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Research Article

Subject Behavior of Collaborative Innovation in Civil-Military Integration: An Evolutionary Game Analysis

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Based on the evolutionary game mode, this study constructs the evolutionary game model of collaborative innovation in civil-military integration considering the reward-punishment mechanism of the government. The subject behavior of core enterprises and noncore enterprises in the collaborative innovation of civil-military integration is investigated from a microperspective. The results suggest that the key factors influencing the enthusiasm of enterprises to participate in collaborative innovation are the level of technology spillover, technology absorption capacity, the share of excess benefits, the reward for active participation in collaborative innovation, and the punishment for passive participation. The game evolution result of the two parties will converge to (actively participate in collaborative innovation, actively participate in collaborative innovation) when the government rewards obtained by the party actively participating in collaborative innovation exceed the technology spillover loss and the excess benefits exceed the difference between the acquired technology spillover and the penalty for passive participation. These findings may provide a decision-making reference for the government to formulate the strategy of collaborative innovation in civil-military integration.

1. Introduction

Collaborative innovation in civil-military integration is the development of independent innovation, which promotes the effective utilization of research and development factors through the rational allocation of resources. To support the collaborative innovation of civil-military integration, the Chinese government has proposed a series of implementation opinions, such as "accelerating the construction of an integrated civil-military innovation system," "resolutely breaking the monopoly and strengthen the optimal allocation of innovative resources," and "giving priority to the collaborative innovation of civil-military integration in key areas." These implementation opinions suggest that how to carry out the collaborative innovation of civil-military integration is one of the core problems to be solved in China's national defense construction.

However, there are some problems in the collaborative innovation of civil-military integration in China. First, the existing operation modes of civil-military collaborative innovation communities are mostly loose without forming an industrial chain, which results in the ineffective allocation of innovation resources. Second, there is the asymmetry of supply and demand information between military enterprises and civil enterprises; that is, the collaborative innovation of civil-military integration lacks a resource-sharing platform. Third, civil enterprises are not treated equally when cooperating with military enterprises and the collaborative innovation of civil-military integration lacks detailed rules and regulations. The purpose of this study is to investigate the subject behavior of collaborative innovation in civil-military integration.

Existing literature on collaborative innovation of civil-military integration focuses on the construction of a collaborative innovation system and the design of institutional policies. Lavallee [1] proposed that military enterprises should moderately open up, weaken technical barriers, and adjust the military standardization system to

strengthen cooperation between military enterprises and civil enterprises. Using the SFA model, Jeong et al. [2] evaluated the technological innovation efficiency of Korean military enterprises, and they found that the key to collaborative innovation is to design a reasonable equilibrium point of benefit distribution mechanism. Burch et al. [3] argued that the important preparatory work for carrying out civil-military collaborative innovation is to establish technical standards, laws and regulations, and procurement systems for civil-military collaborative innovation. Peng et al. [4] compared the development of civil-military collaborative innovation systems in developed countries (United States, Japan, Germany) from the aspects of incentive mechanism, restraint mechanism, and legal policy guarantees, and they discussed the impact of defense demand-pull, civilian demand-pull, and technological progress on the operating mode of the military-civilian collaborative innovation system. The development of civil-military integration requires strengthening the top-level design and building a collaborative innovation mechanism guided by the government, with enterprises as the main body, and market-oriented, so as to realize the resource sharing of military and civilian enterprises [5–12].

Some researchers are concerned about the problems of carrying out the collaborative innovation of civil-military integration. The problems related to the development of military-civilian integrated collaborative innovation can be summarized into three types, namely, regulation barriers, information barriers, and technical barriers. For regulation barriers, military industry enterprises greatly benefit from monopoly benefits and the defense industry system does not separate government and enterprise, which makes it difficult to realize resource sharing in the cooperative innovation between military enterprises and civil enterprises [13, 14]. The pricing of military products is not conducive to the optimal allocation of resources [15]. It is difficult for civil enterprises to obtain production licenses for military products [16]. Existing rules do not clearly define the scope, rights, and responsibilities of civil-military collaborative innovation [17]. For information barriers, the information on supply, demand, and production between military industrial enterprises and civil enterprises is closed. There is a lack of effective platforms for information exchange between military and civilian enterprises [18]. For technical barriers, there are significant differences in the technical standards of military and civilian enterprises, hindering the effective transfer of military technology and civil technology [19].

