Hindawi
Mathematical Problems in Engineering
Volume 2019, Article ID 3938716, 17 pages
https://doi.org/10.1155/2019/3938716

Research Article

The Cooperative Stability Evolutionary Game Analysis of the Military-Civilian Collaborative Innovation for China's Satellite Industry

Fang Wei and Wang Chan

School of Management, Northwestern Polytechnical University, Xi'an 710072, China

Correspondence should be addressed to Fang Wei; fwx1998@nwpu.edu.cn

Received 16 September 2018; Revised 23 January 2019; Accepted 5 February 2019; Published 21 February 2019

Academic Editor: Konstantinos Karamanos

The military-civilian collaborative innovation is an implementation path for most countries to develop strategic emerging industries. The satellite industry is an important area in strategic emerging industries. Based on the evolutionary game theory, we build an evolutionary game model of China's satellite industry military-civilian collaborative innovation with military enterprises and civil enterprises as the main participators under the bounded rationality. Then we analyze the long-term evolution of the system and the factors influencing cooperative stability and perform numerical simulation using Matlab. Our research shows that the cooperative stability of China's satellite industry military-civilian collaborative innovation is positively related to the cooperation revenue, liquidated damages, and government incentives and negatively related to basic income, R&D costs, information communication costs, technology secondary conversion costs, risk costs, and betrayal income. The reasonable income distribution coefficient is conducive to the cooperative stability, and we give a primary standard for government incentives. Finally, corresponding management implications are put forward.

1. Introduction

The satellite industry has always been an important area in China's strategic emerging industries [1], contributing enormously to both national defense and regional economic growth. In the last decade, 20 percent of GDP annual growth of China has been driven by strategic emerging industry. Traditionally, satellite industry under the umbrella of the aerospace industry has been very secretive and under the control of government and military. China's satellite industry developed in the 1970s. In 2014, China permitted the civilian companies to enter the Chinese satellite industry and provided a platform to unleash the potential in the global satellite industry of worth 420 billion dollars. Currently, the satellite industry is divided into two parts: military satellite industry and civilian satellite industry. Satellite industrial chain consists of the satellite and ground equipment manufacturing, launching, satellite application, and operational service industry. The first three parts are more military in nature, while satellite application and operation service industries occupy large proportion in civilian market. In 2016, China introduced a 5-year plan for strategic emerging industries which concentrates on the industrial upgradation, innovation, and technological development. Due to the high chances of failure and risk in the satellite industry, China's macro-policies has led to the development of satellite industry military-civilian collaborative innovation, which is objectively driven by similar industrial needs of military-civilian and is based on the effective interaction between military and civilian technology.

Considering the industrial demand and global satellite industry, military-civilian collaborative innovation has become a necessity for the satellite industry. Typically, satellites have the following applications: communications, weather monitoring, resource exploration, navigation, and investigation. In addition to the investigation for military purposes, the other four functions are applicable in military and civilian markets. Therefore, satellites have an attribute of military and civilian sharing regarding functional purposes with different emphasis in the field. Similar industrial demands can stimulate civilian enterprises to seek military-civilian cooperation for market development. Satellite industry reflects the attributes of military-civilian collaborative innovation concerning technology application. The technology involved in satellite industry is mostly dual-use. The key point to distinguish between military and civilian use lies in signal conversion mechanism and information confidentiality, and there is no distinct difference in transmission or receiving device. Therefore, the satellite industry can maximize the military-civilian collaborative innovation and carry out technical cooperation and benign interaction. Up to April 20, 2018, China has more than 200 satellites in orbit, and the average annual growth rate of satellite applications and strategic emerging industries has exceeded 20%.

