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Evolutionary Game of the Civil-Military Integration With Financial Support

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ABSTRACT How to provide financial support efficiently is becoming an essential way for military enterprises to take the strategy of Civil-Military Integration (CMI) in China. In this paper, we used the evolutionary game theory to build a model for military enterprises to choose the approach of the CMI with financial support. After derivation and simulation of the model, the results showed that the profit and cost from the CMI or the financial support changes could cause the different evolutionary stable states (ESS). Setting the financial support degree in a relevant range could encourage firms to participate in the CMI and reduce the spillover. Besides, the initial proportion of military enterprises that choose the CMI could affect and predict the trend of future development, which provides a reference for policy-makers.

INDEX TERMS Evolutionary game, civil-military integration, military enterprises, financial support.

I. INTRODUCTION

In China, the implementation of Civil-Military Integration (CMI) in military enterprises have become an important concern for scholars and policy-makers recently, which means to use defense technology and facilities to make civilian products. Military enterprises were in a long-term self-sufficient system [1], which makes them have the issues of redundant personnel and low efficient productivity [2]. They have lost development vitality because of the shortage of competitors in the same market. These issues push military enterprises to take transformation. Besides, military enterprises have some excellent foundations for producing civilian products. In China, military enterprises could obtain the priority of R&D funds, technology talents, and convenient social resources. The advanced technology and strict production process of military productivities could make consumers trust their characteristics of “high technical content and high reliability” and prefer the production made by military firms. Therefore, taking the CMI for military firms is becoming inevitable.

The issue of Civil-Military Integration in military enterprises has been the focus of scholars’ attention since the Cold War. Jelušič [3] studied the defense conversion on the quantitative economic and qualitative political after

the cold war. Vergne [4] used qualitative and quantitative methods to explore how the arms industry modify the military implications for diversification. Mérindol and Versailles [5] founded the dual-use policies in France was not only for as a civilian-military transfer mechanism but represent now a dimension central to military R&D policies. Ascosta *et al.* [6] examined that the size of defense companies has a positive and significant relationship with the production of civilian patents. Jing and Benner [7] conducted an embedded multiple-case study method that shows how different patterns for the conversion of military firms to the civilian market. In the study on the policy of the CMI in Chinese military enterprises, scholars have focussed on the behaviors of government (e.g., Liang *et al.* [8], Zhao and Huang [9], Li and Bo [10]), the efficiency of dual-use technology (e.g., Li and Chen [11], Dongri *et al.* [12]), the CMI innovation system (e.g., Han *et al.* [13], You *et al.* [14]) and so on. Whether relying on qualitative and quantitative methods of analysis, academics have paid constant attention to the CMI.

Although the importance given by academia and the government’s efforts to promote the development of the CMI vigorously, military enterprises still face many problems in the implementation process. Because the standards of military and civil product are different, taking the CMI needs military firms to start a new civil production line which spent extra cost [15]. Unlike the contemporary design and production of

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procedures in commercial manufacturers, the traditional production cycle of military enterprise is not flexible enough [16] to adapt to fast-changing market demands [17]. Besides, the confidentiality of defense technology makes military firms have to face the risk of technology leakage in the process of the CMI [18].

In the process of the CMI, financial support plays an essential role, which has several particular ways to promote efficiency in China. Local government and financial institutions or private enterprises establish the Civil-Military Integration Fund, which used for providing financial support to the promotion of R&D dual-use technologies and the transformation of achievements. Such as in 2017, the Shanghai Civil-Military Integration Industry Investment Fund was established, which was funded by 11 units with a total size of 4 billion yuan. Shandong Province has united the national and private capital to set up the fund with 10 billion yuan in Qingdao New District, etc. Besides, local governments actively encourage financial institutions to provide financial support for CMI enterprises through the establishment of franchised institutions, and the promotion of diversified financial products. For example, Mianyang City built the first CMI technology bank and the first CMI insurance company. Also, Mianyang cooperated with the Industrial and Commercial Bank of China to establish 5 CMI financial service centers. Since then, Mianyang has established a financial support service system under the guidance of the municipal government's financial office and the participation of science and technology branches and service centers.

Financial defense support has been studied extensively. There are mostly focus on the relationship between defense expenditure and economic growth directly or indirectly (e.g., Atesoglu [19], Dunne *et al.* [20], Smith and Tuttle [21]). These studies pay more attention to the effect of defense spending on the entire economic performance. Besides, some studies have investigated the finance programs from the government to the defense industry, like federal tax policy and bank [22], debt financing, guns versus butter trade-off, or the printing of new money [23]. Thus, finance defense programs employed various measures over time. Moreover, Wingerter [24] explained that the defense perspective and ideology, the belief of requiring protective weapons, the investment of the military contractor corporations, and the privacy advocacy groups are the reasons why so much financial investment persists on the defense industry in the US. Bowlin [25] measured the financial condition of the defense-oriented business segment from the perspective of performance and took the feedback for the policy-maker.

Despite the volume of studies on financial support from the aspect of the macro military industry, some studies have discussed the relationships with the financial mechanism and the army firms. Financial support mechanisms could encourage firms to participate in the strategy with the addition of profit and reduction of risk. Goyal *et al.* [26] examined how changes in growth opportunities affected by the level and structure of defense corporate debt policy.

Besancenot and Vranceanu [27] used game theory to analyze how to support military firms from public finance or private finance and indicated that a low-risk firm prefers the state-financed scheme while a perfect information set-up firm would apply for bank credit. However, few papers have studied the financial support for the military companies to take the CMI.

