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Research on the Evolutionary Game of Industry-University-Research Collaboration in Vocational Education for Developing New Quality Productive Forces

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SUMMARY: *To solve the dilemma of deep integration of industry, academia, and research in vocational education and empower the development of new quality productivity, this study takes the government, enterprises, and vocational colleges as the core subjects. Based on the triple helix theory, the cooperation between industry, academia, and research is divided into two stages: incentive and governance. A dynamic evolutionary game model of three parties is constructed, and the strategic evolution laws and key parameter influence mechanisms of each subject are revealed through MATLAB numerical simulation. The experimental results indicate that the deep integration of industry, academia, and research heavily relies on government funding and policy support, and excessive incentives can easily trigger opportunistic behavior; The impact of cooperation costs during the incentive phase is relatively weak, while the governance costs during the governance phase significantly determine the sustainability of cooperation; The risk cost is crucial for both stages of strategy selection, and the risk sensitivity of enterprises in the governance stage is higher than that of universities. Government intervention plays a decisive role when the initial willingness to cooperate between schools and enterprises is low, and strong government intervention is needed to achieve stable integration in situations of information asymmetry. Finally, countermeasures are proposed from the perspectives of government guidance, collaboration of emerging technologies, balance of interests among multiple parties, and integration of the four chains.*

KEYWORDS: *Vocational education; New Quality Productivity Evolutionary game theory; Industry university research cooperation; Triple helix theory*

1 Introduction

At present, China is accelerating the transformation and upgrading of its economic development mode, and the internal quality of traditional productive forces is undergoing profound changes. In 2023, China will make accelerating the development of new quality productive forces an important strategic direction for future economic structure optimization and industrial innovation and upgrading. To cultivate and strengthen new quality productive forces, it is necessary to promote the deep integration of technological innovation and industrial innovation. Modern vocational education is highly coupled with economic and social development, and undertakes the important mission of cultivating applied and composite technical and skilled talents, assisting in technological research and development, and accelerating the industrialization of scientific and technological achievements. In this era,

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promoting the deep integration of industry, academia, and research in the field of vocational education not only directly determines the quality of technical and skilled talent cultivation and industrial service capabilities, but also serves as a core path and key measure for cultivating and developing new quality productive forces, achieving the deep integration of the education chain, talent chain, industry chain, and innovation chain.

The current industry university research cooperation in China's vocational education field still faces many prominent challenges, including superficial cooperation, lack of deep integration, loose connections among stakeholders, and imperfect benefit sharing mechanisms. Although various stakeholders are trying to achieve a stable game balance, the goal of empowering the development of new quality productivity through vocational education has not yet been achieved. Existing research has explored the mode of industry university research cooperation from multiple perspectives, including connotation deconstruction, mechanism construction, practical cases, and governance frameworks [5-7]. However, at the level of game theory analysis, existing research mostly focuses on the interaction between bilateral entities (such as universities and enterprises) [8], and rarely includes the government, enterprises, and vocational colleges in the evolutionary game framework at the same time. Moreover, it often overlooks the dynamic and phased characteristics of the process of deep industry university research cooperation. Given the crucial guiding role of the government in the development of new quality productivity, this study incorporates the government into the game framework as the core participant [9], with the entire process of vocational education industry university research cooperation as the core, and constructs a tripartite dynamic evolutionary game model covering the government, enterprises, and vocational colleges to adapt to the needs of the new quality productivity development era. By using MATLAB software for numerical simulation, the strategic choices and influencing factors of each participant are visually presented, aiming to provide theoretical support and practical reference for building a vocational education industry university research deep integration system that matches the development needs of new quality productivity.

2 Evolutionary Game Analysis

The deep integration of industry university research cooperation in the field of vocational education aims to empower the development of new quality productive forces, achieve functional synergy in the cultivation of high-quality skilled talents, and promote the deep connection between technological innovation and production practice. The relationship between the government, enterprises, and vocational colleges can be defined as a triple helix relationship centered on cooperation, which is highly in line with the practical needs of deep integration of industry, academia, and research. This study introduces the triple helix theory to systematically analyze the collaborative mechanisms and interactive logic among various stakeholders, providing theoretical support for the deep integration of industry, academia, and research.

The government, enterprises, and vocational colleges correspond to the power core, economic core, and knowledge core respectively [12], forming a dynamic interactive relationship among the three types of subjects, jointly constructing a three-helix collaborative system with the core characteristics of "horizontal linkage interaction, vertical iteration and upgrading" [13]. In the process of deep integration of industry, academia and research in vocational education, the achievement of the intention of school enterprise cooperation is the core driving force for the vertical promotion of the triple helix structure. Vocational colleges and enterprises need to bear the related costs of information collection, cooperation negotiation, agreement negotiation, and contract drafting. At this stage, the core function of the government is to focus on introducing incentive policies, building cooperation platforms, guiding and promoting cooperation consensus between schools and enterprises. After intentions are solidified, they incur costs related to communication, implementation, and supervision, shifting the government's focus to governance mechanisms. Thus, clarifying transaction costs before and after cooperation intentions is central to evolutionary game analysis. This study divides the spiral advancement of collaboration into incentive and governance phases and constructs a triple helix model for vocational education industry-university-research collaboration (see Figure 1).

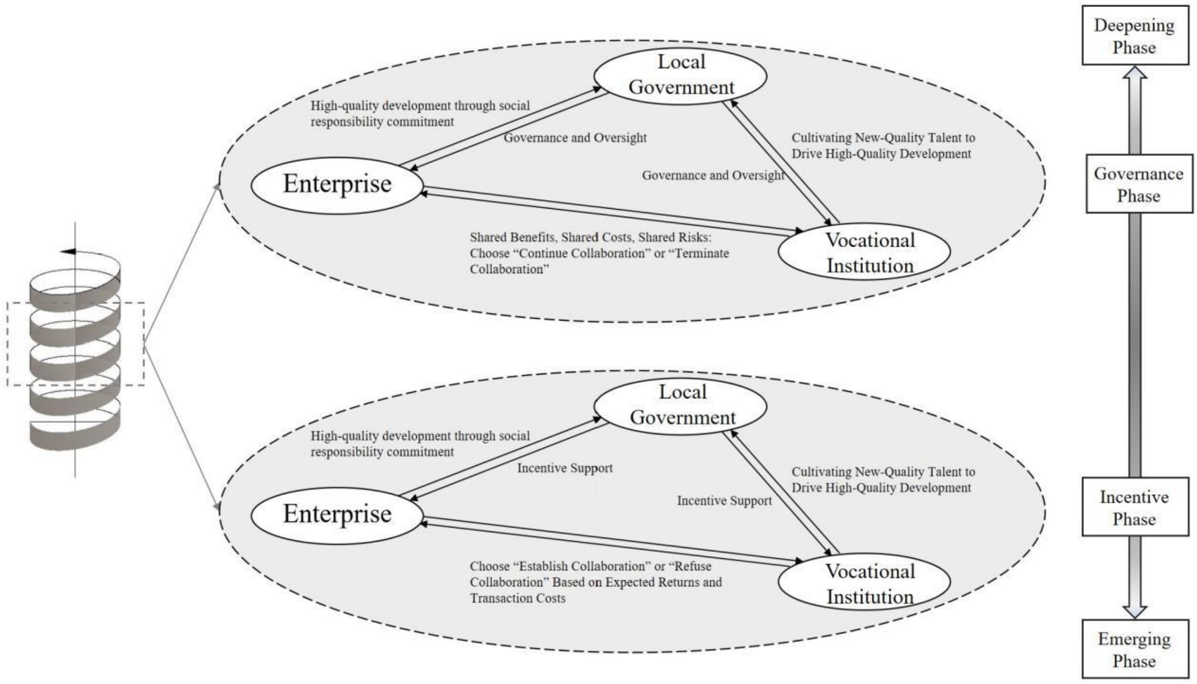


Figure 1: Analytical Diagram of the Triple Helix Model for Vocational Education Industry-University-Research Collaboration