Successful implementation of military-civilian collaborative innovation has been witnessed to develop strategic emerging industries in developed countries. However, military-civilian collaborative innovation is still in its infancy in developing countries and needs strategies to implement it effectively. Reality proved that military-civilian collaborative innovation can effectively enhance the ability of transition from peacetime to wartime, reduce the transaction costs, and improve the efficiency of social resources utilization. It has become urgent and inherent requirement for us to promote military-civilian collaborative innovation to adapt to the transformation of the world's national defense industry [2, 3]. Due to the refinement of social division, the intensification of international competition, and the acceleration of technology update speed, military enterprise alone can hardly bear the costs and risks of all scientific and technological research and development, and it is impossible to have all the knowledge and technology needed for sustainable innovation. Military-civilian collaborative innovation has become an inevitable choice for achieving sustainable innovation and sharing resources in China's satellite industry. However, in reality, there are still problems such as uneven distribution of cooperative benefits and high conversion costs, which result in inefficient military-civilian collaborative innovation and unstable or even broken cooperation. Based on this, it is of great importance to explore the stability of military-civilian collaborative innovation in China's satellite industry, and this issue needs to be resolved through scientific research.

Therefore, considering the importance of satellite industry in strategic emerging industries, government's plan for strategic upgradation and sustainable innovation, and scarcity of studies exploring stability of military-civilian collaborative innovation in China's satellite industry, the aim of this paper is to build a military-civilian collaborative innovation evolutionary game model after initial cooperation based on the theory of collaborative innovation and evolutionary game theory, after extracting the characteristic elements of both sides, and refining the model parameters, by taking military enterprises and civilian enterprises in China's satellite industry as two sides of the game. This paper explores the dynamic evolution process of military-civilian collaborative innovation under bounded rationality, analyzes factors that affect cooperative stability, and uses Matlab simulation to visually display the impact of related parameters. Finally, management implications are put forward.

This paper is structured as follows. Section 2 reviews the relevant literature on cooperative stability, evolutionary game theory, and military-civilian collaborative innovation. Section 3 builds the evolutionary game model of military-civilian collaborative innovation for China's satellite industry. Section 4 analyzes evolutionary stability strategy and influencing factors of military-civilian collaborative innovation for China's satellite industry. Section 5 is relevant numerical analysis. Section 6 is main conclusions and management implications.

2. Literature Review

2.1. Cooperative Stability. Based on the interpretation of stability in different disciplines, many scholars have defined cooperative stability from different perspectives and formed the following views. *Destabilizing factor determinism*: Using cooperative behavior theory, it is believed that the trajectory of cooperation depends on unstable factors [4]. *Resource complementarity*: Cooperation to achieve relatively complementary resource demand is the most stable state of cooperation. Once this demand is weakened, the partnership will no longer be stable [5]. *Game theory*: The essence of cooperation in the game process: the stability of the alliance between multiple agents depends on the equivalence of the information obtained. Only when the relationship of the game sides reaches the information symmetry, the alliance will reach a stable state [6]. *Social dilemma (institutionalism)*: Institution is the core to ensure cooperative stability, which is based on the effective trust mechanism and mature constraint mechanism [7, 8]. Also, an effective benefits distribution mechanism, cooperation performance, communication ties, and individual recognition of the organization can enhance the willingness to cooperate among the multiple agents and maintain the cooperative stability [9, 10].

In summary, the description of cooperative stability of military-civilian collaborative innovation in the satellite industry is as follows: After the preliminary cooperation between military and civilian satellite industry has been reached, in the process of long-term cooperation, due to other external or internal factors of cooperation, the state of the cooperative system is disturbed, resulting in the volatility and tortuosity of cooperation trajectory. The system itself can self-resist or mediate so that the overall state restores the original balance. With the help of external forces, the cooperation between game sides is more closely related, the cooperative willingness continues to rise, and game sides share more cooperation benefits; then the system is developing steadily and eventually reaches a steady state.

