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Computer-aided Numerical Simulation Analysis of Collaborative Innovation within Government-Industry-University-Institute Models Using Evolutionary Game Theory

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Abstract: Collaborative innovation among government, industry, universities, and institutes (GIUI) is an essential approach for achieving national development driven by innovation and enhancing regional competitiveness. However, the existing collaborative innovation faces challenges such as uneven distribution of benefits, unequal risk sharing, and inadequate institutional and policy support. This study harnesses the power of numerical simulation to dissect the complexities of GIUI collaboration, using the evolutionary game theory to construct a payoff matrix. By conducting numerical simulations using the Matlab software program, we identify two asymptotically stable points in the system. Our findings highlight that variables such as the gain coefficient (t) from government engagement with industry and academic institutes, the preferential tax rate (K) offered to industry, and the subsidy (A) invested in academic institutes significantly influence the consensus towards collaborative innovation. Furthermore, our analysis suggests that governments should actively monitor and coordinate the distribution of benefits within complex multi-agent collaborative innovation networks. By taking an active role in ensuring a fair and efficient distribution, governments can directly address the challenges arising from the current framework. This study employs computational methods to offer an advanced approach to understanding and optimizing the dynamics of collaborative innovation within the GIUI framework. By utilizing computer methods such as numerical simulation, we gain valuable insights into the complexities of collaborative innovation and provide a foundation for government decision-making.

Keywords: Government, Industry, University and Institute, Collaborative Innovation, Evolutionary Game Theory, Computer Methods, Numerical Simulation.

I. INTRODUCTION

The widespread application of numerical simulation in engineering and management processes significantly enhances decision-making effectiveness[1].The integration of computer-aided numerical simulation analysis has emerged as a valuable tool for studying collaborative innovation [2]. These advanced systems empower researchers to analyze the dynamic dynamics of collaborative processes, explore diverse scenarios, and evaluate the effectiveness of different strategies. By simulating interactions among multiple stakeholders, these systems play a crucial role in identifying bottlenecks, assessing intervention impacts, and optimizing collaborative efforts [3]. Simulation techniques facilitate the modeling and analysis of collaborative processes, enabling the testing of multiple scenarios and the evaluation of various strategies. This comprehensive approach not only helps identify bottlenecks but also assesses the impact of interventions and optimizes collaborative efforts.

Global economic competition intensifying, and technology rapidly iterating and updating will create unprecedented new markets, new demands, new supplies and new values. In a highly complex and uncertain environment, innovation is essential for an enterprise to formulate organizational strategies, bring innovation to the market, meet customer needs and ensure survival[4], but relying sole on in-house expertise and limited resources to achieve continues innovation appears to be a difficult task. Therefore, the high-quality development of innovation subjects can be better promoted by the complex cooperation of different innovation subjects to realize the achievements of 1+1>2 in the collaborative innovation process, to create a dynamic innovation ecosystem and to construct the ‘industry-university- institute’ innovation collaborative system (university-institute hereinafter referred to as academic institutes) [5].

‘Industry-university-institute’ refers to the effective combination of innovation factors by cooperating with enterprises as the technology demand side and universities and academic institutes as the technology supply side, to create knowledge and technology research around common goals [6]. With the characteristics of

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complementary resources and technology sharing, ‘Industry-university-institute’ collaborative innovation has become new ways for businesses to collaborate across borders [7]. At the same time, Industry-university-institute cooperative innovation is a new organizational mode that is fiercely challenged by the state and region, which has become the new mainstream of national innovation activities. At the same time, the theoretical research on insight into cooperative innovation mechanism has gradually become prominent. Obviously, collaboration is the trend of technological prosperity, while cross-organizational collaborative innovation is a huge challenge. There are many problems in the process of multi-party cooperation, such as the performance of cooperative innovation is not as high as expected, the sustainability of cooperative development and so on [8].

Industry, a group of productive enterprises or organizations that produce or supply goods, services, or sources of income. Enterprise innovation is a complex and multi-dimensional system. The culture, system, human resources and other factors of the city where the enterprise is located are essential conditions for innovation. Originating from the external market environment, the enterprise's own activity ability and innovation strength can better promote the enterprise innovation. While the external factors can be established through the interaction between enterprises, they still need the support of the city or the government [9]. Government is one of the important subjects of cooperative innovation, and the combination of different subjects conducive to win-win results and greater efficiency. The government and science and technology authorities should clarify their leading position, guide various parties to strengthen the cooperation of ‘Industry-university-institute’, and guide the construction of the service system of third-party evaluation institutions and standardize various service works [10].

In the context of low-carbon technology innovation, a study analyzes the cooperation process among universities, enterprises, and governments using numerical simulation. This research found that tripartite cooperation could improve the social values of all parties involved. By constructing a collaborative innovation model of government, universities, and enterprises, the study revealed that the influence of government incentive policies differs between universities and enterprises, with enterprises being more sensitive to punishment and income distribution [11]. In the realm of university-industry collaborative innovation, a stochastic evolutionary game model was constructed to analyze the benefits of alliances between universities and firms. The study found that the inappropriateness of a deterministic model and the construction of a stochastic evolutionary game model can provide insights into the impact of innovation efficiency, the degree of complementarity of knowledge, and knowledge spillover coefficients on collaborative innovation alliances [12].