2.1 Basic Assumptions of the Evolutionary Game

In the process of industry-university-research collaboration in vocational education, institutions, enterprises, and governments engage in mutual gaming to pursue maximum benefits. Institutions and enterprises will choose to collaborate when the expected benefits outweigh transaction costs, and refuse to collaborate when the expected benefits are less than transaction costs. Local governments provide policy support and funding for industry-university-research collaboration under the context of new quality productive forces, which can promote technological innovation in vocational institutions and industrial upgrading in enterprises. By facilitating the smooth alignment between the supply and demand of high-quality skilled talent, they reduce investment costs and commitment risks for institutions and enterprises in collaboration. In this process, enterprises leverage government-specific subsidies and policy incentives to enhance the level of new quality productive forces through foundational research, knowledge transformation, and optimization of human capital structures. Table 1 shows variables and definitions of the tripartite game in industry-university-research collaboration.

Specifically, during the incentive phase, institutions tend to cultivate higher-level technical and skilled talents to boost employment; enterprises aim to achieve higher labor productivity and acquire new quality talents that align with their corporate culture, thus willing to provide training for potential labor forces; local governments monitor real-time developments, provide feedback to the central government, and obtain reward mechanisms such as central government transfer payments to incentivize institutions and enterprises to participate in collaboration. During the governance phase, institutions need to engage extensively with enterprises, adjust training programs, and safeguard students' legitimate rights; enterprises provide suggestions on institutional training plans, curriculum design, practical training bases, and training standards; local governments standardize the allocation of responsibilities, rights, and benefits among institutions and enterprises during governance to ensure orderly and efficient fulfillment of obligations and supervise contract implementation. Based on the above context, the assumptions of this study's model are as follows:

Assumption 1 (H1): All participating entities are boundedly rational and adhere to the principle of maximizing their own benefits. Through long-term gaming, participants continuously adjust and improve their strategies, ultimately reaching a system equilibrium, with strategy choices x, y, z~[0, 1]

Assumption 2 (H2): In the incentive phase, the expected benefits for both institutions and enterprises choosing to collaborate exceed those when only one party chooses to collaborate.

Assumption 3 (H3): In the governance phase, the expected benefits for both institutions and enterprises choosing to continue collaboration exceed those when only one party chooses to collaborate. Due to contractual constraints, if one party breaches the agreement, it must pay penalties and compensation to the government and the other party; if both parties breach simultaneously, no penalties or compensation will be imposed.

Table 1: Variables and Definitions of the Tripartite Game in Industry-University-Research Collaboration

Variable	Variables in the Incentive Phase	Variable	Variables in the Governance Phase
P_1^1	Initial benefits of vocational institutions before industry-institution collaboration	P_2^1	Initial benefits of vocational institutions after industry-institution collaboration
P_1^2	Initial level of new quality productive forces in enterprises before collaboration	P_2^2	Initial level of new quality productive forces in enterprises after collaboration
C_1	Information and decision-making costs incurred by institutions and enterprises to establish collaboration	C_2	Communication and training costs incurred by institutions and enterprises for governance of collaboration
S_1	Government funding support to enhance the level of new quality productive forces	S_2	Government funding support to enhance the level of new quality productive forces
G_1	Government policy support to enhance the level of new quality productive forces	G_2	Government policy support to enhance the level of new quality productive forces
T_1	Integration risk costs of industry-institution collaboration	T_2	Integration risk costs of industry-institution governance
R_1^1	Expected benefits when both institutions and enterprises choose collaboration	R_2^1	Expected benefits when both institutions and enterprises choose to continue collaboration
R_1^2	Expected benefits when only one party (institution or enterprise) chooses collaboration	R_2^2	Expected benefits when only one party (institution or enterprise) chooses to continue collaboration
P_1^3	Social benefits and transfer payments obtained by the government through supporting collaboration	M_1	Fines paid by institutions to the government for breach of contract
α	Cost-sharing coefficient between institutions and enterprises for total collaboration costs, $0<\alpha<1$	N_1	Breach penalties paid by institutions to enterprises for contract violation
β	Funding-sharing coefficient between institutions and enterprises for total government support, $0<\beta<1$	M_2	Fines paid by enterprises to the government for breach of contract
γ	Risk cost reduction coefficient due to the enhanced level of new quality productive forces, $0<\gamma<1$	N_2	Breach penalties paid by enterprises to institutions for contract violation
δ	Benefit-sharing coefficient between institutions and enterprises under mutual collaboration, $0<\delta<1$	P_2^3	Social benefits and transfer payments obtained by the government through supporting collaboration
ε	Benefit-sharing coefficient when only one party (institution or enterprise) collaborates, $0<\varepsilon<1$	η	Cost-sharing coefficient between institutions and enterprises for total governance costs, $0<\eta<1$
ζ	Coefficient of benefits obtained when the government withdraws support, $0<\zeta<1$	θ	Funding-sharing coefficient between institutions and enterprises for total government support, $0<\theta<1$
		ι	Risk cost reduction coefficient due to the enhanced level of new quality productive forces, $0<\iota<1$
		κ	Benefit-sharing coefficient between institutions and enterprises under mutual collaboration, $0<\kappa<1$
		ν	Benefit-sharing coefficient when only one party (institution or enterprise) collaborates, $0<\nu<1$
		μ	Coefficient of benefits obtained when the government withdraws support, $0<\mu<1$

2.2 Establishment of the Evolutionary Game Model

Based on the model assumptions and utilizing the aforementioned parameters, an evolutionary game model for industry-university-research collaboration is established. The tripartite game payoff matrices for both phases are presented in Table 2 and Table 3.

Table 2: Payoff Matrix for the Incentive Phase

Vocational Institution			Enterprise: Establish Collaboration (y_1)	Enterprise: Refuse Collaboration (1-y_1)
Local Government	Support Collaboration (z_1)	Establish Collaboration (x_1)	$P_1^1+\delta R_1^1+\beta S_1-\alpha C_1-(1-\gamma)T_1,$	$P_1^1+\varepsilon R_1^2+\beta S_1-\alpha C_1(1-\gamma)T_1,$
			$P_1^2+(1-\delta)R_1^1+(1-\beta)S_1-(1-\alpha)C_1-(1-\gamma)T_1,$	$P_1^2-(1-\alpha)C_1,$
			$P_1^3-S_1-G_1$	$P_1^3-\beta S_1-G_1$
		Refuse Collaboration (1-x_1)	$P_1^1-\alpha C_1,$	$P_1^1-\alpha C_1,$
			$P_1^2+(1-\varepsilon)R_1^2+(1-\beta)S_1-(1-\alpha)C_1-(1-\gamma)T_1,$	$P_1^2-(1-\alpha)C_1,$
			$P_1^3-(1-\beta)S_1-G_1$	$P_1^3-G_1$
	Withdraw Support (1-z_1)	Establish Collaboration (x_1)	$P_1^1+\delta R_1^1-\alpha C_1-T_1,$	$P_1^1+\varepsilon R_1^2-\alpha C_1-T_1,$
			$P_1^2+(1-\delta)R_1^1-(1-\alpha)C_1-T_1,$	$P_1^2-(1-\alpha)C_1,$
			ζP_1^3	ζP_1^3
		Refuse Collaboration (1-x_1)	$P_1^1-\alpha C_1,$	$P_1^1-\alpha C_1,$
			$P_1^2+(1-\varepsilon)R_1^2-(1-\alpha)C_1-T_1,$	$P_1^2-(1-\alpha)C_1,$
			ζP_1^3	ζP_1^3