2.2. Evolutionary Game. The evolutionary game theory stems from the evolutionary theory of biology, following the rules of natural selection and survival of the fittest. It combines analytical methods of game theory with dynamic evolution process based on bounded rationality and analyzes how to make the game sides of limited information conduct a dynamic game on the vested benefit to maximize the value. The game sides will continue to learn, imitate, test, and summarize; find the best decisions in the game process;

and finally reach an equilibrium state. Evolutionary stability strategy and replication dynamics are two core concepts in evolutionary game theory [11]. The evolutionary stability strategy refers to the status when game sides may not be able to make the optimal decision at the beginning based on the bounded rationality and need to learn and improve in the game process [12]. After some time, all game sides will tend to take a stable strategy. Replication dynamics is a dynamic differential equation that describes the frequency or frequentness at which a population adopts a particular strategy [13]. Its core idea is that adoption of a strategy or payment is higher than the average fitness of the population, and this strategy will be widely recognized in the population.

Evolutionary game theory has been widely used in decision-making, production management, project management, supply chain management, social networks, etc. Tongyao Feng [14] analyzed the behavior evolution trend of both parties using evolutionary game theory; the results indicate that stable evolutionary strategies exist under both cooperation and noncooperation, and the evolutionary results are influenced by the initial proportion of both decision-making processes. Wei He [15] constructed a model based on the dynamic evolutionary game theory, which incorporates several main factors influencing the development of modular production network. Qianqian Shi [16] developed an evolutionary game model to explore the cooperation tendency of multiple suppliers gaining a deeper insight into the suppliers' cooperative relationships. Chengrong Pan [17] employed the evolutionary game theory to analyze the cooperation between the microgrid and conventional grid, with the discussion focusing on the factors that influence the game players' selection of strategies, and additionally made a numerical simulation analysis. Congdong Li [18] analyzed the mutual evolutionary regularity of the private sector and government supervision department and the influence of public participation level on public and private behavior based on evolutionary game theory. Si-hua Chen [19] established an asymmetrical evolutionary game model of enterprise supervision to regard contextual factors and individual factors as risk preferences of knowledge workers. Qing Sun [20] designed a computational system that integrates the side, the evolutionary game, and the social network, which grasps the dynamic evolution features in information adoption game over time and explores microlevel interactions among users in different network structure under various scenarios.

2.3. Military-Civilian Collaborative Innovation. Regarding theoretical application, many scholars apply collaborative innovation theory to the military-civilian integration strategy. Trainor [21] discussed how a large organization with disparate operating elements could learn from experience, which is illustrated through a case study of the US Army enhancing learning for its organizations involved in developing base camps to support military forces worldwide based on military-civilian collaborative. Brickey [22] demonstrated the successful application of knowledge management theory between the US military and civil communities, enriching the theoretical system of military-civilian collaborative innovation. Merindol [23] took the application of dual-use policies in the framework of Knowledge-Oriented Policies (KOP) in France from 1990 to 2000 as an example; research conclusion is that dual-use policies represent now a dimension central to military R&D policies and should not be understood only as a civilian-military transfer mechanism. Totimeh [24] explored and identified the qualitative case study with the success factors needed to successfully implement knowledge management in a military-civilian organization. Molas-Gallart [25] discussed a conflict between private defense firms and government procurement agencies related to intellectual property management issues that emerged during the privatization process of the main UK defense research establishment, and it is concluded that in the process of military-civilian collaborative innovation among different sides, "partnership" can effectively resolve intellectual property disputes and enhance the efficiency of collaborative innovation.

Secondly, research has been carried out on the important role, institutional standards, influencing factors, and countermeasure research of military-civilian collaborative innovation. Mclvor [26] discussed the significance of the military-civilian integration strategy and believed that military-civilian collaborative innovation is conducive to the overall development of the national defense economy and the civilian economy; Jeong [27] took the trend of the technical efficiency of the Korean national defense firms in 1990–2005 as the research object by applying Stochastic Frontier Analysis (SFA). The results show that military-civilian collaborative innovation can effectively improve the speed of national technology innovation. Yun Zhikai [28] believed that the intellectual property system could be continuously created and improved under the military-civilian collaborative innovation system, and under this system, intellectual property rights can be fully pushed into the process of scientific research and development, production, and management. To promote healthy development of military-civilian collaborative innovation and dual-use technology, it is necessary to adjust the military-civilian standardization system [29]. Kulve [30] believed that the realization and popularization of social and technological networks are conducive to military-civilian collaborative innovation from the perspective of rational allocation of resources such as science and technology, talents, and capital. Yepes [31] studied the implementation process of collaborative innovation management system from the five factors of technology observation, innovation, planning and implementation of innovative projects, technology transfer, and results in protection. Lavallee [32] proposed a countermeasure to promote the development of dual-use technology based on the global perspective, to realize the synergy between the military and civilian sectors. Ross [33] studied the influencing factors of the operational performance of the military-civilian collaborative innovation team and provided effective suggestions.