To fill the void in the literature, we investigated how financial support affects the process of the CMI for military enterprises. We used the evolutionary game theory to build a dynamic selection model for military firms and made simulations to exam how different degrees of financial support influence the military firms' strategy of the CMI.

Evolutionary games are models for repeated anonymous strategic interactions and widely accepted to conduct academic research and to solve management problems [28] with the decision-making, active factors, system evolution, etc. Many scholars studied the CMI with the evolutionary game theory. Zhao *et al.* [29] employed evolutionary game theory to study government guidance between the military enterprises and private enterprises in the CMI. Wei and Chan [30] constructed an evolutionary game model to test the cooperative stability of Military-Civilian collaborative innovation in China's satellite industry. Liang *et al.* [8] analyzed the technology transfer in the military-civil system with the evolutionary game theory based on the complex network. Yu *et al.* [31] developed a model of resource allocation with the dynamic evolutionary game theory. Thus, applying the evolutionary game theory in the CMI could help us better understand the financing support mechanisms play in the CMI for defense enterprises.

The structure of the paper is organized as follows: In the next section, we provide the research design of the evolutionary game theory model and related notation. In Section 3, the evolutionary game model is formulated to study the military firm decision behaviors with financial support. Then we analyze their payoff matrix and the replicator dynamic system, propositions, and relevant lemmas to confirm the evolutionarily stable strategy. Section 4 provides the simulation experiments to verify the ESS. Conclusions are in the last part of Section 5.

II. RESEARCH DESIGN

In this section, we could ensure how the evolutionary game theory represents the military firms' decision to accept or reject the program of CMI under financial support.

The evolutionary game theory stems from evolutionary biology. Participants in an evolutionary game follow the assumption of bounded rationality, which more conforms to reality. In the process of gaming, party sides obtain some limited external information based on their conditional constraints. The changes of other competitors and cooperators' decisions and actions might inspire decision-makers to modify their behavior content. The players will learn, imitate, find the best decisions continually, and finally reach the stability state after many times games. Thus, the game becomes

repeated interactive acts, which are called replication dynamics. Replication dynamics describes the frequency or frequentness at which a population adopts a particular strategy, which is a dynamic differential equation in mathematical operations [32]. Since both parties are able to modify their decisions through this form, the system ends up with a mutually satisfactory equilibrium status, rather than an optimal state [33]. Therefore, bounded rationality, replication dynamics, and equilibrium state are three essential factors in evolutionary game theory.

Let's analyze the relationship between evolutionary game theory and military enterprises. Firstly, military enterprises follow the limited rationality hypothesis. There is both competition and cooperation between military enterprises. In contrast to the general competitive market environment, there are close ties within the same system between military enterprises affiliated with the relevant administrative departments of the state in China. Similar cultures and management models lead to a strong synergy between military enterprises, which also allows them to learn from each other. Moreover, because of the complex and changeable marketing environment, incomplete information, and differences in resource ownership levels, the military enterprises cannot fully grasp the full knowledge of rules and structures in the CMI process. That confirms the military firms to the assumption of bounded rationality. Secondly, changing conditions and limited rationality make it impossible for military enterprises to find a strategy that suits them immediately. Instead, they imitate, learn, and adapt to their conditions, continually optimizing and improving their decisions. Besides, military enterprises prefer to take reference to defense-type enterprises that are similar to their situation and status. That is consistent with the replication dynamic. Thirdly, the strong links between military enterprises, which are also part of the national defense technology and innovation system, have led both game sides to pursue the overall satisfaction and maximize the benefits. Therefore, evolutionary game theory is suitable for studying the military firms' strategy in the CMI progress.

The study is about the dynamic game in whether military enterprises adopt the CMI strategy, which is a two-sides symmetric game. The assumptions are as follows:

Assumption 1: In this research model, we consider the military industry as a system and divide it into two different limited rational groups: Group 1 (G1) and Group 2 (G2). Both groups are composed of members with continuous learning from multiple gaming. During the game, one member from each of the two groups is repeatedly randomly selected to play the game. The member of each group is called Enterprise 1 and Enterprise 2.

Assumption 2: The military firms have two strategies, that is, to participate in the Civil-Military Integration (I) and not to participate in the CMI (NI). Thus, the initial proportions of adopting (I) is x , and rejecting (NI) is $(1 - x)$ in G1. And in G2, the initial proportions of (I) is y , and (NI) is $(1 - y)$.

TABLE 1. Notation.

| Notation | Meaning |
|-------------|--|
| R_i | the profit when enterprises use the original development decision |
| P_i | the interest when only one enterprise chooses to the CMI |
| T_i | the threaten when enterprises take the CMI, including the technology of security, the extra management cost of the new production line, etc. |
| E_i | the profit of the spillover |
| π | the income when both sides enterprises decide to take the CMI at the same time |
| α_i | the proportion of interest distribution |
| β_i | subsidy coefficient of financial support for increasing the profit |
| λ_i | subsidy coefficient of financial support for decreasing the risk |

$i = 1, 2$ represents the Enterprise 1 and Enterprise 2.

TABLE 2. Payoff matrix of the military enterprises with financial support.

| | | Military E2 | |
|-------------|----|---|---|
| | | I | NI |
| Military E1 | I | $R_1 + \alpha_1\beta_1\pi - (1 - \lambda_1)T_1$ | $R_1 + \beta_1P_1 - (1 - \lambda_1)T_1$ |
| | NI | $R_2 + \alpha_2\beta_2\pi - (1 - \lambda_2)T_2$ | $R_2 + E_2$ |
| | | $R_1 + E_1$ | R_1 |
| | | $R_2 + \beta_2P_2 - (1 - \lambda_2)T_2$ | R_2 |

Assumption 3: When two game sides choose (I) at the same game, the overall income is π . Because the whole system consists of Group 1 (G1) and Group 2 (G2), the proportion of interest distribution is $\alpha_i (i = 1, 2)$, and $\alpha_1 + \alpha_2 = 1$ [34].