However, even though the government has issued a number of incentive policies such as encouraging ‘Industry-university-institute’ innovation and demand, subsidies for public service platforms, the ‘Industry-university-institute’ collaborative innovation still faces many problems, mainly focusing on behaviors such as the majority of participants prefer to maximize their respective interests, and a small number of participants cheat and supplement, and the interaction system of market drive, government guidance, capital support and bridging platform has not yet been formed. As a result, Cross-border cooperation and innovation ended in discord.

Therefore, scholars have carried out multi-faceted research on multi-participant collaborative innovation, such as connotation, model and influencing factors. Among them, the Triple Helix Model [13], a typical cooperative relationship among tripartite cooperation putforward by Etzkowitz in 1997, which is a commonly used theory of collaborative innovation of multiple entities. In this model, the cooperation subjects have clear organizational boundaries. There is a clear division of labor and cooperation among three parts, which further reveals the multiple reciprocal relations between different cooperation subjects when the commercialization of knowledge has reached a certain stage. The organizations that maintain the triple helix overlap are more complex cross-organizations and more likely to be hybrid autonomous organizations [14].

Based on the triple helix theory, scholars have carried out in-depth research on the mode and application of collaborative innovation from different perspectives and methods. The government should formulate various policies to lower the threshold of innovation cooperation to enhance the leadership ability of enterprise leaders to take risks and innovate [15]. Collaborative research is one of the key indicators to test the research strength of a university, especially to judge the research and innovation ability of scholars, where collaborative innovation has advantages over delegation or endowment [16]. The sharing enthusiasm of innovation alliance is affected by many factors, such as the cost of sharing, the intensity of subsidies, the penalty fee, the reputation incentive of the platform and so on [17]. Encouraging technological innovation, implementing producer responsibility extension measures, transferring management cost, establishing reasonable benefit adjustment mechanism to promote the multi-benefit win-win, greatly affect the stability of inter-organization cooperation and long-term economic feasibility of cooperation [18].

A study using the official data of China in 2020 found that the cooperation between the government and academic and research institutions is conducive to breeding innovation opportunities, but the cooperation effect with the industry is not obvious [19].

II. Bring forward and Construct the Model of 'Government-Industry-University-Institute'(GIUI) Collaborative Innovation

Collaborative innovation requires cooperation among various entities, which means risk bearing and benefit distribution. In today's society, the talents of enterprises come from the research institutes. The research institutes are able to develop continuously depending on the needs of the enterprises. The enterprises cannot leave the research institutes, and the institutes cannot leave the enterprises. Therefore, this leads to the deep cooperation between enterprises and institutes. Both parties invest resources and manpower for collaborative innovation. However, there are often some contradictions, mainly whether the interests are evenly distributed. Therefore, it is necessary to include the government as a participant in the process of benefit distribution and coordination in this system. As the main parts of collaborator, the government is added to the game, and the influence of government financial support and policy support on cooperative innovation is considered. By constructing a tripartite evolutionary game model of government, university and enterprise participation willingness, the research building a new game model, the innovation mechanism of multi-party cooperation under the guidance of the government is analyzed, Multi-party game strategies considering different situation changes, and the solution strategy with better evolution and more stability is sought. Meanwhile, the key points affecting the multi-party cross-border cooperation innovation strategy are found by analyzing the numerical changes.

From a dynamic capabilities perspective, strategic management within the context of open innovation emphasizes the importance of integrating external resources and capabilities. Firms must develop dynamic capabilities to effectively manage open innovation and leverage external resources, the amalgamation of diverse sectoral resources is crucial for successful innovation [20].

Chesbrough examines the outcomes of open innovation, emphasizing its potential challenges and limitations [21]. While open innovation can lead to enhanced firm performance, Chesbrough underscores the significance of mitigating associated risks. This is particularly pertinent in GIUI collaborations, where integrating diverse resources can introduce complexities that necessitate meticulous risk management. Cultural factors, such as trust and social norms, exert a significant influence on innovation behavior and outcomes [22]. The GIUI model encompasses multifaceted collaborations that are intricately shaped by these cultural dynamics, which can either foster or hinder innovation.

The comprehensive framework proposed by Du et al. offers a systematic approach for effectively managing open innovation projects that involve both science-based and market-based partners [23]. Their approach emphasizes the importance of achieving a harmonious integration between scientific and market perspectives.

Some researcher have explored collaborative innovation in the digital age [24], highlighting the transformative impact of digital technologies on collaboration and emphasizing the need for firms to develop complementary capabilities [25].