Regarding industrial application, since 2008, affected by financial crisis, many countries have begun to vigorously develop strategic emerging industries that represent a new round of economic growth and technological revolution in order to stimulate economic growth. Strategic emerging industries are based on major technological breakthroughs and major development needs; they are those industries with intensive knowledge and technology, low consumption of material resources, great growth potential, and good comprehensive benefits and have a major leading and driving role in the overall and long-term development of the economy and society. Adopting military-civilian collaborative innovation in strategic emerging industries and then attaching importance to the mutual transformation of military technology and civil technology, such as renewable energy, bioengineering, aerospace, Internet of Things, and other industries have achieved a series of results.

According to those mentioned above, existing literature mostly focuses on the internal operational mechanism, influencing factors, and countermeasure research of military-civilian collaborative innovation at the macro level. There are not many quantitative studies on the mathematical model of military-civilian collaborative innovation at the micro level, and it is mostly how to achieve the cooperation between the military-civilian, analyze the timing and conditions of the collaborative innovation, and less study the stability of the military-civilian collaborative innovation process after the cooperation. Based on evolutionary game theory, we build an evolutionary game model of China's satellite industry military-civilian collaborative innovation with military enterprises and civil enterprises as the main participators under the bounded rationality. Then we analyze the long-term evolution of the system and factors influencing cooperative stability and perform numerical simulation using Matlab.

3. Evolutionary Game Model of China's Satellite Industry Military-Civilian Collaborative Innovation

3.1. Problem Description and Model Hypothesis. Before the evolutionary game model building, it is necessary to clarify the responsibilities, objectives, and mutual interests of each game's multiple agents, to identify the key influencing factors of the military-civilian collaborative innovation relationship stability in China's satellite industry. For the sake of analysis, the satellite industry has been simplified into two departments: the military sector and the civilian sector. It is assumed that military enterprises and civilian enterprises are the two major decision-making sides of the evolutionary game model [34]. The common goal pursued by these two sides is collaborative innovation, which refers to sharing resources, complementing each other and cooperating to complete product R&D and production, and sharing costs and benefits. In addition to the common demands, two game sides also have a different emphasis. Military enterprises must meet the basic standards of national security because of their policy, speciality, and confidentiality. The civilian enterprises can rely on military enterprises' favorable resources to the maximum extent, develop technological innovation, break down technical barriers, grab market share, minimize costs, and maximize benefits. The difference between the military-civilian collaborative innovation sides has led to an increase in product standardization costs. At the same time, various risks brought about by the external environment and market competition have made the game sides in an information asymmetric state. However, after the initial cooperation of the game sides is reached based on bounded rationality, it is difficult to determine the next strategic taking. At this time, it is necessary to repeat trials and games, absorb experience and adjust strategies, and finally form a stable strategy.

Based on the above discussion, the following basic hypotheses are made.

Hypothesis 1. After the initial cooperation between the military enterprise and civilian enterprise, the two sides, based on bounded rationality, continue to learn and adjust their strategies in the process of collaborative innovation until they reach a balanced strategy. Assume that the strategic combination of the two sides in the game is {continuing cooperation, quit in the midway}, then the probability of military enterprise taking the strategy of {continuing cooperation} is x $(0 \leq x \leq 1)$, and the probability of military enterprise taking the strategy of {quit in the midway} is $1 - x$. Similarly, the probability of civilian enterprise taking the strategy of {continuing cooperation} is y $(0 \leq y \leq 1)$, and the probability of civilian enterprise taking the strategy of {quit in the midway} is $1 - y$.