Assumption 4: When one firm chooses (I) and the other chooses (NI), the strategy of selecting (I) will give the firm some interest, we name it as P_i . At this time, the production, operation, and marketing activities in this company are released to change and produce new information and knowledge. According to the theory of endogenous economic growth, knowledge has the characteristics of non-competitiveness and partial exclusivity, which has resulted in spillovers of positive externalities [35]. Thus, the other enterprise gains these spillover effects and yields behaviors such as hitchhiking. We define the spillover effect as E_i . Where $E_i < P_i$.

Assumption 5: When the military firms decide to choose the strategy (I), there will be two subsidy ways from financial institutions to support the behaviors: increasing the profit and decreasing the risk [36]. The subsidy coefficients embody on the $\beta_i (\beta_i > 1; i = 1, 2)$ and $\lambda_i (0 < \lambda_i < 1; i = 1, 2)$, respectively.

The notation of the research is showing in Table 1.

Based on the above assumptions and notations, the payoff matrix of military enterprises' strategies is shown in Table 2.

III. EVOLUTIONARY GAME MODEL DISCUSSION

A. STABLE POINTS IN THE EVOLUTIONARY GAME

In the initial stage of the two-player game, let $x(0 \leq x \leq 1)$ denotes the proportion of enterprises in the group who choose to ready to accept the CMI (I) and the ratio who rejects the CMI (NI) is $1 - x$. Simultaneously, the proportion of the enterprises in another group who choose (I) is $y(0 \leq y \leq 1)$, and $(1-y)$ means the percentage of enterprises who want (NI).

Suppose that U_1^x represents the expected earnings of enterprises-G1 that accept the CMI and U_1^{1-x} represents the anticipated earnings of G1 that keep the original plan and refuse to the CMI. The two strategies of Group 1 are as follows,

$$U_1^x = y[R_1 + \alpha_1\beta_1\pi - (1 - \lambda_1) T_1] + (1 - y)[R_1 + \beta_1P_1 - (1 - \lambda_1) T_1] \quad (1)$$

$$U_1^{1-x} = y(R_1 + E_1) + (1 - y)R_1 \quad (2)$$

Suppose that U_2^y and U_2^{1-y} are expected earnings of enterprises-G2 that accept the strategy of the CMI and reject it, respectively. The anticipated return of enterprises-G2 using these two strategies is as follows,

$$U_2^y = x [R_2 + \alpha_2\beta_2\pi - (1 - \lambda_2)T_2] + (1 - x) [R_2 + \beta_2P_2 - (1 - \lambda_2) T_2] \quad (3)$$

$$U_2^{1-y} = x(R_2 + E_2) + (1 - x)R_2 \quad (4)$$

In the concept of evolutionary game theory, the replicator dynamics equation is used to study which strategy most enterprises will choose at some point in time. The replicator dynamic equation of the enterprises-G1 is,

$$f(x, y) = dx/dt = x(1 - x)(U_1^x - U_1^{1-x}) = x(1 - x) \{y[\alpha_1\beta_1\pi - E_1 - \beta_1P_1] + \beta_1P_1 - (1 - \lambda_1)T_1\} \quad (5)$$

The replicator dynamic equation of the enterprises-G2 is,

$$g(x, y) = dy/dt = y(1 - y)(U_2^y - U_2^{1-y}) = y(1 - y) \{x[\alpha_2\beta_2\pi - E_2 - \beta_2P_2] + \beta_2P_2 - (1 - \lambda_2)T_2\} \quad (6)$$

For the system (S), let

$$\begin{cases} f(x, y) = dx/dt = 0 \\ g(x, y) = dy/dt = 0 \end{cases} \quad (7)$$

We can get the stable points $(x, y) \in \{(x, y) | 0 \leq x \leq 1, 0 \leq y \leq 1\}$ include (0,0), (0,1), (1,0), (1,1). When $\alpha_i\beta_i\pi - E_i - (1 - \lambda_i) T_i < 0 < \beta_iP_i - (1 - \lambda_i) T_i, (i=1, 2)$ is satisfied, (x^*, y^*) will be the stable point of the system (S), where $x^* = -\frac{\beta_2P_2 - (1 - \lambda_2)T_2}{\alpha_2\beta_2\pi - E_2 - \beta_2P_2}, y^* = -\frac{\beta_1P_1 - (1 - \lambda_1)T_1}{\alpha_1\beta_1\pi - E_1 - \beta_1P_1}$.