The utilization of open innovation in scientific problem-solving, encompassing the crowdsourcing of solutions to intricate challenges [26], presents potential advantages while simultaneously acknowledging inherent obstacles. Therefore, collaborative innovation is carried out in multi-disciplinary fields [27], and future studies should explore the dynamics of collaborative innovation in different environments. For example, the problem of co-creation of collaborative value in digital platforms, digital collaboration is both a new opportunity and a solution to previous challenges [28]. The impact of digital technologies on collaborative innovation processes is transformative, leading to the proposal of innovative governance structures for collaboration in GIUI through new concepts, models, and mechanisms [29]. The establishment of effective collaboration frameworks requires the provision of adaptable spaces that cater to participants' diverse needs and practices [30].

Lots of research underscores the importance of open innovation, collaborative innovation, and the integral roles of universities, industry, and government in the innovation process. These studies collectively suggest that successful GIUI collaborations require a balanced approach that incorporates both scientific and market perspectives, enabling collaborative spaces, and a deep understanding of the actors' needs and practices. Government-Industry-University-Institute (GIUI) collaborative innovation model represents a paradigm shift in driving innovation and value creation. This model is predicated on open innovation principles, which advocate for the strategic integration of external resources and capabilities through cross-sectoral collaboration.

Based on the above research, we propose a new game model of government participation in multi-party collaborative innovation. In the new game model of government involvement, the main bodies are the government, enterprises, universities and research institutes (hereinafter referred to as academic institutes). The government undertake supporting, guiding and supervising the cooperation between enterprises and academic institutes. Enterprises and academic institutes open to each other to share their own resources, contacts and so on. Both sides coordinate and complement their own shortcomings. Through continuous game evolution, the cooperation risks can be reasonably shared and the cooperation gains can be shared reasonably, so that the collaborative innovation of both parties can be carried out more smoothly, the optimal decision is made, and the ultimate goal of reducing innovation cost and improving innovation income is realized. The specific collaborative innovation model as Figure 1.

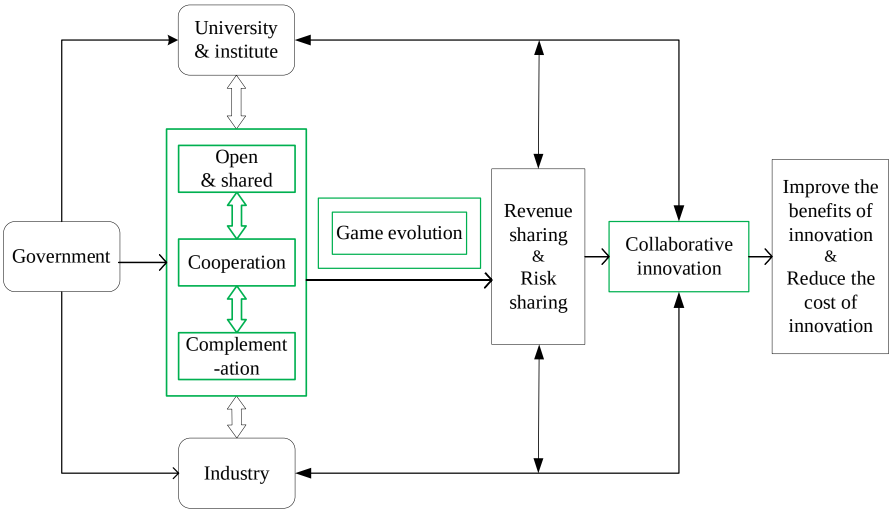

Figure 1: Conceptual Model of 'Government-Industry-University- Institute' Collaborative Innovation

From the analysis of market practice, enterprises and academic institutes are the leading forces of collaborative innovation, so that the guiding and coordinating role of the government is often ignored. The government, as the party that supervises and provides incentives, also receives tax revenue from the sales revenue paid by enterprises for the development of new products, which can be quantified in the national tax bureau. In the initial period of collaborative innovation, universities and enterprises define their respective rights and obligations in the form of contracts, and pay a certain amount of deposit in advance as the guarantee for the execution of contracts.

In the actual progress of cooperation, the government will regularly assess the operational performance across the organization and the completion of the tasks of all participants as the basis for the follow-up funding. Based on this, the following assumptions are given:

(1) Cooperative subjects. In the process of mutual game between the subjects of 'Government-Industry-University-Institute' to make the interests reach equilibrium, there are three main types of participants in the game, namely the government, enterprises and academic institutes. The government is responsible for supervising, coordinating and participating in the equal distribution of benefits; enterprises are responsible for technological innovation and putting theory into practice; academic institutes are responsible for theoretical innovation and research of the latest scientific research achievements. The ultimate goal of the game is to maximise the distribution of benefits by involving all actors in the collaborative innovation process.

(2) Collaboration strategy. In the game process of this study, the government can choose to participate in the coordination and not to participate in the coordination, the set is (participate in coordination, not participate in coordination). Enterprises and academic institutions can freely choose whether to agree to the coordination of the government according to their own interests, and the set is (agree to coordinate, disagree to coordinate).