Hypothesis 2. Setting two game sides whether to take the strategy of {continuing cooperation} or the strategy of {quit in the midway}, there are basic benefits based on their technological advantages, military enterprise income is R_1, and civilian enterprise income is R_2. If both game sides take a strategy of {continuing cooperation} and share the benefits of cooperation R and there is a coefficient of the income distribution $d_1, d_2(d_1 + d_2 = 1)$, military enterprise obtains the cooperative benefits $d_1 R$, and civilian enterprise obtains the cooperative benefits $d_2 R$. After initial cooperation, the information obtained by the two sides in the follow-up cooperation will be asymmetry, system defects, and other reasons, which will cause the two sides not to take advantage of each other and the technical cooperation and sharing of resources to create certain difficulties; then they will take the strategy of {quit in the midway} and collaborative innovation exists in name only. At this point, both sides have only basic benefits R_1 and R_2. If one side takes the strategy of {quit in the midway}, it has the first advantage and the initiative right rather than the side who insists on {continuing cooperation}; then after learning the sharing technology, the unilateral termination of the cooperative relationship, the technological innovation alone obtains the technology spillover benefits, which are called betrayal incomes. The betrayal incomes of the military enterprise are K_1, and the betrayal incomes of the civilian enterprise are K_2.

Hypothesis 3. After initial cooperation between military enterprise and civilian enterprise, if the two sides choose to continue to cooperate, they will continue to invest in collaborative innovation. According to the inherent differences between the two sides in the management system, technical standards, and product purposes, the cost can be divided into three categories. The first is the R&D cost; the R&D cost of the military enterprise is C_1, and the R&D cost of the civilian enterprise is C_2. The second is the

Table 1: Payment matrix.

Payment Matrix		civilian enterprise	
		continuing cooperation y	quit in the midway $1-y$
military enterprise	continuing cooperation x	$d_1R+G-C_1-I_1-C_3$ $d_2R+G-C_2-I_2-C_4-C_f$	$C+G-D_1$ R_2+K_2-C
	quit in the midway $1-x$	R_1+K_1-C $G+C-D_2-C_f$	R_1-D_1 R_2-D_2

information communication cost due to lack of convenient communication channels; the information communication cost of the military enterprise is I_1, and the information communication cost of the civilian enterprise is I_2. The third is secondary conversion cost due to differences in technical standards; the secondary conversion cost of the military enterprise is C_3, and the secondary conversion cost of the civilian enterprise is C_4. Also, compared with military enterprise, civilian enterprise has the risk of losing market share when conducting collaborative innovation cooperation, and we record the losses caused by these risks in the civilian enterprise as the cost risk C_f; that is to say, the greater the cost risk of civilian enterprise, the greater the C_f. In the process of cooperation, if one of the sides takes the strategy of {quit in the midway}, it will be required to pay the other side's liquidated damages C. When civilian enterprise takes the strategy of {quit in the midway}, the damage caused to the military enterprise is D_1, and when military enterprise takes the strategy of {quit in the midway}, the damage caused to the civilian enterprise is D_2.

Hypothesis 4. Promoting military-civilian collaborative innovation in China's satellite industry can expedite development of S&T, expand economic construction, accelerate marketization and industrialization of scientific research results, and adjust the national and regional economic and industrial structure. Therefore, to improve the success rate of military-civilian collaborative innovation in China's satellite industry, the government provides policy support and financial incentives to participate in active cooperation strategies. To facilitate analysis of the problem, government's various preferential measures are quantified as G.

From the above four hypotheses, an evolutionary game payment matrix for military-civilian collaborative innovation in China's satellite industry can be obtained, as shown in Table 1.