TABLE 3. $tr(J)$ and $det(J)$ of each stable point.

| Stable point | $tr(J)$ | $det(J)$ |
|--------------|--|--|
| (0,0) | $[\beta_1P_1 - (1 - \lambda_1)T_1] + [\beta_2P_2 - (1 - \lambda_2)T_2]$ | $[\beta_1P_1 - (1 - \lambda_1)T_1][\beta_2P_2 - (1 - \lambda_2)T_2]$ |
| (0,1) | $[\alpha_1\beta_1\pi - E_1] - (1 - \lambda_1)T_1 - [\beta_2P_2 - (1 - \lambda_2)T_2]$ | $-\alpha_1\beta_1\pi - E_1 - (1 - \lambda_1)T_1[\beta_2P_2 - (1 - \lambda_2)T_2]$ |
| (1,0) | $-\beta_1P_1 - (1 - \lambda_1)T_1 + [\alpha_2\beta_2\pi - E_2 - (1 - \lambda_2)T_2]$ | $-\beta_1P_1 - (1 - \lambda_1)T_1[\alpha_2\beta_2\pi - E_2 - (1 - \lambda_2)T_2]$ |
| (1,1) | $-\alpha_1\beta_1\pi - E_1 - (1 - \lambda_1)T_1 - [\alpha_2\beta_2\pi - E_2 - (1 - \lambda_2)T_2]$ | $[\alpha_1\beta_1\pi - E_1 - (1 - \lambda_1)T_1][\alpha_2\beta_2\pi - E_2 - (1 - \lambda_2)T_2]$ |
| (x^*, y^*) | 0 | A |

B. EVOLUTIONARY EQUILIBRIUM STABILITY ANALYSIS

When the stability point of the replicator dynamics equation is evolutionary equilibrium, which is equal to the local asymptotic stability point, it is regarded as ESS. The asymptotic stability of the stable points about x and y is evaluated using the standard Jacobian matrix J [37], which is

$$J = \begin{bmatrix} \partial f/\partial x & \partial f/\partial y \\ \partial g/\partial x & \partial g/\partial y \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad (8)$$

where

$$\begin{aligned} a_{11} &= (1 - 2x) [y(\alpha_1\beta_1\pi - E_1 - \beta_1P_1) + \beta_1P_1 - (1 - \lambda_1) T_1] \\ a_{12} &= x(1 - x) (\alpha_1\beta_1\pi - E_1 - \beta_1P_1) \\ a_{21} &= y(1 - y) (\alpha_2\beta_2\pi - E_2 - \beta_2P_2) \\ a_{22} &= (1 - 2y) [x(\alpha_2\beta_2\pi - E_2 - \beta_2P_2) + \beta_2P_2 - (1 - \lambda_2) T_2] \end{aligned}$$

Table 3 shows $tr(J)$ and $det(J)$ value of the stable points. We can obtain ESS when the stable points satisfy the trace $tr(J) < 0$ and the determinant $det(J) > 0$ [38].

Where namely, $\theta_i = \alpha_i\beta_i\pi - E_i - (1 - \lambda_i) T_i, (i=1, 2)$ denotes the minimum additional income when the firm chooses strategy (I) with financial support and $\varepsilon_i = \beta_iP_i - (1 - \lambda_i) T_i @ comma(i=1, 2)$ means the additional income. Through the analysis of the benefits of both players, we can get nine situations to judge the asymptotic stability in tables 4-9. Since the payment matrix is symmetrical, we summarize six status as follows,

(1) When $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < \varepsilon_2 < 0$, in Situation 1, the ESS is (0,0).

$$A = -\frac{[\beta_2P_2 - (1 - \lambda_2) T_2][\alpha_2\beta_2\pi - E_2 - (1 - \lambda_2) T_2][\beta_1P_1 - (1 - \lambda_1) T_1][\alpha_1\beta_1\pi - E_1 - (1 - \lambda_1) T_1]}{[\alpha_1\beta_1\pi - E_1 - \beta_1P_1][\alpha_2\beta_2\pi - E_2 - \beta_2P_2]}$$

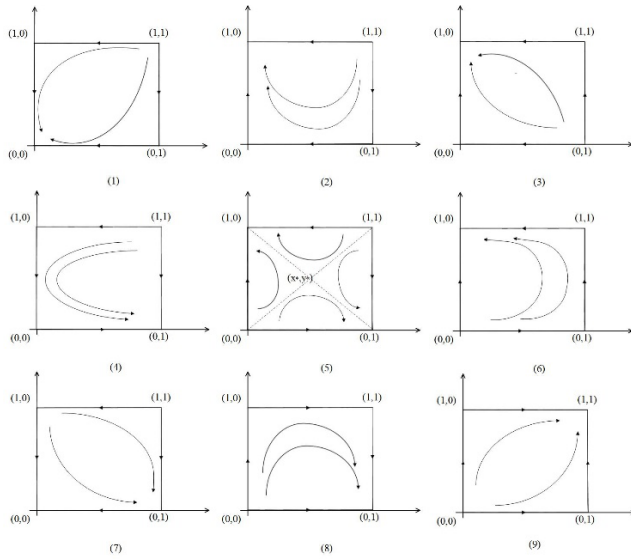


FIGURE 1. Strategy evolution diagram in each situation.

(2) When $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < 0 < \varepsilon_2$ in Situation 2, or $\theta_1 < 0 < \varepsilon_1$ and $\theta_2 < \varepsilon_2 < 0$ in Situation 4, the ESS is (0,1) and (1,0), respectively.

(3) When $\theta_1 < \varepsilon_1 < 0$ and $0 < \theta_2 < \varepsilon_2$ in Situation 3, or $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < \varepsilon_2 < 0$ in Situation 7, the ESS is (0,1) and (1,0), respectively.

(4) When $\theta_1 < 0 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$, in Situation 5, the ESS is (0,1) and (1,0).

(5) When $\theta_1 < 0 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$ in Situation 6, or $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$ in Situation 8, the ESS is (0,1) and (1,0), respectively.

(6) When $0 < \theta_1 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$ in Situation 9, the ESS is (1,1).