(3) Cooperation costs. The cost paid by the government in the process of participating in the coordination is C_g, the cost paid by the enterprise in the process of consent and coordination is C_e, and the cost paid by the academic institutes in the process of consent and coordination is C_s.

(4) Cooperation benefits. Social competition is increasingly fierce, in order to advance with the times, each subject will carry out a certain degree of independent reform, but also obtain the corresponding innovation benefits. The benefit that the government does not participate in the coordination is R_g. If the government participates in the coordination process, it will obtain the additional income brought by the enterprise and the academic institutions. Therefore, the additional income coefficient r_1 brought by the enterprise and the additional income coefficient r_2 brought by the academic institutions are introduced. When the enterprise does not agree to

coordinate the collaborative innovation income, the cooperation of both parties is broken, and the enterprise can only obtain its own innovation benefit Re; similarly, when the academic institutions does not agree to coordinate the collaborative innovation benefit, the cooperation of both parties is broken, and the academic institutions can only obtain its own innovation benefit R_s; in the collaborative innovation process in which the government participates in the coordination, if both the enterprise and the academic institutes agree to coordinate, both parties will obtain the gain brought by the government coordination, introducing the same gain coefficient t for both parties; if both parties do not agree to the coordination, the government neither rewards nor punishes. If the enterprise agrees to the coordination and the academic institutes does not agree to the coordination, the government will give tax preference K to the enterprise, while the academic institutes' disagreement will bring it a certain benefit BS. If the enterprise does not agree to the coordination and the academic institutes agrees to the coordination, then the government will invest the subsidy of A in the academic institutes, while the enterprise's disagreement will bring it a certain benefit Be. In the process of collaborative innovation in which the government does not participate in the coordination, if both the enterprise and the academic institutes agree to coordinate, the contradiction will not expand further even without the coordination of the government, which will bring some benefits to each other, which is T. If the enterprise agrees to the coordination but the academic institutes does not agree to the coordination or unilaterally withdraws from the collaborative innovation, the academic institutions shall pay the enterprise penalty P_1 according to the contract signed by both parties. Meanwhile, it will still bring certain benefits B_s to the enterprise due to the disagreement of the academic institutes. If the enterprise does not agree to the coordination and the institute agrees to coordinate or unilaterally withdraw from the collaborative innovation, the enterprise shall pay the penalty P_2 to the institute according to the contract signed by both parties, while at the same time the enterprise will still receive certain benefits due to its non-agreement to coordinate B_e. If both parties do not agree on coordination, the contract is automatically abandoned, the cooperation is ended, and there is no gain or penalty.

(5) Participation probability. In this new game system, if the probability that the government chooses to participate in the coordination and supervise the interest coordination between the enterprises and the academic institutions is $x(0 \leq x \leq 1)$, then the probability of not participating is $(1-x)$; when the conflict of interest and contradiction occurs, the probability of the enterprise agreeing to the coordination is $y(0 \leq y \leq 1)$, and the probability of the enterprise not agreeing to the coordination is $(1-y)$; when the conflict of interest and contradiction occurs, the probability of the academic institutes agreeing to the coordination is $z(0 \leq z \leq 1)$. The probability that the academic institutes disagrees with coordination is $(1-z)$.

III. Analysis of Evolution Mechanism of 'Government -Industry-University-Institute' Collaborative Innovation Game

A. *Game Payment Matrix*

In the model, the government, enterprises and academic institutes make strategy selection according to their own will. Assuming that the intention of the government to participate in collaborative innovation, if the probability of participating in collaborative innovation is x, the willingness of the government to choose not to attend in collaborative innovation is 1-x; the intention of enterprises to select collaborative innovation is:

The following table1 shows the pay matrix strategy portfolio and the revenue profile of governments, enterprises, and academic institutes under different scenarios. Among them, for the government, Y means that the government participates in the supervision and coordination of the benefit distribution of the enterprise and the academic institutes, otherwise N means that the government does not participate in the supervision and coordination; for the enterprises and the academic institutions, Y means that the enterprise and the academic institutes agree to the coordination, whereas N means that the enterprise and the academic institutes do not agree to the coordination.

Table 1: Game Payment Matrix of Government, Enterprises and Academic Institutes

Policy Combination	Government g	Enterprises e	Academic institutes s
(Y,Y,Y)	$Rg(1+r_1+r_2)-C_g$	$Re(1+t)-C_e$	$Rs(1+t)-C_s$
(Y,Y,N)	$Rg(1+r_1+r_2)-C_g-K$	$Re+K-C_e$	$Rs+Bs$
(Y,N,Y)	$Rg(1+r_1+r_2)-C_g-A$	$Re+Be$	$Rs+A-C_s$
(Y,N,N)	$Rg(1+r_1+r_2)-C_g$	Re	Rs
(N,N,N)	Rg	Re	Rs
(N,Y,N)	Rg	$Re+P_1-C_e$	$Rs+Bs-P_1$
(N,N,Y)	Rg	$Re+Be-P_2$	$Rs+p_2-C_s$
(N,Y,Y)	Rg	$Re+T-C_e$	$Rs+T-C_s$

B. Collaborative Innovation Replication Dynamic System and Stability Analysis

According to the results of many games, the government, enterprises and academic institutes can adjust whether the government chooses to participate in the cooperative innovation strategy, and whether the enterprises and the academic institutes agree to the government's regulation. The dynamic evolution process of their decisions can be represented by the dynamic replication system.