Besides, some scholars pay attention to the development mode and realization path of collaborative innovation in civil-military integration. For example, Liu and Yang [20] believed that there are differences in compatibility between military technology and civil technology, and collaborative innovation policies should be developed to improve the compatibility of the two types of technologies. Taking strategic emerging industries as an example, Qiao and Zeng [21] proposed three ways to promote collaborative innovation in civil-military integration. Yang [22] put forward the development path of collaborative innovation of civil-military integration from the four aspects of strategy, technology, regulation, and information.

To sum up, most of the existing studies have discussed the theoretical framework, existing problems, and development paths of the civil-military integration collaborative innovation from the perspective of theoretical analysis, but there are insufficient investigations on the operational mechanism and the evolution of subject behavior of civil-military integration collaborative innovation. Besides, there are much qualitative research on macroproblems, but little research is carried out from the microperspective of enterprises by using quantitative methods such as model derivation and game evolution. In this study, an evolutionary game model is used to analyze the subject behavior of collaborative innovation of civil-military integration. The evolutionary game model is an improved traditional game model, which does not require the participants to be completely rational and complete information conditions [23]. Thus, the evolutionary game model is more suitable for the investigation of complex subject behavior in the collaborative innovation of civil-military integration.

As a result, there are three main contributions of this study: first, this study utilizes the evolutionary game model to explore the evolution process of collaborative innovation between core and noncore subjects, which may extend the research on collaborative innovation to civil-military integration. Second, this study systematically analyzes the realization mechanism of collaborative innovation in civil-military integration under the mechanism of reward and punishment, which may provide guidance for civil-military enterprises to carry out technological innovation cooperation. Third, some suggestions for promoting civil-military integration are proposed based on the results of the evolutionary game model, which may be of great significance for the government to formulate civil-military integration strategies.

2. Subject Behavior of Cooperative Innovation in Civil-Military Integration

The key to carrying out the civil-military integration collaborative innovation is to coordinate the distribution of interests of the main body. The subject of the civil-military integration collaborative innovation has both the desire for cooperation and the conflict of interests, which can be regarded as a cooperative competition game problem. In the collaborative innovation of civil-military integration, many game players act as nodes and the interests of each side are multilevel (see Figure 1). The boundary of the multilevel is open. There are not only interest games among groups, but also interest games within groups. The game relationship between the subjects of collaborative innovation in civil-military integration is shown in Figure 1.

Taking into account the bounded rationality of the innovation subject, this study uses the evolutionary game model to investigate the subject behavior of the civil-military integration collaborative innovation and analyzes the external factors affecting the evolution of the collaborative innovation of civil-military integration. In the collaborative innovation of civil-military integration, enterprises with more resources (e.g., knowledge, technology,

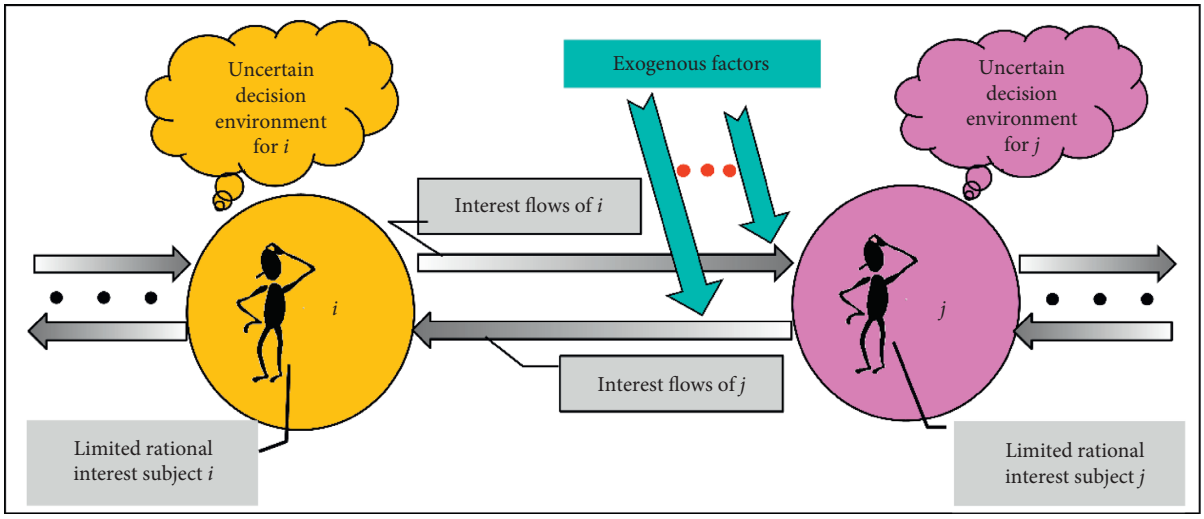

Figure 1: The game relationship between the subjects of collaborative innovation in civil-military integration.

and information) are at the core and play a leading role in the overall operation. Noncore enterprises that rarely establish contact with other enterprises are marginalized. This study uses the dynamic game model to investigate the evolution process of collaborative innovation between core and noncore subjects and systematically analyzes the realization mechanism of collaborative innovation in civil-military integration.