3.2. Establishing Dynamic Equations. According to evolutionary game payment matrix shown in Table 1, in the process of military-civilian collaborative innovation, the expected benefit of a military enterprise taking a strategy of {continuing cooperation} is

$$U_{1A} = y\left(d_1R+G-C_1-I_1-C_3\right) + \left(1-y\right)\left(C+G-D_1\right). \quad (1)$$

The expected benefit of a military enterprise taking a strategy of {quit in the midway} is $U_{1B} = y(R_1+K_1-C) + (1-y)(R_1-D_1)$.

The average expected benefit is $\overline{U_1} = xU_{1A} + (1-x)U_{1B}$.

The expected benefit of a civilian enterprise taking a strategy of {continuing cooperation} is $U_{2A} = x(d_2R+G-C_2-I_2-C_4-C_f) + (1-x)(G+C-D_2-C_f)$.

The expected benefit of a civilian enterprise taking a strategy of {quit in the midway} is $U_{2B} = x(R_2+K_2-C) + (1-x)(R_2-D_2)$.

The average expected benefit is $\overline{U_2} = yU_{2A} + (1-y)U_{2B}$.

To facilitate the analysis of cooperative stability of military-civilian collaborative innovation, we build the replication dynamic equation for the game sides to take a strategy of {continuing cooperation}. The replication dynamic equation for the military enterprise to take a strategy of {continuing cooperation} is as follows.

$$F(x) = \frac{dx}{dt} = x\left(U_{1A}-\overline{U_1}\right) = x(1-x) \cdot \left[C+G-R_1+\left(d_1R-C_1-I_1-C_3-K_1\right)y\right] \quad (2)$$

The replication dynamic equation for the civilian enterprise to take a strategy of {continuing cooperation} is as follows.

$$M(y) = \frac{dy}{dt} = y\left(U_{2A}-\overline{U_2}\right) = y(1-y) \cdot \left[G+C-C_f-R_2+\left(d_2R-C_2-I_2-C_4-K_2\right)x\right] \quad (3)$$

The collaborative innovation evolution game of military enterprise and civil enterprise can be described by two-dimensional dynamic systems consisting of differential equations (2) and (3).

Let $F(x) = 0$, $M(y) = 0$; we can get the system's five equilibrium points (x,y) as $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, $((R_2+C_f-C-G)/(d_2R-C_2-I_2-C_4-K_2), (R_1-C-G)/(d_1R-C_1-I_1-C_3-K_1))$.

4. Analysis of the Evolutionary Stability Strategy and Influencing Factors of Military-Civilian Collaborative Innovation in China's Satellite Industry

Military-civilian collaborative innovation is a process of continuous integration, adaptation, and perfection. When the time t tends to infinity, do military and civilian enterprise take a strategy of {continuing cooperation} or {quit in the midway}? This involves evolutionary game stability problem in the process of military-civilian collaborative innovation,

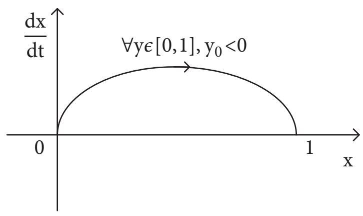

Figure 1: Phase diagram in Condition 1.

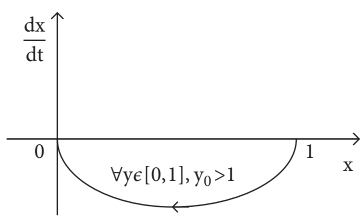

Figure 2: Phase diagram in Condition 2.

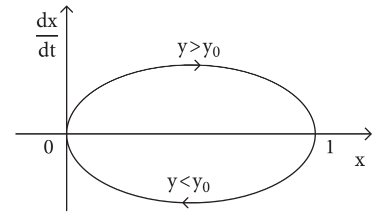

Figure 3: Phase diagram in Condition 3.

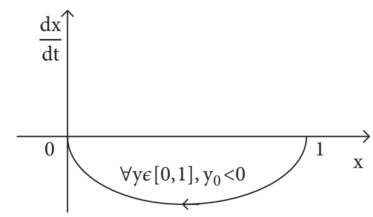

Figure 4: Phase diagram in Condition 4.