Table 3: Payoff Matrix for the Governance Phase

Vocational Institution			Enterprise: Continue Collaboration(y_2)	Enterprise: Terminate Collaboration(1-y_2)
Local Government	Support Collaboration (z_2)	Continue Collaboration (x_2)	$P_2^1+\kappa R_2^1+\theta S_2-\eta C_2-(1-\iota)T_2,$	$P_2^1+\nu R_2^2+\theta S_2+N_2-(1-\iota)T_2,$
			$P_2^2+(1-\kappa)R_2^1+(1-\theta)S_2-(1-\eta)C_2-(1-\iota)T_2,$	$P_2^2-M_2-N_2,$
			$P_2^3-S_2-G_2$	$P_2^3+M_2-\theta S_2-G_2$
		Terminate Collaboration (1-x_2)	$P_2^1-M_1-N_1,$	$P_2^1-M_1,$
			$P_2^2+(1-\nu)R_2^2+(1-\theta)S_2+N_1-(1-\iota)T_2,$	$P_2^2-M_2,$
			$P_2^3+M_1-(1-\theta)S_2-G_2$	$P_2^3+M_1+M_2-G_2$
	Withdraw Support (1-z_2)	Continue Collaboration (x_2)	$P_2^1+\kappa R_2^1-\eta C_2-T_2,$	$P_2^1+\nu R_2^2+N_2-T_2,$
			$P_2^2+(1-\kappa)R_2^1-(1-\eta)C_2-T_2,$	$P_2^2-N_2,$
			μP_2^3	μP_2^3
		Terminate Collaboration (1-x_2)	$P_2^1-N_1,$	$P_2^1,$
			$P_2^2+(1-\nu)R_2^2+N_1-T_2,$	$P_2^2,$
			μP_2^3	μP_2^3

3 Calculation of Stable Strategies in the Evolutionary Game

3.1 Solution of the Evolutionary Game Model

3.1.1 Incentive Phase

Based on the payoff matrix, the replicator dynamic equations for vocational institutions, enterprises, and local governments are derived as follows:

$$F(x_1) = \frac{\mathrm{d}x_1}{\mathrm{d}t} = x_1\left(U_{11}^1 - \overline{U_1^1}\right) = x_1(1-x_1)[(1-y_1)\varepsilon R_1^2 + \delta y_1 R_1^1 + (\gamma z_1 - 1)T_1 + \beta z_1 S_1] \quad (1)$$

$$F(y_1) = \frac{\mathrm{d}y_1}{\mathrm{d}t} = y_1\left(U_{11}^2 - \overline{U_1^2}\right) = y_1(1-y_1)[(1-\varepsilon - x_1 + \varepsilon x_1)R_1^2 - (1-\delta)x_1 R_1^1 + (\gamma z_1 - 1)T_1 + (1-\beta)z_1 S_1] \quad (2)$$

$$F(z_1) = \frac{\mathrm{d}z_1}{\mathrm{d}t} = z_1\left(U_{11}^3 - \overline{U_1^3}\right) = z_1(1-z_1)[(1-\zeta)P_1^3 - (y_1 + \beta x_1 - \beta y_1)S_1 - G_1] \quad (3)$$

3.1.2 Governance Phase

In the governance phase, the replicator dynamic equations for vocational institutions, enterprises, and local governments can be expressed as:

$$F(x_2) = \frac{\mathrm{d}x_2}{\mathrm{d}t} = x_2\left(U_{21}^1 - \overline{U_2^1}\right) = x_2(1-x_2)[(1-y_2)\nu R_2^2 + \kappa y_2 R_2^1 + \theta z_2 S_2 + (\iota z_2 - 1)T_2 + z_2 M_1 + y_2 N_1 + (1-y_2)N_2 - \eta y_2 C_2] \quad (4)$$

$$F(y_2) = \frac{\mathrm{d}y_2}{\mathrm{d}t} = y_2\left(U_{21}^2 - \overline{U_2^2}\right) = y_2(1-y_2)[(1-\nu - x_2 + \nu x_2)R_2^2 + (x_2 - \kappa x_2)R_2^1 + (\iota z_2 - 1)T_2 + z_2 M_2 + (1-x_2)N_1 + x_2 N_2 + (1-\theta)z_2 S_2 + (\eta - 1)x_2 C_2] \quad (5)$$

$$F(z_2) = \frac{\mathrm{d}z_2}{\mathrm{d}t} = z_2\left(U_{21}^3 - \overline{U_2^3}\right) = z_2(1-z_2)[(1-\mu)P_2^3 - (x_2 - 1)M_1 - (y_2 - 1)M_2 - (\theta x_2 + y_2 - \theta y_2)S_2 - G_2] \quad (6)$$

3.2 Tripartite Evolutionary Stability Analysis

3.2.1 Incentive Phase

Since the probability of strategy selection by game participants is time-dependent and evolves over time, the overall evolutionary game system stabilizes when the replicator dynamic equations for vocational institutions, enterprises, and local governments reach equilibrium. In asymmetric games, stable states must correspond to pure strategies; thus, the equilibrium points after excluding mixed strategies are: $E_1(0,0,0), E_2(0,0,1), E_3(0,1,0), E_4(0,1,1)$, $E_5(1,0,0), E_6(1,0,1), E_7(1,1,0), E_8(1,1,1)$ (see Table 4).

To analyze the eigenvalue signatures of these equilibrium points, Assumption 4 (H4) is proposed: $\delta R_1^1 + \beta S_1 - (1-\gamma)T_1 > 0; (1-\delta)R_1^1 + (1-\beta)S_1 - (1-\gamma)T_1 > 0; (1-\zeta)P_1^3 - S_1 - G_1 > 0$, When other participants choose "collaborate, " the net benefit of choosing "collaborate" exceeds that of "refuse collaboration". Three scenarios emerge:

Scenario 1: $\varepsilon R_1^2 + \beta S_1 - (1-\gamma)T_1 < 0$ *and* $(1-\varepsilon)R_1^2 + (1-\beta)S_1 - (1-\gamma)T_1 < 0$, when the government actively promotes collaboration but other participants "refuse collaboration," the net benefit of choosing "collaborate" is less than that of "refuse collaboration." The system stabilizes at two equilibrium points: $E_2(0,0,1), E_8(1,1,1)$.

Scenario 2: $\varepsilon R_1^2 - T_1 > 0$ or $(1-\varepsilon)R_1^2 - T_1 > 0$, when the government withdraws support and any participant gains higher net benefits from "collaborate" than "refuse" despite others' refusal, the system converges to a single equilibrium point:$E_8(1,1,1)$.

Scenario 3: $\varepsilon R_1^2 - T_1 < 0$ *and* $\varepsilon R_1^2 + \beta S_1 - (1-\gamma)T_1 > 0$ *or* $(1-\varepsilon)R_1^2 - T_1 < 0$ *and* $(1-\varepsilon)R_1^2 + (1-\beta)S_1 - (1-\gamma)T_1 > 0$, when the government actively promotes collaboration and participants gain higher net benefits from "collaborate" despite others' refusal, but lose benefits if the government withdraws support, the system stabilizes at a single equilibrium point:$E_8(1,1,1)$.