3. Evolutionary Game Model

3.1. Model Hypothesis. The subjects in the collaborative innovation of civil-military integration are divided into core enterprises and noncore enterprises. Following Sandholm [24], we assumed that A represents the core enterprises and B represents the noncore enterprises; both of them are bounded rationality. Innovation subjects of different types and scales will choose different motivations, opportunities, and degrees of participation based on their own innovation ability. Therefore, this study divides the behavior of collaborative innovation enterprises into active participation and passive participation according to the degree of participation. The behavioral strategies of core enterprise (A) and noncore enterprise (B) are {S1: actively participate in collaborative innovation; S2: passively participate in collaborative innovation}. x denotes that A actively participates in collaborative innovation. $1 - x$ means that A passively participates in collaborative innovation. y denotes that B actively participates in collaborative innovation. $1 - y$ means that B passively participates in collaborative innovation. Each game is a random matching game between core enterprise and noncore enterprise. Table 1 lists the benefit matrix of the collaborative innovation game.

According to Thum-Thysen et al. [25] and Zhao et al. [26], the innovation costs of both parties include intangible cost and tangible cost. Intangible cost is the technology spillover of enterprises A and B in the collaborative innovation process, denoted as T_A and T_B, respectively; tangible cost is the individual investment of enterprises A and B in the collaborative innovation process, denoted as C_A and C_B, respectively.

Assuming that enterprises A and B passively participate in collaborative innovation, their benefits are P_A and P_B, respectively. Assuming that enterprises A and B actively participate in collaborative innovation, they can not only obtain benefits P_A and P_B but also excess benefits P_{AB}. When one party actively participates and the other party passively participates, the passive participant will receive some benefits brought by the technology spillover due to the active participant. The coefficient of the imitative ability of enterprises A and B is μ_A and μ_B, respectively.

Assume that the distribution proportion of the excess benefits from collaborative innovation of enterprise A is p and that of enterprise B is q. $q < 0.5 < p < 1$ since enterprise A is superior to enterprise B in terms of resources, information, technology, production capacity, and so forth. The greater the p value, the higher the core position of enterprise A. In addition, the government will give necessary incentives M to enterprises that actively participate in collaborative innovation, and corresponding punishment N to opportunists (i.e., passive participant), so as to guide and restrain the behavior of participants in collaborative innovation [27].

3.2. Game Model. According to Section 3.1, the expected benefit that enterprise A actively participates in collaborative innovation can be obtained by the following equation:

$$U_A S_1 = [P_A + \mu_A (pP_{AB} + T_B) - T_A] y + (P_A + M - T_A)(1 - y). \quad (1)$$

The expected benefit that enterprise A passively participates in collaborative innovation can be defined by the following equation:

$$U_A S_2 = (P_A + \mu_A T_B - N) y + P_A (1 - y). \quad (2)$$

Table 1: Payment matrix for collaborative innovation strategy selection.

Core enterprise A	Noncore enterprise B	
	Active participation y	Passive participation $1-y$
Active participation x	$P_{A+}\mu_A\ (pP_{AB}+T_B)-T_A$ $P_B+\mu_B\ (qP_{AB}+T_A)-T_B$	$P_A+M-T_A,\ P_B+\mu_B T_A-N$
Passive participation $1-x$	$P_A+\mu_B T_B-N,\ P_B+M-T_B$	$P_A,\ P_B$

The average expected benefit of the mixed strategy of enterprise A is expressed by the following equation:

$$\begin{aligned} EU_A &= xU_AS_1+(1-x)U_AS_2, \\ &= x\{[P_A+\mu_A(pP_{AB}+T_B)-T_A]y \\ &\quad +(P_A+M-T_A)(1-y)\}+(1-x) \\ &\quad [(P_A+\mu_A T_B-N)y+P_A(1-y)]. \end{aligned} \tag{3}$$