C. EVOLUTIONARY RESULT ANALYSIS

According to the above results, the different situations' strategies diagram of military firms with financial support could be obtained by analyzing the evolutionary process of the system (S), as shown in Fig.1. And the specific analysis result is as follows,

(1) When $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < \varepsilon_2 < 0$, Situation 1 shows that (0,0) is the ESS of the system (S), (0,1) and (1,0) are the saddle points, and (1,1) is the unstable point. The system's evolution process is shown in Fig. 1 (1). The military firms in two groups all reject to adopt the CMI strategy. The additional net implementation of the CMI strategy obtained by enterprises 1 and 2 is negative, indicating that the adoption of (I) couldn't only increase revenue, but could reduce corporate benefit. The enterprises that have chosen (I) in the group could turn to the original production methods instead. After multiple games, the proportion of companies choosing (I) in the system will gradually decrease until it reaches the ESS where all companies in the system decide to adopt (NI).

(2) When $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < 0 < \varepsilon_2$, or $\theta_1 < 0 < \varepsilon_1$ and $\theta_2 < \varepsilon_2 < 0$, the stability is exhibited in Table 5. The

TABLE 4. Status 1.

| Situation 1 $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < \varepsilon_2 < 0$ | | | |
|---|---------|----------|----------------|
| Stable point | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | - | + | ESS |
| (0,1) | ? | - | Saddle point |
| (1,0) | ? | - | Saddle point |
| (1,1) | + | + | Unstable point |

TABLE 5. Status 2.

| Stable point | Situation 2 $\theta_1 < \varepsilon_1 < 0$ and $\theta_2 < 0 < \varepsilon_2$ | | | Situation 4 $\theta_1 < 0 < \varepsilon_1$, and $\theta_2 < \varepsilon_2 < 0$ | | |
|--------------|---|----------|----------------|---|----------|----------------|
| | $tr(J)$ | $det(J)$ | Stability | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | ? | - | Saddle point | ? | - | Saddle point |
| (0,1) | - | + | ESS | ? | - | Saddle point |
| (1,0) | ? | - | Saddle point | - | + | ESS |
| (1,1) | + | + | Unstable point | + | + | Unstable point |

system's evolution process is shown in Figure 1 (2) and (4). They indicate that (0,0) is the saddle point, and (1,1) is the unstable point. The ESS appears on the profitable player, at which time the other player's additional income is negative. For reasons of symmetry, we choose Situation 2 as the representative for analysis. The adoption of (I) in the Military Enterprise 1 could lead to a reduction in corporate profits and reject continuing the strategy of CMI. At this time, although Enterprise 2 has some risks from free-riding ($\theta_2 < 0$), its net income is positive ($0 < \varepsilon_2$), which has the advantage of competition in the same market environment. After multiple games, the number of enterprises accepting CMI in Group 1 will gradually decrease, but the number in Group 2 increases until the system reaches the ESS.

(3) When $\theta_1 < \varepsilon_1 < 0$ and $0 < \theta_2 < \varepsilon_2$ in Situation 3, or $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < \varepsilon_2 < 0$ in Situation 7, the side with the positive additional income will get the ESS, which is shown in Table 6 and Fig.1 (3) and (7). We use Situation 3 as the representative, which shows that (0,0) and (1,1) are the saddle points, (1,0) is the unstable point, and (0,1) is the ESS. In this situation, Enterprise 1 receives the negative revenue from the CMI and the high cost of investment, and the minimum additional income of Enterprise 2 is positive. Thus, the system's ESS is Enterprise 1 choose to reject (NI), and Enterprise 2 adopt (I).

(4) When $\theta_1 < 0 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$, in Situation 5, Table 7 and Fig. 1 (5) shows that (0,1) and (1,0) are the ESS of the system (S), (x^*, y^*) is the saddle point, (0,0) and (1,1) are the unstable points. For both sides, the revenue from the CMI is higher than the cost of the investment but less than the

TABLE 6. Status 3.

| Stable point | Situation 3 $\theta_1 < \varepsilon_1 < 0$ and $0 < \theta_2 < \varepsilon_2$ | | | Situation 7 $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < \varepsilon_2 < 0$ | | |
|--------------|---|----------|----------------|---|----------|----------------|
| | $tr(J)$ | $det(J)$ | Stability | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | ? | - | Saddle point | ? | - | Saddle point |
| (0,1) | - | + | ESS | + | + | Unstable point |
| (1,0) | + | + | Unstable point | - | + | ESS |
| (1,1) | ? | - | Saddle point | ? | - | Saddle point |

TABLE 7. Status 4.

| Situation 5 $\theta_1 < 0 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$ | | | |
|---|---------|----------|----------------|
| Stable point | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | + | + | Unstable point |
| (0,1) | - | + | ESS |
| (1,0) | - | + | ESS |
| (1,1) | + | + | Unstable point |
| (x^*, y^*) | ? | - | Saddle point |

profit from free-riding. Thus, both parties want to hitchhike rather than choose the CMI. Therefore, when one enterprise chooses (I), the other will choose (NI).

(5) When $\theta_1 < 0 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$ in Situation 6, or $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$ in Situation 8, the side with the positive minimum additional income will get the ESS, which is shown in Table 8 and Fig.1 (6) and (8). We use Situation 6 as the representative, which shows that (1,0) and (1,1) are the saddle points, (0,0) is the unstable point, and (0,1) is the ESS. In this situation, the revenue from CMI of Enterprise 1 is higher than the cost ($0 < \varepsilon_1$), but the spillover effect and free-riding take so much more risk that the minimum additional income is negative. Because of that, when the minimum additional income of Enterprise 2 is positive, the system's ESS is Enterprise 1 choose to reject (NI), and Enterprise 2 adopt (I).