Table 4: Local Stability Analysis of Equilibrium Points in the Incentive Phase

Equilibrium Point	Scenario 1		Scenario 2		Scenario 3	
E_i	$(\lambda_1,\lambda_2,\lambda_3)$	Stability	$(\lambda_1,\lambda_2,\lambda_3)$	Stability	$(\lambda_1,\lambda_2,\lambda_3)$	Stability
$(0,0,0)$	$(-,-,+)$	Unstable	$(+,+,+)$	Saddle Point	$(-,-,+)$	Unstable
$(0,0,1)$	$(-,-,-)$	ESS	$(+,+,-)$	Unstable	$(+,+,-)$	Unstable
$(0,1,0)$	$(+,+,+)$	Saddle Point	$(+,-,+)$	Unstable	$(+,+,+)$	Saddle Point
$(0,1,1)$	$(+,+,-)$	Unstable	$(+,-,-)$	Unstable	$(+,-,-)$	Unstable
$(1,0,0)$	$(+,+,+)$	Saddle Point	$(-,+,+)$	Unstable	$(+,+,+)$	Saddle Point
$(1,0,1)$	$(+,+,-)$	Unstable	$(-,+,-)$	Unstable	$(-,+,-)$	Unstable
$(1,1,0)$	$(-,-,+)$	Unstable	$(-,-,+)$	Unstable	$(-,-,+)$	Unstable
$(1,1,1)$	$(-,-,-)$	ESS	$(-,-,-)$	ESS	$(-,-,-)$	ESS

3.2.2 Governance Phase

Similarly, based on the analysis, the pure-strategy equilibrium points of the governance-phase game system are: $E_1(0,0,0), E_2(0,0,1), E_3(0,1,0), E_4(0,1,1), E_5(1,0,0), E_6(1,0,1), E_7(1,1,0), E_8(1,1,1)$ (see Table 5).

Assumption 5 (H5): $\kappa R_2^1 - (1-\iota)T_2 + \theta S_2 - \eta C_2 + M_1 + N_1 > 0; (1-\kappa)R_2^1 + (1-\theta)S_2 - (1-\eta)C_2 - (1-\iota)T_2 + M_2 + N_2 > 0; (1-\mu)P_2^3 - S_2 - G_2 > 0$, when other participants choose "continue collaboration, " the net benefit for each participant choosing "continue collaboration" exceeds that of "terminate collaboration" . Three scenarios emerge:

Scenario 4: $\nu R_2^2 - (1-\iota)T_2 + \theta S_2 + M_1 + N_2 < 0$ *and* $(1-\nu)R_2^2 + (1-\theta)S_2 - (1-\iota)T_2 + M_2 + N_1 < 0$, when the government actively promotes collaboration while other participants "terminate collaboration, " the net benefit of choosing "continue collaboration" is less than that of "terminate collaboration." In this case, the system has two stable equilibrium points: $E_2(0,0,1), E_8(1,1,1)$.

Scenario 5: $\nu R_2^2 + N_2 - T_2 > 0$ *or* $(1-\nu)R_2^2 + N_1 - T_2 > 0$, when the government withdraws support, and any participant gains higher net benefits from "continue collaboration" than "terminate collaboration" even if others terminate collaboration, the system converges to a single equilibrium point : $E_8(1,1,1)$.

Scenario 6: $\nu R_2^2 + N_2 - T_2 < 0$ *and* $\nu R_2^2 - (1-\iota)T_2 + \theta S_2 + M_1 + N_2 > 0$ *or* $(1-\nu)R_2^2 + N_1 - T_2 < 0$ *and* $(1-\nu)R_2^2 + (1-\theta)S_2 - (1-\iota)T_2 + M_2 + N_1 > 0$,

when the government actively promotes collaboration and other participants "terminate collaboration, " the net benefit of "continue collaboration" exceeds that of "terminate collaboration"; If the government withdraws support, the net benefit of "continue collaboration" is less than that of "terminate collaboration, "the system stabilizes at a single equilibrium point :$E_8(1,1,1)$.

Table 5: Local Stability Analysis of Equilibrium Points in the Governance Phase

Equilibrium Point	Scenario 1		Scenario 2		Scenario 3	
E_i	$(\lambda_1,\lambda_2,\lambda_3)$	Stability	$(\lambda_1,\lambda_2,\lambda_3)$	Stability	$(\lambda_1,\lambda_2,\lambda_3)$	Stability
$(0,0,0)$	$(-,-,+)$	Unstable	$(+,+,+)$	Saddle Point	$(-,-,+)$	Unstable
$(0,0,1)$	$(-,-,-)$	ESS	$(+,+,-)$	Unstable	$(+,+,-)$	Unstable
$(0,1,0)$	$(+,+,+)$	Saddle Point	$(+,-,+)$	Unstable	$(+,+,+)$	Saddle Point
$(0,1,1)$	$(+,+,-)$	Unstable	$(+,-,-)$	Unstable	$(+,-,-)$	Unstable
$(1,0,0)$	$(+,+,+)$	Saddle Point	$(-,+,+)$	Unstable	$(+,+,+)$	Saddle Point
$(1,0,1)$	$(+,+,-)$	Unstable	$(-,+,-)$	Unstable	$(-,+,-)$	Unstable
$(1,1,0)$	$(-,-,+)$	Unstable	$(-,-,+)$	Unstable	$(-,-,+)$	Unstable
$(1,1,1)$	$(-,-,-)$	ESS	$(-,-,-)$	ESS	$(-,-,-)$	ESS

4 MATLAB Numerical Simulation Analysis

To more intuitively analyze the dynamic evolution of industry-university-research collaboration and the sensitivity of relevant parameters, initial parameter values are set, and numerical simulations are conducted using MATLAB. In the selection of simulation values, Sterman and Zhu Yan [14] argue that simulation models aim to reveal the essential laws of system behavior, with the most critical aspect being ensuring the correctness of the model structure. The choice of initial parameter values affects the relative amplitude of system evolution but does not alter the overall trajectory. Therefore, with the assistance of vocational school administrators and enterprise experts, and by drawing on the parameter-setting principles of Wu Jie et al. [15], this study assigns values to model parameters based on the practical development of deep industry-university-research collaboration.

4.1 Evolutionarily Stable Strategies

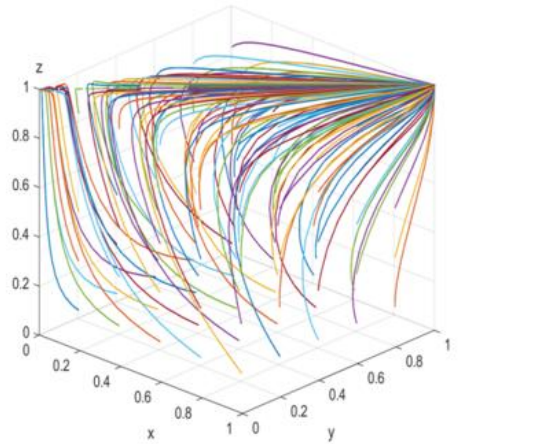
4.1.1 Incentive Phase

A unified premise $\delta R_1^1+\beta S_1-(1-\gamma)T_1>0; (1-\delta)R_1^1+(1-\beta)S_1-(1-\gamma)T_1>0; (1-\zeta)P_1^3-S_1-G_1>0$ is established to ensure that when other participants choose "collaborate, " the benefits of collaboration outweigh those of non-collaboration.