In the process of benefit coordination of this new system, the government chooses E_{g1} as the expected benefit to participate in the coordination, E_{g2} to choose not to participate in the coordination, and E_g as the average expected benefit.

$$E_{g1} = yz[Rg(1+r_1+r_2) - C_g] + y(1-z)[Rg(1+r_1+r_2) - C_g - K] + (1-y)z[Rg(1+r_1+r_2) - C_g - A] + (1-y)(1-z)[Rg(1+r_1+r_2) - C_g]$$

$$E_{g2} = (1-z)(1-y)Rg + y(1-z)Rg + (1-y)zRg + yzRg$$

$$E_g = xE_{g1} + (1-x)E_{g2} \tag{1}$$

In the process of benefit coordination, the expected benefit of government coordination is E_{e1}, the expected benefit of government coordination is E_{e2}, and the average expected benefit is E_e.

$$E_{e1} = xz[Re(1+t) - C_e] + x(1-z)[Re - C_e + K] + (1-x)(1-z)(Re + P_1 - C_e) + (1-x)z(Re + T - C_e)$$

$$E_{e2} = xz(Re + B_e) + x(1-z)Re + (1-x)(1-z)Re + (1-x)z(Re + Be - P_2)$$

$$E_e = yE_{e1} + (1-y)E_{e2} \tag{2}$$

In this course of evolution, the expected benefit of government coordination is E_{s1}, E_{s2} is the expected benefit of government coordination, and the average expected benefit is E_s.

$$E_{s1} = xy[Rs(1+t) - C_s] + x(1-y)(Rs - C_s + A) + (1-x)(1-y)(Rs + P_2 - C_s) + (1-x)y(Rs + T - C_s)$$

$$E_{s2} = xy(Rs + Bs) + x(1-y)Rs + (1-x)(1-y)Rs + (1-x)y(Rs + Bs - P_1)$$

$$E_s = zE_{s1} + (1-z)E_{s2} \tag{3}$$

Following the evolutionary game theory, the replication dynamics equations for government, enterprise, and academic institutes are listed as follows, drawing on Taylor and Jonker's Replicator Dynamics model imitation dynamics equation [31]:

$$\begin{cases} f(x) = \frac{dx}{dt} = x(E_{g1} - E_g) = x(1-x)(E_{g1} - E_{g2}) \\ f(y) = \frac{dy}{dt} = y(E_{e1} - E_e) = y(1-y)(E_{e1} - E_{e2}) \\ f(z) = \frac{dz}{dt} = z(E_{s1} - E_s) = z(1-z)(E_{s1} - E_{s2}) \end{cases} \tag{4}$$

Let f (x)=0, f (y)=0, f (z)=0, the equilibrium points of the system are (1, 1, 1), (1, 1, 0), (1, 0, 1), (1, 0, 0), (0, 0, 0), (0, 1, 0), (0, 0, 1), and (0, 1, 1), respectively.

The Jacobian matrix of the model system can be obtained according to the above-mentioned duplicated dynamic equation. According to the analysis of the evolution results of game, when all the eigenvalues are non-positive, the equilibrium point is the stable point of the new system. The Jacobian matrix is as follows:

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

By substituting the eight equalization points into the Jacobian matrix in turn, the eigenvalues of each equilibrium point in the system corresponding to the Jacobian matrix can be obtained in table 2.

Table 2: Eigenvalues of Jacobian Matrix

Equilibrium point	Characteristic Value T_1	Characteristic Value T_2	Characteristic Value T_3
$E_1(1,1,1)$	$-\mathrm{Rg}(r_1+r_2)+C_g$	$-\mathrm{Ret}+C_e+B_e$	$-\mathrm{Rst}+C_s+\mathrm{Bs}$
$E_2(1,1,0)$	$K+C_g-\mathrm{Rg}(1+r_1+r_2)$	C_e-K	$\mathrm{Rst}-C_s-\mathrm{Bs}$
$E_3(1,0,1)$	$A+C_g-\mathrm{Rg}(r_1+r_2)$	$\mathrm{Ret}-C_e-\mathrm{Be}$	C_s-A
$E_4(1,0,0)$	$C_g-\mathrm{Rg}(r_1+r_2)$	$K-C_e$	$A-C_s$
$E_5(0,0,0)$	$\mathrm{Rg}(r_1+r_2)-C_g$	P_1-C_e	P_2-C_S
$E_6(0,1,0)$	$\mathrm{Rg}(r_1+r_2)-C_g-K$	C_e-P_1	$T-C_s-\mathrm{Bs}+P_1$
$E_7(0,0,1)$	$\mathrm{Rg}(r_1+r_2)-C_g-A$	$T-C_e-\mathrm{Be}+P_2$	C_s-P_2
$E_8(0,1,1)$	$\mathrm{Rg}(r_1+r_2)-C_g$	$\mathrm{Be}-P_2-T+C_e$	$\mathrm{Bs}-P_1-T+C_s$