(6) When $0 < \theta_1 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$, in Situation 9, For both sides, the revenue from the CMI is higher than the cost. As shown in Fig. 1 (9), (1,1) is the ESS of system (S), (0,1) and (1,0) are the saddle points, and (0,0) is the unstable point. Therefore, when the military firms in two groups all adopt the CMI strategy, the system (S) becomes the ESS.

IV. THE SIMULATION AND DISCUSSION

A. PARAMETER INITIALIZATION SETTINGS

In this section, a simulation of the model is conducted through MATLAB to clarify the impact of the CMI and the financial support of the model.

TABLE 8. Status 5.

| Stable point | Situation 6 $\theta_1 < 0 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$ | | | Situation 8 $0 < \theta_1 < \varepsilon_1$ and $\theta_2 < 0 < \varepsilon_2$ | | |
|--------------|---|----------|----------------|---|----------|----------------|
| | $tr(J)$ | $det(J)$ | Stability | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | + | + | Unstable point | + | + | Unstable point |
| (0,1) | - | + | ESS | ? | - | Saddle point |
| (1,0) | ? | - | Saddle point | - | + | ESS |
| (1,1) | ? | - | Saddle point | ? | - | Saddle point |

TABLE 9. Status 6.

| Situation 9 $0 < \theta_1 < \varepsilon_1$ and $0 < \theta_2 < \varepsilon_2$ | | | |
|---|---------|----------|----------------|
| Stable point | $tr(J)$ | $det(J)$ | Stability |
| (0,0) | + | + | Unstable point |
| (0,1) | ? | - | Saddle point |
| (1,0) | ? | - | Saddle point |
| (1,1) | + | + | Unstable point |

TABLE 10. Fixed parameter initialization settings.

| Notation | π | α_i | P_1 | T_1 | E_1 | P_2 | T_2 | E_2 | β | λ |
|-------------------------|-------|------------|-------|-------|-------|-------|-------|-------|---------|-----------|
| Initialization settings | 20 | 0.5 | 10.5 | 8.5 | 5 | 11 | 9 | 5.5 | 1 | 0 |

After the research team surveyed military enterprises and related financial institutions involved in the CMI, this article was conducted interviews with professional technicians and middle managers in the form of actual surveys. Based on the results of the interviews, consult experts in the relevant field research guidelines in the form of mail, phone, and meetings. This paper sets the relevant parameters by combining the summarizing experts' opinions and the way of the simulation parameters in the existing literature. The specific parameter initializations are shown in Table 10.

B. EFFECT OF INITIAL PROPORTION OF ADOPTING THE CMI ON GAME EQUILIBRIUM

Due to the characteristics of evolutionary games, the initial proportion adopting the strategy of the CMI in the group could affect the process of reaching the ESS. According to the values of x and y , there is a special case discussed. That is, when $y = y^*$, the effect of x on G1's behavior is discussed, and when $x = x^*$, the effect of y on G2's behavior is discussed.

Based on the parameter initializations setting, $x^* = 0.3077$ and $y^* = 0.3636$. Thus, when $y = y^* = 0.3636$, the effect of $x = 0.1, 0.3, 0.5, 0.6, 0.7, 0.9$ and 0.3077 on G1's behavior is shown in Fig.2 (a); when $x = x^* = 0.3077$, the effect of

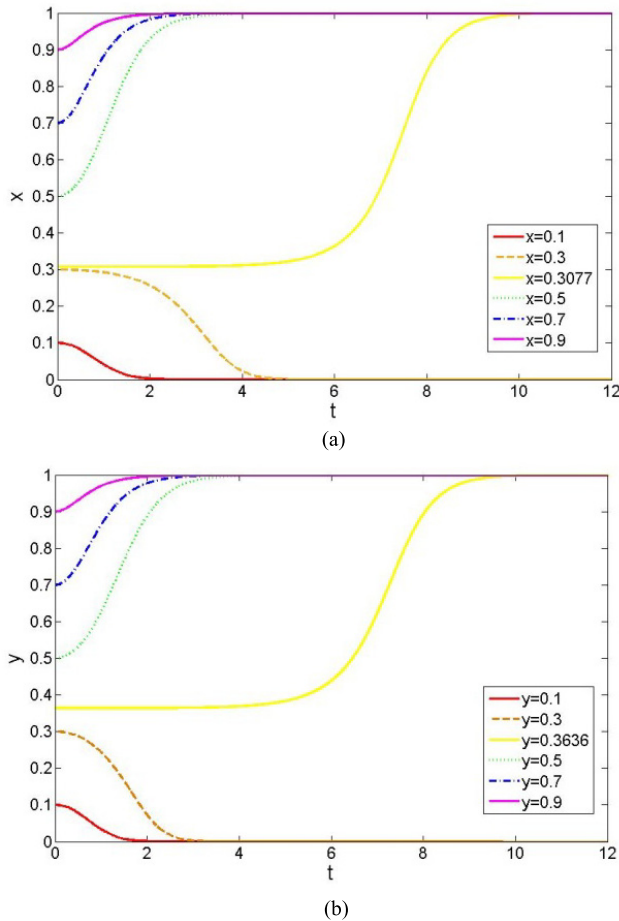


FIGURE 2. (a) Effect of x on the G1's behaviors. (b) Effect of y on the G2's behaviors.

$y = 0.1, 0.3, 0.5, 0.6, 0.7, 0.9$ and 0.3636 on G2's behavior is shown in Fig.2 (b).