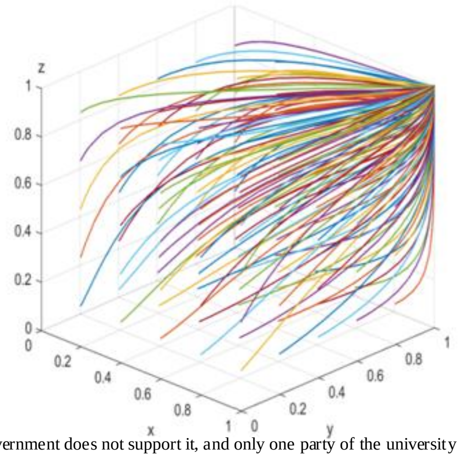
For Scenario 1, when $\varepsilon R_1^2+\beta S_1-(1-\gamma)T_1<0$ and $(1-\varepsilon)R_1^2+(1-\beta)S_1-(1-\gamma)T_1<0, E_2(0,0,1), E_8(1,1,1)$are evolutionarily stable equilibrium points. Parameter Set 1: $P_1^1=20; P_1^2=20; P_1^3=40; R_1^1=30; R_1^2=8; S_1=5; C_1=10; T_1=15; G_1=10; \alpha=\beta=\gamma=\delta=\varepsilon=\zeta=0.5$, The evolutionary paths are shown in Figure 2(a). Simulation results indicate that the probability of the government "supporting collaboration" continuously increases. In most cases, the probability of institutions "collaborating" also increases, though a small fraction of cases show institutions leaning toward "refusing collaboration." This occurs because in Scenario 1, when the initial willingness of Institution-Enterprise leans toward collaboration and the premise that each party gains higher benefits from collaboration holds, the probability of all three parties "collaborating" gradually rises. However, if the initial willingness of any party is too low, the benefits of "refusing collaboration" are likely higher than those of "collaborating, " leading to low Institution-Enterprise collaboration willingness during contract signing, with only the government actively promoting cooperation.

For Scenario 2, when $\varepsilon R_1^2 - T_1 > 0$ or $(1-\varepsilon)R_1^2 - T_1 > 0, E_8(1,1,1)$ is the equilibrium point. Parameter Set 2: $P_1^1 = 20; P_1^2 = 20; P_1^3 = 40; R_1^1 = 30; R_1^2 = 20; S_1 = 5; C_1 = 10; T_1 = 8; G_1 = 10; \alpha = \beta = \gamma = \delta = \varepsilon = \zeta = 0.5$, as shown in Figure 2(b), the probability of all three parties "collaborating" continuously increases. In Scenario 2, collaboration risks are low, and the benefits of unilateral collaboration are high—meaning that losses from the other party's breach are minimal, while the expected benefits of collaboration remain high. Consequently, all parties tend to "collaborate." This scenario is more common in regions with advanced industry-university-research collaboration, where risk costs are low, expected benefits remain high, and the government no longer needs excessive intervention, as Institution-Enterprise maintain strong collaboration willingness.

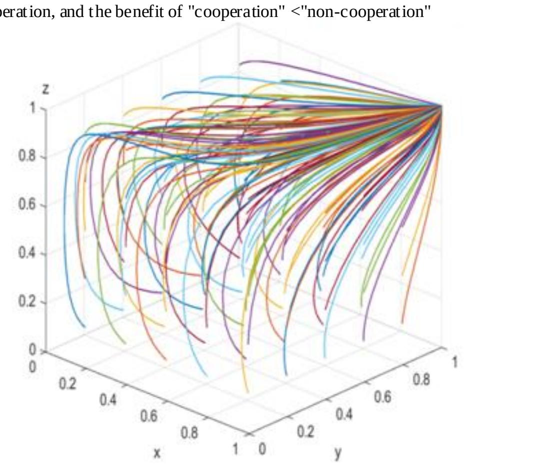
For Scenario 3, when $\varepsilon R_1^2 - T_1 < 0\ and\ \varepsilon R_1^2 + \beta S_1 - (1-\gamma)T_1 > 0\ or\ (1-\varepsilon)R_1^2 - T_1 < 0\ and\ (1-\varepsilon)R_1^2 + (1-\beta)S_1 - (1-\gamma)T_1 > 0, E_8(1,1,1)$ is the equilibrium point. To satisfy these conditions and differentiate outcomes, Parameter Set 3:$P_1^1 = 20; P_1^2 = 20; P_1^3 = 40; R_1^1 = 30; R_1^2 = 15; S_1 = 5; C_1 = 10; T_1 = 15; G_1 = 10; \alpha = \beta = \gamma = \delta = \zeta = 0.5$ and Parameter Set 4: $P_1^1 = 20; P_1^1 = 20; P_1^3 = 40; R_1^1 = 30; R_1^2 = 25; S_1 = 5; C_1 = 10; T_1 = 15; G_1 = 10; \alpha = \beta = \gamma = \delta = \zeta = 0.5$, with results shown in Figure 2(c) and 2(d). The numerical simulation results indicate that when the initial willingness of vocational colleges to cooperate with enterprises is at a low level, government intervention becomes a key decisive factor in whether industry university research cooperation can be successfully achieved. This feature is particularly prominent in the fourth set of parameter simulation results. In scenario 3, when there is a significant information asymmetry between vocational colleges and enterprises, the benefits obtained from unilateral participation in cooperation are difficult to offset potential risks. At this time, strong government guidance and intervention are necessary to achieve stable and sustainable deep integration of industry, academia, and research.



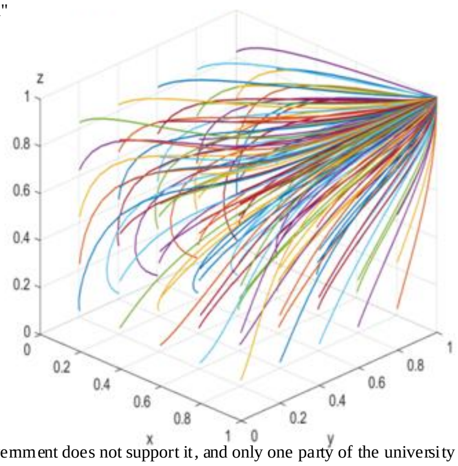
(a) Government support, only one party of school and enterprise is biased towards cooperation, and the benefit of "cooperation" <"non-cooperation"



(b) The government does not support it, and only one party of the university and enterprise is biased towards cooperation. The benefits of "cooperation"> "non-cooperation"



(c) Government support, only one party of school and enterprise is biased towards cooperation, and the benefit of "cooperation" >"non-cooperation"



(d) The government does not support it, and only one party of the university and enterprise is biased towards cooperation. The benefits of "cooperation" < "non-cooperation"

Figure 2: Evolutionary Stability Analysis of the Incentive Phase

4.1.2 Governance Phase

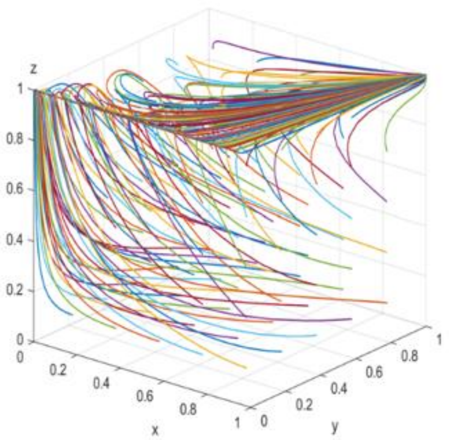
A unified premise $\kappa R_2^1 - (1-\iota)T_2 + \theta S_2 - \eta C_2 + M_1 + N_1 > 0; (1-\kappa)R_2^1 + (1-\theta)S_2 - (1-\eta)C_2 - (1-\iota)T_2 + M_2 + N_2 > 0; (1-\mu)P_2^3 - S_2 - G_2 > 0$ ensures that when other participants "continue collaboration, " the benefits of "continue collaboration" for each participant exceed those of "terminate collaboration."