In order to determine the positive and negative signs of each eigenvalue, it is assumed that $Rg(r_1 + r_2) - C_g > 0$, that is, the net income of the government participating in coordination is greater than the net income of not participating in coordination; $Ret - C_e > Be$, that is, with the participation of the government, the net income that the enterprises agree to coordinate is greater than the net income that does not agree to coordinate; $Rst - C_s > Bs$, that is, with the participation of the government, the net income that the academic institutes agree to coordinate is greater than the net income that they do not agree to coordinate; $T - C_e > Be - P_2$, that is, without the participation of the government, the net income that the enterprises agree to coordinate is greater than the net income that does not agree to coordinate; $T - C_s > Bs - P_1$. That is, without the participation of the government, the net income of the academic institutions that agree to coordination is greater than the net income of the academic institutes that do not agree to coordination; It can be seen that only the eigenvalues of the Jacobian matrix corresponding to $E_1(1,1,1)$ equilibrium point are less than 0, $E_2(1,1,0)$, $E_3(1,0,1)$, $E_5(0,0,0)$, $E_6(0,1,0)$, $E_7(0,0,1)$, $E_8(0,1,1)$ The eigenvalues of the Jacobian matrix corresponding to the equilibrium point are greater than 0, $E_4(1,0,0)$ The eigenvalues of the corresponding Jacobian matrix of the equilibrium point contain eigenvalues whose symbols cannot be determined. At this time, if $K < C_e$. That is, the tax preference K given by the government to the enterprise is less than the cost paid by the enterprise to agree to coordinate, and $A < C_s$. That is to say, the government's reward A for academic institutes is less than the cost of academic institutes agreeing to coordinate, then the equilibrium point $E_4(1,0,0)$ jacobian matrix of the characteristic values are less than 0, the $E_1(1,1,1)$, $E_4(1,0,0)$ two equilibrium points of the asymptotic stable points of the system.

IV. Matlab Numerical Simulation and Analysis of the 'Government -Industry-University-Institute' Collaborative Innovation

From the above analysis, it is clear that only when the government participates in coordinating and supervising the distribution of benefits, enterprises and academic institutes can better carry out collaborative innovation. The factors that influence the choice of enterprises and academic institutes are: the gain coefficient (t) brought by government participation to enterprises and academic institutes, the tax preference (K) given by the government to enterprises and the subsidy (A) invested by the government in academic institutes. In order to ensure that the data is correct and convincing, the unknown parameters are assigned and Matlab software is used to simulate the specific evolutionary paths of the game for companies and universities and research institutes.

Case 1: Mechanism analysis of influence of gain coefficient change on willingness to cooperate

The parameters are: Rg=10, r_1=0.2, r_2=0.3, Re=12, Rs=11, K=2, A=2.5, Bs=2, Be=2.5, P_1=1, P_2=1, T=0.5, C_g=2, C_e=1.5, C_s=1.5, x=y=z=0.5. Under the condition that the initial intentions of the three participants are the same, the influence of the gain coefficient (t) brought by the government participation on the evolution of the strategies of enterprises and academic institutes is observed. The parameters of t=0.3, t=0.5 and t=0.7 are simulated with the other parameters unchanged, as shown in figure 2, figure 3, figure 4.

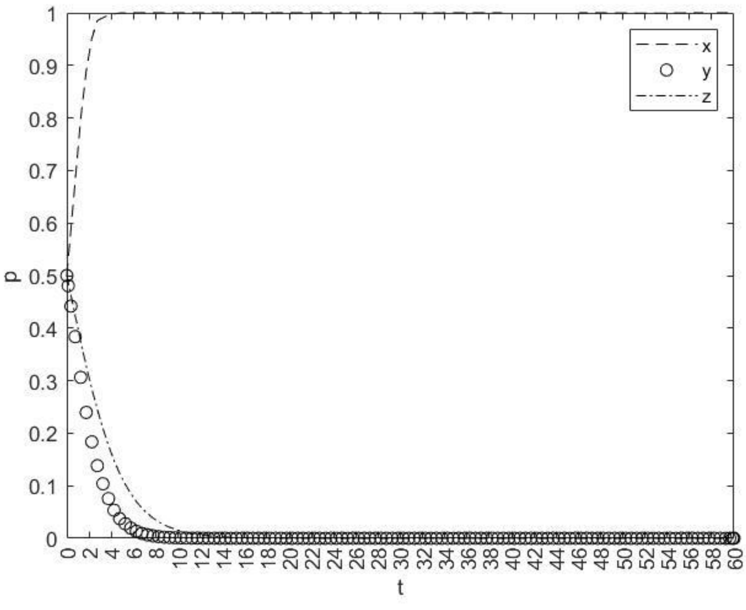

Figure 2: Effect of Gain Factor on Strategy Evolution (t=0.3)