From the Fig.2, when $y = y^*$ and $x \in [0, 1]$, the ESS could be different. When $x \in (0, 0.3077)$, the military enterprises in G1 will choose (NI); and when $x \in (0.3077, 1)$, the military enterprises in G1 will choose (I). Similarly, when $x = x^*$ and $y \in (0, 0.3636)$, the military enterprises in G2 will choose (NI); and when $y \in (0.3636, 1)$, the military enterprises in G1 will choose (I).

In general, the initial proportion of adopting CMI (x and y) keeps changing in the range of $(0,1)$. From the above evolution trend, we could consider the situation that the larger the initial proportion of companies adopting CMI in the group, the faster the system evolves to the ESS. For reaching stabilization, the initial proportion in one group is at least $(0.3077, 0.3636)$, which will be used in the subsequent simulation analysis.

C. EFFECT OF FINANCIAL SUPPORT ON GAME EQUILIBRIUM

1) EFFECT OF INCREASING THE PROFIT ON GAME EQUILIBRIUM

The impact of financial support policies on increasing the profit is represented by $\beta (\beta \geq 1)$. When other parameters are

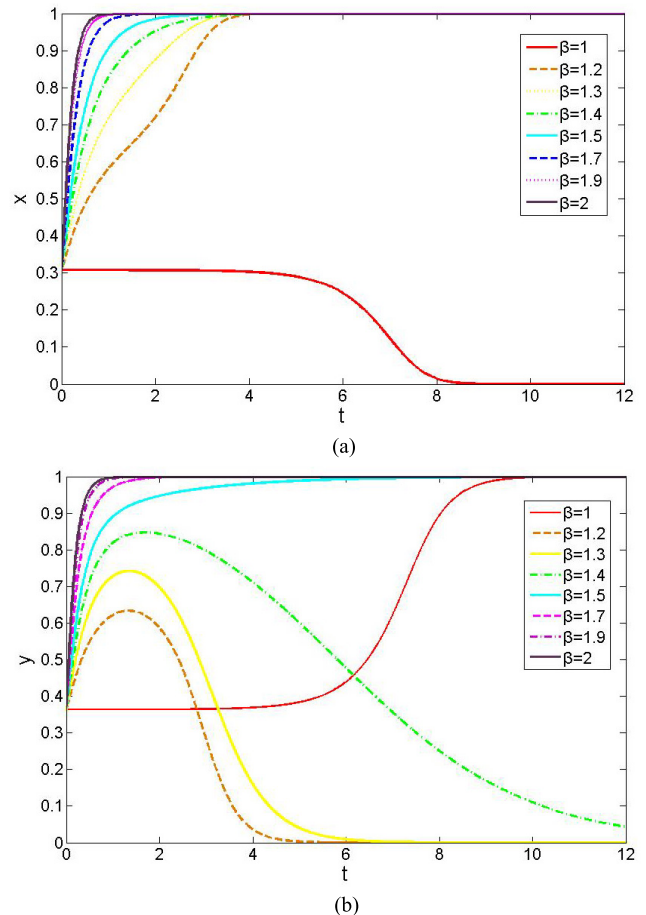


FIGURE 3. (a) Effect of β on Military Enterprise G1. (b) Effect of β on Military Enterprise G2.

constant, the effect of β on the military enterprises' behavior in G1 is shown in Fig.3 (a); and the effect of β on the military enterprises' behavior in G2 is shown in Fig.3 (b).

By calculating values of $\theta_1, \varepsilon_1, \theta_2$ and ε_2 in which β is substituted into the formula of θ_i and ε_i , we could determine the strategy choice when the two groups finally reach the ESS through the evolutionary process in Fig.3 (a) and (b). When $\beta = 1$, the military enterprises' strategy for both sides will be (NI, I); when $\beta = 1.2$ and 1.3 , the military enterprises' approach will be (I, NI). Both cases are suitable for Status 4. When $\beta = 1.4$, the enterprises in G1 will choose (I), whereas the enterprises in G2 will choose (NI). Unlike the above cases, this case is consistent with Status 5. When $\beta = 1.5, 1.7$ and 1.9 , both sides will decide to adopt (I), which could verify Status 6.

For G1, the higher financial support on increasing the profit could absorb the more significant number in the group to accept the strategy of CMI. The strategy choices are also shifting from (NI) to (I) as improving the degree of financial support. However, for G2, as financial support improvement, the choice of strategy will change from (I) to (NI) and then turn back to (I). The results implicate that the impact of financial support on the corporate plan is not only related to