For Scenario 4, when $\nu R_2^2 - (1-\iota)T_2 + \theta S_2 + M_1 + N_2 < 0$ *and* $(1-\nu)R_2^2 + (1-\theta)S_2 - (1-\iota)T_2 + M_2 + N_1 < 0, E_2(0,0,1), E_8(1,1,1)$ are equilibrium points. Parameter Set 5: $P_2^1 = 30; P_2^2 = 30; P_2^3 = 55; R_2^1 = 60; R_2^2 = 15; C_2 = 20; S_2 = 10; T_2 = 50; G_2 = 15; M_1 = 5; M_2 = 5; N_1 = 5; N_2 = 5; \eta = \theta = \iota = \kappa = \nu = \mu = 0.5$, Evolutionary paths are shown in Figure 3(a). Simulation results indicate that the probability of the government "supporting collaboration" steadily increases, but in a minority of cases, Institution-Enterprise ultimately lean toward "terminate collaboration." The cooperative attitude of institutions has a more significant impact on strategic outcomes than that of enterprises. This occurs because in Scenario 4, when Institution-Enterprise governance willingness is too low, influenced by information asymmetry, they tend toward pessimistic assumptions and conservative actions, perceiving higher net benefits from breaching contracts than continuing collaboration.

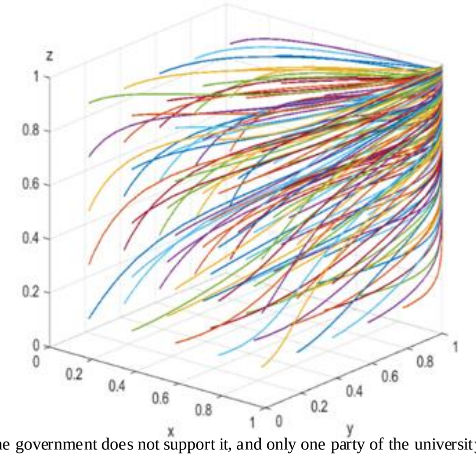
For Scenario 5, when $\nu R_2^2 + N_2 - T_2 > 0$ *or* $(1-\nu)R_2^2 + N_1 - T_2 > 0, E_8(1,1,1)$ is the equilibrium point. Parameter Set 6: $P_2^1 = 30; P_2^2 = 30; P_2^3 = 55; R_2^1 = 60; R_2^2 = 40; C_2 =$

$20; S_2 = 10; T_2 = 20\ ; G_2 = 15; M_1 = 5; M_2 = 5; N_1 = 5; N_2 = 5; \eta = \theta = \iota = \kappa = \nu = \mu = 0.5$, results are shown in Figure 3(b).

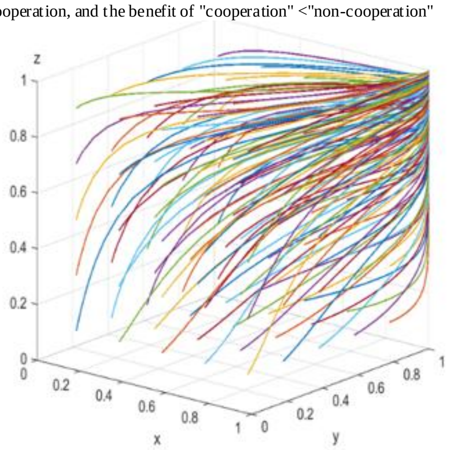
For Scenario 6, when $\nu R_2^2 + N_2 - T_2 < 0$ *and* $\nu R_2^2 - (1-\iota)T_2 + \theta S_2 + M_1 + N_2 > 0$ *or* $(1-\nu)R_2^2 + N_1 - T_2 < 0$ *and* $(1-\nu)R_2^2 + (1-\theta)S_2 - (1-\iota)T_2 + M_2 + N_1 > 0$, $E_8(1,1,1)$ is the equilibrium point. To differentiate outcomes, Parameter Set 7:$P_2^1 = 30; P_2^2 = 30; P_2^3 = 55; R_2^1 = 60; R_2^2 = 30; C_2 = 20; S_2 = 10; T_2 = 20; G_2 = 15; M_1 = 5; M_2 = 5; N_1 = 7; N_2 = 3$, and Parameter Set 8 :$P_2^1 = 30; P_2^2 = 30; P_2^3 = 55; R_2^1 = 60; R_2^2 = 30; C_2 = 20; S_2 = 10; T_2 = 20; G_2 = 15; M_1 = 5; M_2 = 5; N_1 = 3; N_2 = 7; \eta = \theta = \iota = \kappa = \nu = \mu = 0.5$are defined, with evolutionary paths shown in Figure 3(c) and 3(d). Simulations reveal that in Scenarios 5 and 6, the probability of "continue collaboration" consistently rises, indicating that government intervention has minimal impact on strategy selection during the governance phase. Compared to the incentive phase, the system exhibits greater stability. In Scenario 5, without active government intervention, Institution-Enterprise gain higher benefits from continuing governance participation despite the other party's breach. In Scenario 6, even if the government may actively intervene or withdraw, its benefits from "supporting collaboration" always exceed those of "abandoning collaboration, " leading to sustained intervention. Regardless of the other party's actions, Institution-Enterprise benefit more from "continue collaboration, " making it the optimal strategy in both scenarios.



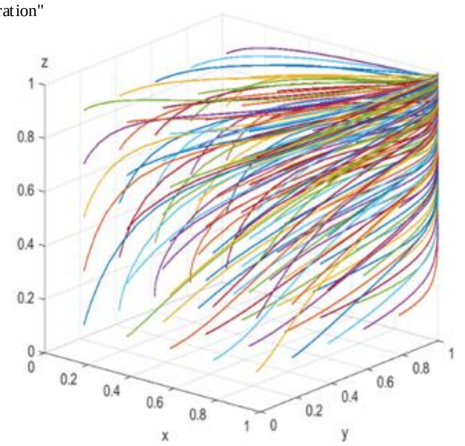
(a) Government support, only one party of school and enterprise is biased towards cooperation, and the benefit of "cooperation" <"non-cooperation"



(b) The government does not support it, and only one party of the university and enterprise is biased towards cooperation. The benefits of "cooperation"> "non-cooperation"



(c) Government support, only one party of school and enterprise is biased towards cooperation, and the benefit of "cooperation" >"non-cooperation"



(d) The government does not support it, and only one party of the university and enterprise is biased towards cooperation. The benefits of "cooperation" < "non-cooperation"

Figure 3: Evolutionary Stability Analysis of the Governance Phase

4.2 Simulation Parameter Analysis

To more intuitively reflect the impact of parameter changes on the collaborative behavior of participants in industry-university-research cooperation, initial parameter values are set based on the aforementioned assumptions, and numerical simulations are conducted using MATLAB.