The replication dynamic equation of enterprise A is as follows:

$$\begin{aligned} F(x) &= x(U_AS_1-EU_A) \\ &= x(1-x)[(\mu_A pP_{AB}-M+N)y+M-T_A]. \end{aligned} \tag{4}$$

Similarly, the replication dynamic equation of enterprise B can be obtained by the following equation::

$$\begin{aligned} F(y) &= y(U_BS_1-EU_B) \\ &= y(1-y)[(\mu_B qP_{AB}-M+N)x+M-T_B]. \end{aligned} \tag{5}$$

By taking the derivative of equations (4) and (5), respectively, the following equation can be obtained:

$$\begin{aligned} F'(x) &= (1-2x)[(\mu_A pP_{AB}-M+N)y+M-T_A], \\ F'(y) &= (1-2y)[(\mu_B qP_{AB}-M+N)x+M-T_B]. \end{aligned} \tag{6}$$

When $F(x)=0$ and $F(y)=0$, five equilibrium points of evolutionary game can be obtained, namely, A (0, 0), B (1, 0), C (0, 1), D (1, 1), and S$(x_0=T_B-M/\mu_B q P_{AB}-M+N,\ y_0=T_A-M/\mu_A pP_{AB}-M+N)$.

The Jacobi matrix is used to analyze the stability of the evolutionary equilibrium points of enterprise A and enterprise B. The Jacobi matrix of the dynamic replication equations of enterprise A and enterprise B can be expressed as follows:

$$J=\begin{bmatrix} (1-2x)[(\mu_A pP_{AB}-M+N)y+M-T_A] & x(1-x)(\mu_A pP_{AB}-M+N) \\ y(1-y)(\mu_B qP_{AB}-M+N) & (1-2y)[(\mu_B qP_{AB}-M+N)x+M-T_B] \end{bmatrix}. \tag{7}$$

3.3. Result and Discussion. According to the local stability analysis method of Jacobi matrix, the parameter relationships of the five equilibrium points are classified as follows (see Table 2):

This study only considers four conditions when condition (1) meets $M>T_A$ and $M>T_B$. The local stability analysis results of the equilibrium points are shown in Table 3.

If $M>TA$, $M>TB$, $TA-N>\mu ApPAB$, and $TB-N>\mu BpPAB$, among the four equilibrium points, only (0, 1) and (1, 0) are progressively stable. This result indicates that in the long-term evolutionary game between core and noncore enterprises, only one party will choose the strategy of active participation in collaborative innovation, while the other party will choose the strategy of passive participation in collaborative innovation to obtain extra benefits from technology spillovers. This result is consistent with Sun and Zhang [28], who argued that the behavior of the innovation subject includes positive innovation, negative innovation, and tort. Although the government will give necessary incentives to enterprises that actively participate in collaborative innovation, the technology spillover obtained by choosing the strategy of passive participation in collaborative innovation is greater than the profit sharing obtained by choosing the strategy of active participation in collaborative innovation for both parties. Innovation income distribution ratio and learning absorptive capacity are the key factors for the two parties to choose which strategy to participate in collaborative innovation.

It can be seen from Figure 2 that the connecting line of points A, D, and S divides the area ABCD into the area ACDSA and the area ABDSA. When the initial state is in the area ABDSA, the result of the long-term evolutionary game will converge to the strategy (actively participate in collaborative innovation, passively participate in collaborative innovation); when the initial state is in the area ACDSA, the result of the long-term evolutionary game will converge to the strategy (passively participate in collaborative innovation, actively participate in collaborative innovation). Both strategy (actively participate in collaborative innovation, passively participate in collaborative innovation) and strategy (passively participate in collaborative innovation, actively participate in collaborative innovation) are evolutionary stable strategies. When $p>q$, the area of ABDSA is larger than that of ACDSA. The probability of both parties choosing the strategy (actively participate in collaborative innovation, passively participate in collaborative innovation) increases, and the game strategy gradually converges to the strategy (actively participate in collaborative innovation, passively participate in collaborative innovation). When

Table 2: *Det (J)* and *Tra (J)* signs of equilibrium points of evolutionary game.