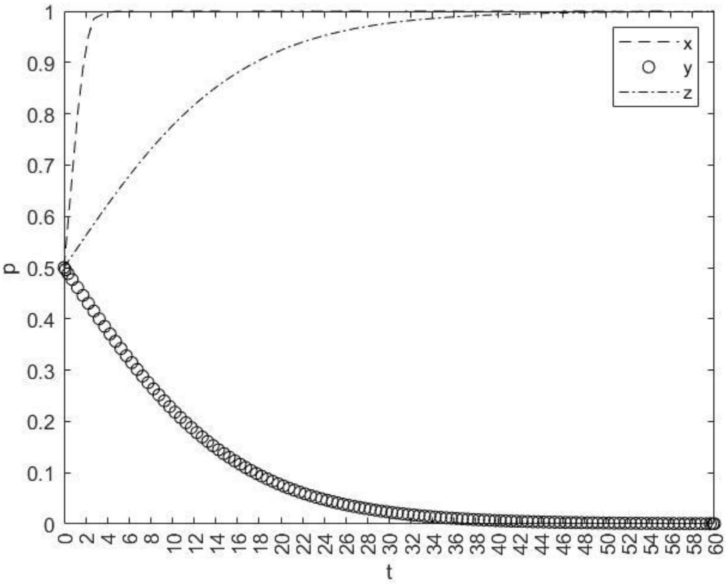

Figure 3: Effect of Gain Factor on Strategy Evolution (t=0.5)

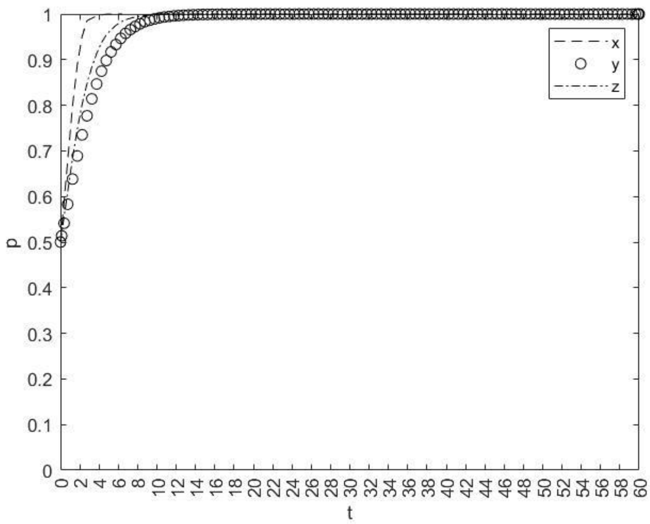

Figure 4: Effect of Gain Coefficient on Strategy Evolution (t=0.7)

The above three figures can be obtained by Matlab software simulation, from which we can get that when the gain coefficient is t=0.3, the government will participate in the collaborative innovation at last due to the difference of the cost of the government, the enterprise and academic institutes and the difference of the benefits brought by the innovation. When the gain coefficient t=0.5, the benefits brought by the agreed coordination will increase. At this point the academic institutes will gradually agree to coordinate for collaborative innovation, while the enterprises will still eventually refuse to coordinate, although their willingness to do so will diminish.

When the gain coefficient t=0.7, the benefit brought by the gain coefficient is further expanded, the collaborative innovation effect is more obvious, the willingness of the tripartite to choose to agree to participate in the collaborative innovation is gradually enhanced, the government will finally participate in the collaborative innovation, the academic institutes are more willing to accept the coordination of the government, and the enterprises will gradually agree to the benefit coordination driven by academic institutes and the interests, so that tripartite can obtain more benefits.

Case 2: Mechanism Analysis of the Influence of Tax Preferential and Subsidy Changes on Cooperation Willingness

The parameters were: Rg=10, t=0.5, r_1=0.2, r_2=0.3, Re=12, Rs=11, Bs=2, Be=2.5, P_1=1, P_2=1, T=0.5, C_g=2, C_e=1.5, C_s=1.5, x=y=z=0.5. Under the condition of the same initial intention of the three participants, the influence of the changes of K and A on the strategy evolution was observed. The parameters of K=1.5 and A=1.5 and K=3 and A=3 are simulated considering the other parameters are not changed, as shown in figure 5, figure 6.

