen from Fig. (a), for private enterprises, the critical value of w is located at 4~6. When w is smaller than this critical value, y converges to 0 and the final equilibrium point converges to (1, 0, 0). When w is larger than this critical value, y converges to 1, and the final equilibrium point converges to (1, 1, 1), indicating that private and state-owned enterprises have already invested relatively large costs in the early stage, so they will not give up the second stage to continue the deep integration in order to obtain the compensation for the other party's default. However, when the penalty for default is small and the project risk is large, private enterprises are more likely to default compared with state-owned enterprises, so it is still necessary to set up an appropriate penalty mechanism in this stage, especially for private enterprises, a relatively large penalty for default should be set up, so as to guarantee the smooth progress of the integration of industry and education.



(a)The impact of w (b)The impact of m

Figure 8: The impact of default penalties for production and commercialization stage

IV. Recommendations for the optimal design of the organizational form of the integration of industry and education

Through the calculation as well as the analysis of the evolutionary game model of collaborative innovation of industry-education integration above, it can be found that in the process of technological innovation cooperation of government-industry-university-research alliance, each subject plays an irreplaceable role. Therefore, based on the results of the study, the proposal of optimal design of the organizational form of industry-academia integration is put forward.

IV. A. Establishment of complete information channels

The game of industry-education integration is to maximize the benefits of the educational ecosystem by making the most appropriate choice strategies for both universities and enterprises. However, in the process of practice, due to the integration of industry and education, the two sides often have asymmetric or even distorted information transmission, resulting in the decision-making did not reach a consensus, so as to fail to achieve the synergy of the relationship, can only be based on their own interests to maximize the assumptions and related decisions, resulting in the final integration of industry and education can not be in-depth integration. With the deepening of the reform of applied undergraduate education, the integration of industry and education is mainly through advocating the joint development of professional talent training programs by enterprise experts, school teachers and the government. Teachers in colleges and universities should first conduct market demand research, analyze the data, and sort out into a complete market demand research report. In this process, enterprise experts who are familiar with professional job standards analyze the logistics positions and obtain the complete work task system required for the specialty. Teachers then carry out task decomposition for job requirements to determine the specific work content of the position. The analyzed vocational ability as well as the refined part in this way has a certain logic, and can train students who are competent for the position. At the same time, the stage results of the professional talent training program are correctly evaluated, and a platform for barrier-free communication of information between the subjects of industry-teaching integration is built.

IV. B. Establishment of incentives and disincentives

The government takes a third-party perspective and utilizes economic means to guide colleges and universities and enterprises to actively participate in the integration of industry and education and give full play to their respective advantages. Teachers of colleges and universities are the main body of the development of talent cultivation programs for the integration of industry and education, and in this process, enterprises and social experts assist them to complete the development of the integration of industry and education. And the government, as one of the main bodies of the integration of industry and education, is both the implementer of the mechanism of integration of industry and education and the supervisor of the reform. With the support of the government, colleges and universities and enterprises should work together to clarify the necessity of the integration of industry and education, clarify the direction of reform and development, provide reasonable incentives and constraints for the integration of industry and education, and satisfy various guarantee conditions for the development of the integration of industry and education.

IV. C. Improvement of policies and regulations on the integration of industry and education

Colleges and universities and enterprises should clarify and sort out their respective rights and obligations by way of agreement in the process of cooperation, establish balanced obligations and responsibilities among the subjects of industry-education integration, ease the game dilemma of industry-education integration, and realize the game equilibrium of the subjects of industry-education integration. To build a sound industry-education integration synergistic mechanism, from the agreement, policies and regulations to clarify the rights and interests of colleges and universities, enterprises and society in the process of industry-education integration, and realize the game equilibrium between the main parties of industry-education integration through a clear contract or legal agreement.

V. Conclusion

With the adjustment of industrial structure and industrial transformation and upgrading, the state has launched the policies of integration of industry and education and school-enterprise cooperation in a timely manner. This paper constructs a game model of the evolution of the integration of industry and education, designs the assignment dynamic equations of multiple parties, explores the stability of the equilibrium point, and analyzes the influence of different factors on the evolution of the integration of industry and education by combining with the arithmetic examples.

(1) Universities and enterprises are the two core subjects of the co-construction mechanism, when the initial willingness of both schools and enterprises is 0.2, the result of the evolution of the integration of education and industry is 0, when the initial willingness is greater than 0.5, the result of the evolution of the integration of education and industry is 1. Similarly, the higher the government incentive subsidies and the higher the income from cooperation, the more it can lead to integration of education and industry of the two sides of the university and the enterprise.

(2) There exists a reasonable coefficient of benefit distribution between school and enterprise, which is conducive to realizing the effective operation of the co-construction mechanism. In the R&D stage and the production and commercialization stage, the critical values of the default penalties of the university and enterprises are 6.25~6.5 and 4~6 respectively, and when the default penalties are larger than the critical values, both sides tend to reach the integration strategy. Therefore, a reasonable penalty mechanism can enhance the willingness of innovative subjects to continue to participate in the integration of industry and education and bring solidity to the deep integration. This is because the innovative subject is more concerned about the reduction of its own interests due to the payment of the penalty for breach of contract than the compensation for the breach of contract of the other party for maintaining the continued integration.

(3) In order to effectively promote the optimization of the organizational form of the integration of industry and education, it is proposed to establish a complete information channel and incentive and constraint mechanism, safeguard the interests of both sides of the main body of the game, construct sound policies and regulations for the integration of industry and education, and clarify the rights and responsibilities of both sides of the main body of the process of the integration of industry and education and a number of other strategies to solve the dilemmas of the game of the integration of industry and education, so that the main body of the game through the game of the relevant strategies to jointly form a stable and harmonious deep integration of industry and education. Educational ecosystem.

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