Condition 1	Condition 2	(0, 0)	(0, 1)	(1, 0)	(1, 1)
$M > T_A$, $M > T_B$	$T_A - N > \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	+, +	+, −	+, −	+, +
	$T_A - N > \mu_A p P_{AB,}$ $T_B - N < \mu_B q P_{AB}$	+, +	+, −	−, ?	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	+, +	−, ?	+, −	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	+, +	−, ?	−, ?	+, −
$M > T_A$, $M < T_B$	$T_A - N > \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	−, ?	+, +	+, −	+, +
	$T_A - N > \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	−, ?	−, ?	−, ?	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	−, ?	+, +	+, −	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	−, ?	+, +	−, ?	+, −
$M < T_A$, $M > T_B$	$T_A - N > \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	−, ?	+, −	−, ?	−, ?
	$T_A - N > \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	−, ?	+, −	+, +	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	−, ?	−, ?	−, ?	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	−, ?	−, ?	+, +	+, −
$M < T_A$, $M < T_B$	$T_A - N > \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	+, −	−, ?	−, ?	+, +
	$T_A - N > \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	+, −	−, ?	+, +	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	+, −	+, +	−, ?	−, ?
	$T_A - N < \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	+, −	+, +	+, +	+, −

Table 3: Local stability analysis results of equilibrium points.

Condition		(0, 0)	(0, 1)	(1, 0)	(1, 1)	(x_0, y_0)
$T_A - N > \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	Det	+	+	+	+	−
	Tra	+	−	−	+	0
	ESS	No	Yes	Yes	No	Saddle point
$T_A - N > \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	Det	+	+	−	−	
	Tra	+	−	?	?	
	ESS	No	Yes	Saddle point	Saddle point	
$T_A - N < \mu_A p P_{AB}$, $T_B - N > \mu_B q P_{AB}$	Det	+	−	+	−	
	Tra	+	?	−	?	
	ESS	No	Saddle point	Yes	Saddle point	
$T_A - N < \mu_A p P_{AB}$, $T_B - N < \mu_B q P_{AB}$	Det	+	−	−	+	
	Tra	+	?	?	−	
	ESS	No	Saddle point	Saddle point	Yes	

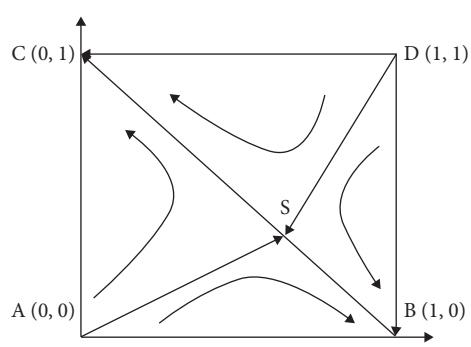

Figure 2: Evolutionary phase of equilibrium points.

$p < q$, the area of ABDSA is smaller than that of ACDSA. The probability of both parties choosing the strategy (passively participate in collaborative innovation, actively participate in collaborative innovation) increases, and the game strategy gradually converges to the strategy (passively participate in collaborative innovation, actively participate in collaborative innovation).

If $M > T_A$, $M > T_B$, $T_A - N > \mu_A p P_{AB}$, and $T_B - N < \mu_B p P_{AB}$, among the four equilibrium points, only (0, 1) is progressively stable. This result indicates that, in the long-term evolutionary game between core and noncore enterprises, only noncore enterprise will choose the strategy of active participation in collaborative innovation; core enterprise will choose the strategy of passive participation in collaborative innovation to obtain extra benefits from technology spillovers. For both parties, the loss caused by technology spillover is less than the government rewards obtained by adopting active collaborative innovation strategies. The technology spillover of core enterprise is greater than the benefits obtained from collaborative innovation. In this case, noncore enterprise has high enthusiasm to participate in collaborative innovation.

If $M > T_A$, $M > T_B$, $T_A - N < \mu A p P_{AB}$, and $T_B - N > \mu_B p P_{AB}$, among the four equilibrium points, only (1, 0) is progressively stable. This result suggests that core enterprise will choose the strategy of active participation in collaborative innovation, while noncore enterprise will choose the strategy of passive participation in collaborative innovation to obtain extra benefits from technology spillovers. For both parties, the loss caused by technology spillover is less than the government rewards obtained by adopting active collaborative innovation strategies, but the

technology spillover of noncore enterprise is greater than the benefits obtained from collaborative innovation. In this case, core companies are more willing to cooperate than noncore participants.