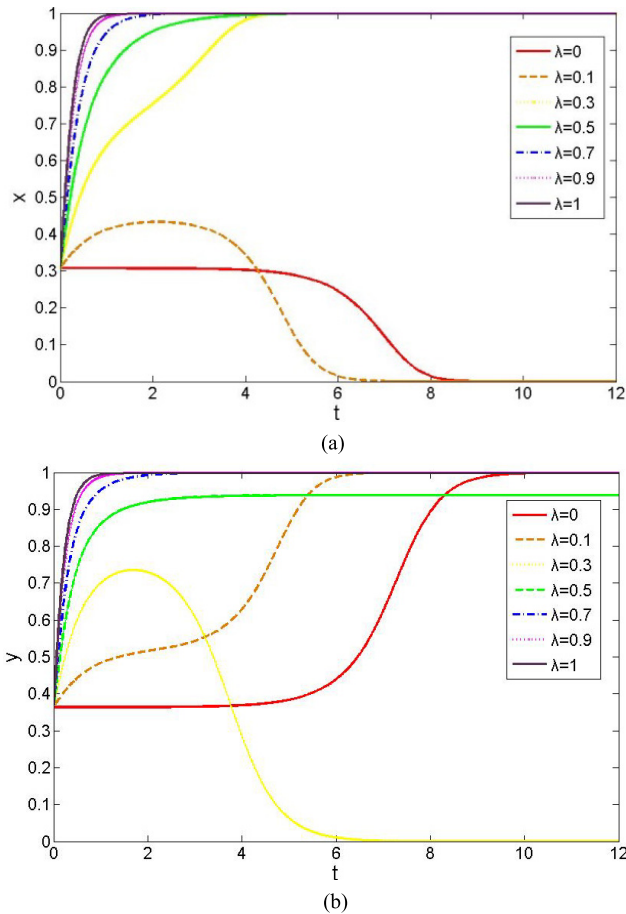


FIGURE 4. (a) Effect of λ on Military Enterprise G1. (b) Effect of λ on Military Enterprise G2.

its factors but also the decisions of the other party in the same market. If the CMI strategy is to be chosen by both parties, the role of financial support on increasing the profit is required to be 1.5 or more.

2) EFFECT OF DECREASING THE RISK ON GAME EQUILIBRIUM

The impact of financial support policies on decreasing the risk is represented by λ , $\lambda \in [0, 1]$. when the other parameters are constant, the effect of λ on the military enterprises' behavior in G1 is shown in Fig.4 (a); and the effect of λ on the military enterprises' behavior in G2 essential in Fig.4 (b).

According to the values of θ_1 , ε_1 , θ_2 and ε_2 and the evolutionary process in Fig.4 (a) and (b), the decisions of two military enterprise groups could be obtained. When $\lambda = 0$ and 0.1, the military enterprises' strategy for both sides will be (NI, I); when $\lambda = 0.3$, the military enterprises' strategy for both groups will be (I, NI). These two cases are suitable for Status 4. When $\lambda = 0.5$, the enterprises in G1 will choose (I), whereas the enterprises in G2 will not reach the steady-state, where are 90% of enterprises choosing (I) and 10% of enterprises choosing (NI) in G2. When $\lambda = 0.7, 0.9$ and 1, both sides will decide to adopt (I), which could verify Status 6.

In general, decreasing the risk is a practical financial support way to motive the process of the CMI. The higher degree of risk reduction, the greater possibility for companies to choose the CMI, as shown by the evolutionary trend of G1 in Fig.4 (a). However, for G2, even when $\lambda = 0.3$ and 0.5, which affect cost reduction, military companies in G2 will still choose to reject the CMI, or only a part choose (I). It is caused by differences of characteristics between enterprises that differentiation of cost reduction effect appeared under the same coefficients of risk reduction. Thus, the decision results of rejecting the CMI will be produced due to cost differences in the competitive environment of the same market. If the CMI strategy is to be chosen by both sides, the role of financial support on decreasing the risk is required to be at least 0.5.

From the game equilibrium analysis of financial support, we could find that both the effects of increasing the profit and decreasing the risk take a substantial impact on military enterprises to adopt the CMI. And the higher degree of financial support could motive more military enterprises to take the strategy and the system reaching the ESS faster. However, when the degree of financial support is not strong enough, military enterprises need to think about other factors and other companies' decision to make a choice. If the cost of the CMI is higher than its benefits, military enterprises will choose to reject the CMI strategy.

V. CONCLUSION

In this paper, adopting the strategy of Civil-Military Integration in military enterprises in the evolutionary process has been studied under the financial support mechanism. This research got results and conclusions in theory and practice.

The implications from the theoretical perspective are as follows. (1) The strategies of military firms are affected by the profit from adopting the CMI, the cost of risk and spillover, and financial support. When the minimum additional income and the additional income of the military enterprises change, six statuses are getting the ESS in different trends. (2) Financial support plays a vital role in encouraging the military enterprises to take the CMI. According to the numerical simulation, the result shows that the approach to increasing the profit and decreasing the risk could push the system faster to reach the ESS. From the overall evolutionary trend, the higher degree of financial support, the more enterprises in the system take the CMI. However, within a particular range, the effect of financial support could make the enterprises choose to reject CMI as the ESS.

From a practical perspective, we proposed several conclusions. There are two implications for policy-makers. First, given the CMI initial proportion could determine the trend of evolutionary stability in the future. And for maximizing the effectiveness of the policy, the proportion of military firms adopting the CMI needs to reach over 30%. Thus, the policy-makers might start by encouraging companies that are more likely to take a CMI strategy, such as those who have previously produced dual-use technology, to quickly increase the

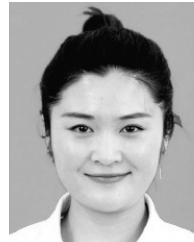
percentage of CMI-taking companies in the market to above 30%. Then, the policy-maker can grasp the overall development and facilitate further macro-control of the military market, and adjust the corresponding policies according to the changes in the proportion of military enterprises entering the civilian market. Second, financial support can encourage military enterprises to take the CMI. The financial support coefficient could strengthen as much as possible within a specific field when formulating relevant policies. When the degree of financial support is not strong enough to cover the cost, other influencing factors that stimulate military enterprises should be considered as a substitute.

However, some limitations in this paper are worth noting. First, this study was conducted with the assumption that there is only consider competition and no cooperation between the military enterprises. Second, the article's model simplifies financial support as enhancing profits and reducing risk, without taking into account specific economic limitations. Thus, future research could focus on the combined effects of competition and cooperation mechanisms in military enterprise strategic decision-making and specific economic conditions in the CMI mode.

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