4.2.1 Incentive Phase

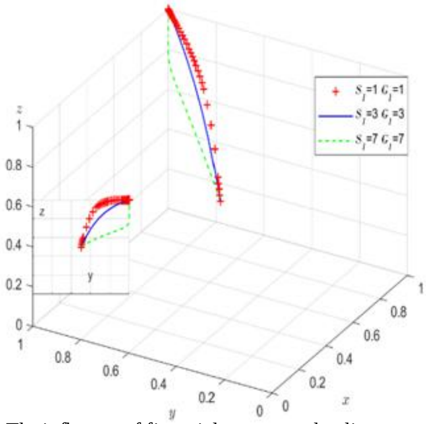
Parameter Set 9: $P_1^1 = 30; P_1^2 = 30; P_1^3 = 30; R_1^1 = 20; R_1^2 = 10; 0 < S_1 < 7.5; 0 < C_1 < 20; 0 < T_1 < 11.7; 0 < G_1 < 7.5; 0 < \gamma < 1; \alpha = \beta = \delta = \varepsilon = \zeta = 0.5$. Satisfies Assumptions 2 and 4 of the incentive phase. Based on Parameter Set 9, the effects of funding support (S_1) , contracting costs (C_1) , and risk costs (T_1) on the evolutionary game dynamics are analyzed.

(1) Impact of Funding and Policy Support on Collaboration Establishment

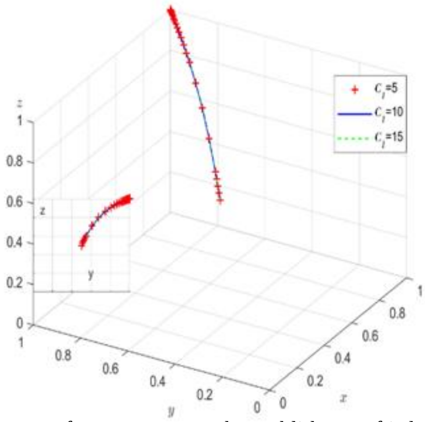
Assign $C_1 = 10, T_1 = 5,$ assign S_1 values of 1, 3, 7, with G_1 values of 1, 3, 7 and γ values of $0.1, 05, 0.9$ adjusting accordingly. Results after 50 iterations are shown in Figure 4(a). Simulations indicate: when the government actively promotes collaboration, stronger financial subsidies and policy support accelerate the evolution of Institution-Enterprise contract signing. As S_1, G_1 increasing, the risk cost coefficient decreases due to government-driven improvements in new quality productive forces, ultimately raising collaboration probabilities. When the government bears excessive funding and policy support, the probability of Institution-Enterprise collaboration stabilizes at 1, after which the government's support probability increases.

(2) Impact of Contracting Costs and Risk Costs on Collaboration Establishment

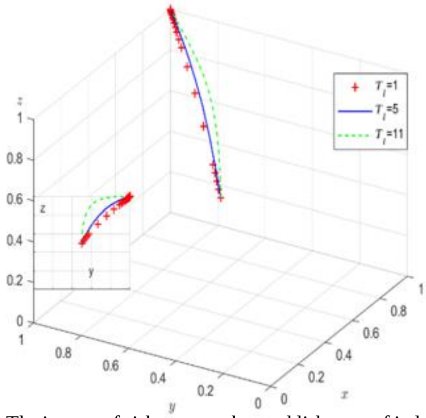
Assign $S_1 = 3, G_1 = 3, T_1 = 5, \gamma = 0.5,$ assign C_1 values of 5, 10, 15, results after 50 iterations are shown in Figure 4(b). Assign $S_1 = 3, G_1 = 3, C_1 = 10, \gamma = 0.5,$ assign T_1 values of 1, 5, 11, results are shown in Figure 4(c). Simulations reveal: during the incentive phase, Institution-Enterprise are more sensitive to expected risk costs , while contracting costs have a relatively minor influence.



(a) The influence of financial support and policy support on the establishment of industry-university-research cooperation



(b) The impact of contract costs on the establishment of industry-university-research cooperation



(c) The impact of risk cost on the establishment of industry-university-research cooperation

Figure 4: Parameter Sensitivity Analysis of the Incentive Phase

4.2.2 Governance Phase

Parameter Set 10: $P_2^1 = 40; P_2^2 = 40; P_2^3 = 40; R_2^1 = 30; R_2^2 = 15; 0 < C_2 < 42.5; 0 < S_2 < 10; 0 < T_2 < 42.5; 0 < G_2 < 10; 0 < M_1 < 20; 0 < M_2 < 20; 0 < N_1 < 20; 0 < N_2 < 20; 0 < \iota < 1; \eta = \theta = \kappa = \nu = \mu = 0.5$, Satisfies Assumptions 3 and 5 . Based on this set, the impacts of funding support (S_2) , policy support (G_2) , governance costs (C_2) , risk costs (T_2) , fines (M) and breach penalties (N) on the evolutionary game are analyzed.

(1) Impact of Funding Support and Policy Costs on Governance Effectiveness

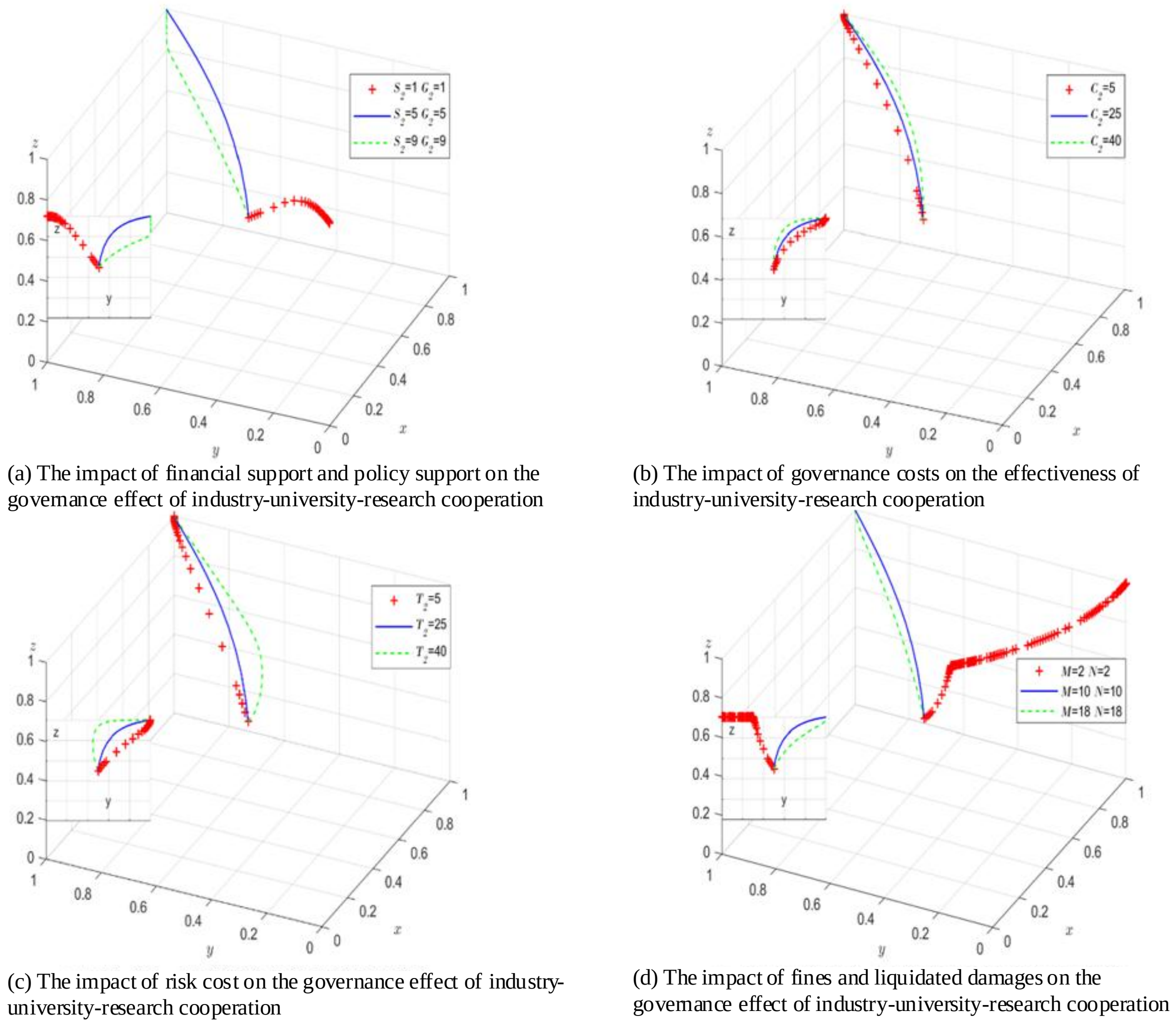
Assign $C_2 = 25, T_2 = 25,$ assign G_2 values of 1, 5, 9, with corresponding S_2 set to 1, 5, 9. Results are shown in Figure 5(a). Simulations indicate that during the governance phase, increased funding and policy support rapidly elevate the level of new quality productive forces in Institution-Enterprise, accelerating their willingness to continue governance participation. However, the government's probability of supporting collaboration grows more slowly. If government support is too weak, leading to low breach costs, the probability of effective governance drops to 0.