If $M > T_A$, $M > T_B$, $T_A - N < \mu ApP_{AB}$, and $T_B - N < \mu BpP_{AB}$, among the four equilibrium points, only (1, 1) is progressively stable. This result means that both core enterprise and noncore enterprise will choose the strategy of active participation in collaborative innovation. For both parties, the benefits of adopting an active cooperation strategy are greater than their own technology spillovers. In this case, both core enterprise and noncore enterprise have high enthusiasm for participating in collaborative innovation.

To sum up, in the long-term evolutionary game between core enterprise and noncore enterprise, the equilibrium point does not converge to (0, 0) but converges to the point where both parties adopt the strategy of active participation in collaborative innovation or the point where one party takes the strategy of active participation in collaborative innovation. For example, when $M > T_A$, $M > T_B$, $T_A - N < \mu ApPAB$, and $T_B - N < \mu BpPAB$, both core enterprise and noncore enterprise tend to adopt the strategy of actively participating in collaborative innovation. Thus, the reward-punishment mechanism formulated by the government and the income distribution mechanism among enterprises can well guide core and noncore enterprises to participate in collaborative innovation. This finding is consistent with Guo et al. [29] and Santos [30], who found that government subsidies have a positive effect on the innovation performance of enterprises. The equilibrium points (0, 1), (1, 0), and (1, 1) are all likely to appear in the collaborative innovation of civil-military integration. Thus, both core enterprise and noncore enterprise should actively build good cooperative relations and strengthen communication. To this end, core and noncore enterprises can consider the following suggestions: (1) establish a special cooperation-exchange platform to share information; (2) formulate specific and detailed rules of conduct; and (3) establish a scientific and reasonable reward-punishment mechanism.

4. Conclusions

This study explores the subject behavior of civil-military integration collaborative innovation using the reward-punishment mechanism of the government for participants in collaborative innovation. This study analyzes the dynamic game process of core and noncore enterprises in the civil-military integration collaborative innovation under the reward-punishment mechanism from a microperspective. The results show that the key factors influencing the enthusiasm of enterprises to participate in collaborative innovation are the level of technology spillover, technology absorption capacity, the share of excess benefits, the reward for active participation in collaborative innovation, and the punishment for passive participation. Under the influence of these key factors, the evolutionary game results of core enterprise and noncore enterprise in the collaborative innovation of civil-military integration converge to four paths. When the government rewards obtained by the party actively participating in collaborative innovation exceed the technology spillover loss, and the excess benefits exceed the difference between the acquired technology spillover and the penalty for passive participation, the game evolution result of the two parties will converge to (actively participate in collaborative innovation, actively participate in collaborative innovation).

Based on the above results, the following suggestions are put forward to promote the collaborative innovation of civil-military integration.

First, the government should foster outstanding subjects of collaborative innovation in civil-military integration. To this end, the government can take the following actions: (1) paying close attention to core subjects (e.g., military enterprises, civil enterprises, universities, and government); the increase in the number of these core subjects and connecting edges is conducive to speeding up information exchange and resource sharing; (2) fostering intermediary organizations such as trade associations, chambers of commerce, law firms, and accounting firms that can promote collaborative innovation. Increasing intermediaries can shorten the distance between collaborative innovation subjects; improve the frequency and efficiency of communication; and promote the flow and transfer of information, resources, and technology.

Second, the government should construct a resource-sharing platform for the collaborative innovation of civil-military integration. To this end, the resource-sharing platform can be constructed from the following three aspects: (1) integrate digital information resources dispersed in different databases across systems to achieve diversified collection, dynamic allocation, and automatic acquisition, providing integrated information services for innovation subjects; (2) strengthen the resource linkage among collaborative innovation subjects; (3) establish a scientific and reasonable benefit distribution mechanism among collaborative innovation subjects.

Third, the government could establish an industrial community for collaborative innovation of civil-military integration. To establish the industrial community, it is necessary not only to strengthen the infrastructure construction such as roads and factories in the industrial community but also to improve the construction of intellectual property protection, financing mechanisms, and talent training models. Military enterprises, civil enterprises, intermediary organizations, and other institutions are encouraged to join the industrial community for the collaborative innovation of civil-military integration.

Fourth, the above results indicate that the reward-punishment mechanism of the government has a significant influence on the collaborative innovation of civil-military integration, and thus the government should formulate a series of policies for the collaborative innovation of civil-military integration. To this end, the government can take the following actions: (1) formulate financial support policies for the collaborative innovation; (2) formulate tax compensation policies for the collaborative innovation; and (3) formulate legal guarantee policies for the collaborative innovation.

Data Availability

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

Conflicts of Interest

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

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