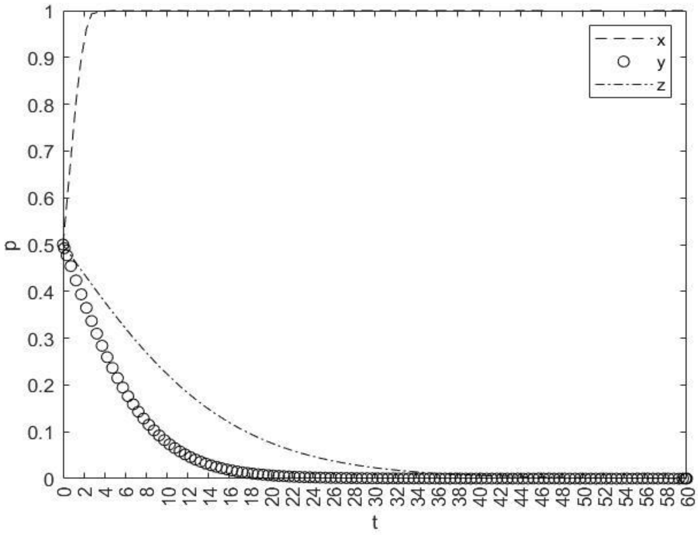

Figure 5: Impact of taxes and subsidies on willingness to cooperate (K=1.5, A=1.5)

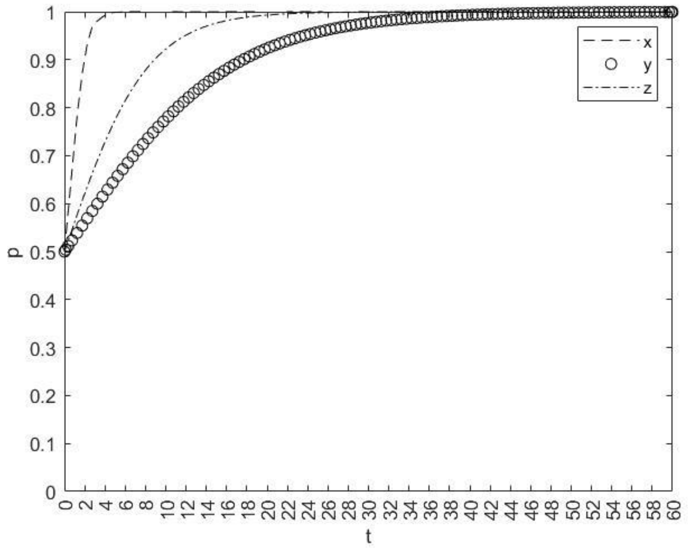

Figure 6: Impact of Taxes and Subsidies on Willingness to Cooperate (K=3, A=3)

According to the above two figures obtained by Matlab software simulation, the simulation results show that when the government deducts 1.5 tax for enterprises and 1.5 government subsidies for academic institutes, the government subsidies do not make the enterprises and the academic institutes get more benefits than independent innovation, so the enterprises and academic institutes reject the benefit coordination, and finally withdraw from collaborative innovation. When the government reduces taxes for enterprises 3 and government subsidies for academic institutes 3, the government subsidies are strengthened. With the increase in the amount of government tax relief for enterprises and the increase in the amount of subsidies for academic institutes agreeing to coordinate their participation in collaborative innovation, the government subsidies have resulted in real benefits for both parties and therefore this has led to a quicker path to agreeing to coordinate collaborative innovation.

V. Conclusions and Suggestions

The evolutionary game theory is used to explore the evolutionary mechanism of the ‘Industry-university-institute’ collaborative innovation game in which the government participates. The pay matrix of the cooperative innovation game involving the government, the enterprises and the academic institutes is established. With the use of replicated dynamic equations and the eigenvalues of the Jacobian matrix corresponding to each equilibrium point, the asymptotic stability point of the system is found and the evolution of collaborative innovation decisions among government, enterprises and academic institutes is systematically analyzed. Combined with quantitative analysis, this research discusses affecting factors that influence the collaborative innovation of government, enterprises and academic institutions. The conclusions are as follows:

The system utilizes a parameter assignment method to obtain two gradual stability points, and the two gradual stability points tell us that no matter whether enterprises and academic institutes agree to coordinate, the government should participate in the coordination of benefit distribution, the gain coefficient (t) brought by the government participation to the enterprises and the academic institutes, the tax preference (K) given by the government to the enterprises, And the subsidy A invested by the government will have an impact on whether the two sides finally agree to coordinate the collaborative innovation. Therefore, government should proactively lead multi-party cooperation and game in the process of industry-university-research collaborative innovation, formulate a reasonable reward system, increase the subsidy to enterprises and academic institutions, and supervise the enterprises and academic institutes to sign strong contracts, punish the breach of contract on the way out of collaborative innovation, so as to make them pay more cost. At the same time, the government should build a fair and reasonable income distribution platform, making enterprises as well as academic institutes will be more willing to accept the government's coordination, so that both parties can obtain their own maximum benefits and attract more enterprises as well as academic institutes to participate in collaborative innovation.

The research on computer-aided numerical simulation analysis of collaborative innovation within GIUI models using evolutionary game theory has provided valuable insights into the dynamics and optimization of collaborative processes. The integration of computational techniques and game theory has shed light on decision-making, and resource allocation strategies. These findings contribute to both theoretical understanding and practical guidance for stakeholders seeking to foster collaborative innovation within the GIUI framework.

Data Availability

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

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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