(2) Impact of Governance Costs and Risk Costs on Governance Effectiveness

Assign $S_2 = 5, G_2 = 5, T_2 = 25, M_1 = M_2 = N_1 = N_2 = 10, \iota = 0.5,$ assign C_2 values of 5, 25, 40 (results in Figure 5(b)) ; Assign $S_2 = 5, G_2 = 5, C_2 = 25, M_1 = M_2 = N_1 = N_2 = 10, \iota = 0.5,$ assign T_2 values of 5, 25, 40 (results in Figure 5(c)). Simulations reveal that both governance and risk costs induce fluctuations in strategy evolution, slowing the rate at which Institution-Enterprise governance participation probabilities rise to 1. Compared to the incentive phase, governance costs now significantly affect strategy curves. Responses to risk costs are more pronounced: excessively high risk costs initially reduce Institution-Enterprise willingness, which later rebounds with strong government intervention.

(3) Impact of Fines and Breach Penalties on Governance Effectiveness

Assign $S_2 = 5, G_2 = 5, T_2 = 25, C_2 = 25, \iota = 0.5$, assign M, N values of 2, 10, 18. Results are shown in Figure 5(d). Simulations indicate that stricter penalties (higher breach costs) rapidly strengthen willingness to participate in governance, while lenient penalty policies weaken collaboration willingness. Compared to institutions, enterprises exhibit stronger responsiveness to breach costs: when penalties are too low, enterprise opportunistic behavior increases, driving collaboration probabilities toward 0, while institutional probabilities rebound after an initial decline.



(a) The impact of financial support and policy support on the governance effect of industry-university-research cooperation

(b) The impact of governance costs on the effectiveness of industry-university-research cooperation

(c) The impact of risk cost on the governance effect of industry-university-research cooperation

(d) The impact of fines and liquidated damages on the governance effect of industry-university-research cooperation

Figure 5: Parameter Sensitivity Analysis of the Governance Phase

5 Research Conclusions and Discussion

This study constructed a two-stage evolutionary game model of industry university research cooperation covering local governments, enterprises, and vocational colleges. Numerical simulations were conducted using MATLAB software, and the results showed that the realization of deep integration of industry university research highly relies on government funding support and policy guidance. However, under the assumption of bounded rationality, if policy incentives are excessive, it is easy to induce opportunistic behavior among cooperative entities. The key factors affecting industry university research cooperation show significant differences at different stages: (1) in the incentive stage, the impact of cooperation costs on the construction of industry university research partnerships is relatively weak; (2) In the governance phase, the cost of governance directly determines the sustainability of cooperation. (3) The risk cost has a critical impact on the strategic choices of both stages, and in the governance stage, the sensitivity of enterprises to risks is significantly higher than that of vocational colleges.

5.1 Give full play to the coordinating role of the government to improve the efficiency of resource allocation

Strategic emerging industries and future industries, as the core driving force of new high-quality productivity, often face challenges such as high investment costs and low expected returns in vocational education cooperation. Government funding and policy support not only reduce the marginal cooperation costs of these industry enterprises, ensuring their active participation, but also help to form a deep integration system between vocational education and new high-quality productivity. Specific measures include incorporating cooperation between vocational colleges and industries into public budgets, providing fiscal incentives (such as tax credits and low interest loans), establishing special funds to reward model enterprises in emerging industries, and developing tailored policies to encourage interdisciplinary cooperation while avoiding a one size fits all approach.

5.2 Strengthen cooperation in emerging technologies and build a governance system

The risk cost has a significant impact on the final results of both stages: (1) in the incentive stage. The various risks caused by information asymmetry, communication costs, and free riding effects need to be resolved by strengthening the momentum of emerging technology cooperation. Financial support for joint research and development projects in fields such as artificial intelligence, big data, and the Internet of Things should be increased, and innovative partnerships that promote high-quality productivity development should be rewarded. (2) In the governance phase. With the increasing risk sensitivity of enterprises, it is necessary to formulate targeted support policies that are suitable for their actual needs, rely on blockchain and big data technology to enhance cooperation transparency, and reduce management and operation costs; At the same time, priority should be given to ensuring that enterprises enjoy financial preferential policies such as tax reductions and talent support, and a sound punishment mechanism should be formulated to curb opportunistic behavior. The ownership of intellectual property rights of all parties involved in cooperation should be clarified, and the sharing and transformation of technological achievements should be promoted through digital platforms to ensure the sustainability of industry university research cooperation.

5.3 Promote multi-party cooperation and achieve two-way collaboration

New quality productivity essentially serves the development of emerging and future industries. There is inherent heterogeneity between vocational education institutions (educational entities) and enterprises (economic entities), which inevitably leads to conflicts of interest and cognitive biases in their cooperation process. Therefore, clarifying the common interests and demands of both parties, and building a fair, reasonable, and balanced mechanism for sharing interests, have become key prerequisites for promoting the deep integration of industry, academia, and research, and achieving the coordinated development of education and industry. In the cooperation incentive stage, a formal contract should be established to clarify the cost sharing, profit distribution, and emergency response plans of both parties, clearly define the specific standards for cost input and profit distribution, and clarify the emergency response mechanism to provide guarantees for stable cooperation. In the stage of cooperative governance, in response to the problems of superficial cooperation, mismatched resource allocation, and disconnect between talent cultivation and industrial demand in current industry university research cooperation, it is necessary to promote precise alignment between cooperation projects and regional economic development needs, synchronously build an industry university research information sharing platform, and achieve real-time matching between talent supply and enterprise demand. Enterprises should actively and deeply participate in the curriculum design, teaching plan formulation, and teaching material development of vocational education, to solve the problem of the disconnect between technical talent training and job requirements, and ensure that the trained talents can adapt to the requirements of modern industrial development. By deeply linking vocational education with strategic emerging industries and cultivating applied talents with corresponding skills, we can promote the two-way empowerment of education, industry, and innovation, and achieve the deep integration of the education chain, talent chain, industry chain, and innovation chain.

Fund projects

National Social Science Foundation project: Study on multidimensional effect and development of rural industrial integration in ethnic minority areas of southern Xinjiang (21XMZ062); High-level talent research start-up project of Shihezi University: Research on the dynamic construction mechanism of vocational education majors based on industrial structure adjustment in the Production Corps (number: RCSK202309).

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Yuhan Chen and Ping Ma have contributed equally to this article.

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