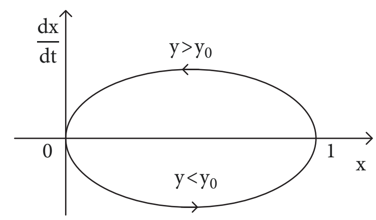

Figure 5: Phase diagram in Condition 5.

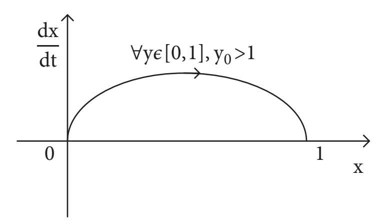

Figure 6: Phase diagram in Condition 6.

and a stable state must have the robustness to small disturbances to become an evolutionary stability strategy. Combining the hypotheses above and the replication dynamic system, according to stability theorem of the differential equation, when derivative of $F(x)$ or $M(y)$ is less than 0, and x or y is itself the equilibrium point of the steady state, then x or y is evolutionary stability strategy of the game sides. Next we use the local stability of the Jacobian matrix to verify whether the strategy combination formed by the two game sides is an evolutionary stability strategy *(ESS)*, and analyze the factors that influence the choice of strategy.

4.1. Stability Analysis of Collaborative Innovation Strategy for Military Enterprise. Derivation of $F(x)$ with respect to x results in the following derivative.

$$F'(x) = (1 - 2x) \cdot \left[C + G - R_1 + \left(d_1 R - C_1 - I_1 - C_3 - K_1\right) y\right] \tag{4}$$

When $F'(x) < 0$, then x is an evolutionary stabilization strategy. Let

$$y_0 = \frac{R_1 - C - G}{d_1 R - C_1 - I_1 - C_3 - K_1}. \tag{5}$$

The following are discussions of the military enterprise's collaborative innovation strategy choices, with phase diagrams showing the dynamic changes of the strategy (Figures 1–6).

Condition 1. $d_1 R - C_1 - I_1 - C_3 - K_1 > 0$, $C + G - R_1 > 0$, obtained by mathematical operations: $d_1 R + G - C_1 - I_1 - C_3 > R_1 + K_1 - C$. That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. $\forall y \in [0, 1]$, $F'(1) < 0$, then $x = 1$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the civilian enterprise takes, the military enterprise will take a strategy of {continuing cooperation} based on limited rationality.

Condition 2. $d_1 R - C_1 - I_1 - C_3 - K_1 > 0$,$C + G - R_1 < 0$, and $-(C + G - R_1) > d_1 R - K_1 - C_1 - I_1 - C_3$, obtained by mathematical operations: $d_1 R + G - C_1 - I_1 - C_3 < R_1 + K_1 - C$. That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken.$\forall y \in [0, 1]$, $F'(0) < 0$, then $x = 0$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the civilian enterprise takes, the military enterprise will take a strategy of {quit in the midway} based on limited rationality.

Condition 3. $d_1 R - C_1 - I_1 - C_3 - K_1 > 0$, $C + G - R_1 < 0$, and $-(C + G - R_1) < d_1 R - K_1 - C_1 - I_1 - C_3$, obtained by mathematical operations: $d_1 R + G - C_1 - I_1 - C_3 > R_1 + K_1 - C$.

That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. When $y > y_0$, $F'(1) < 0$, then $x = 1$ is the military enterprise ESS. When $y < y_0$, $F'(0) < 0$, then $x = 0$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, which strategy the military enterprise will take is based on the strategic probability of civilian enterprise.

Condition 4. $d_1R - C_1 - I_1 - C_3 - K_1 < 0, C + G - R_1 < 0$, obtained by mathematical operations: $d_1R + G - C_1 - I_1 - C_3 < R_1 + K_1 - C$. That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken. $\forall y \in [0,1]$, $F'(0) < 0$, then $x = 0$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the civilian enterprise takes, the military enterprise will take a strategy of {quit in the midway} based on limited rationality.

Condition 5. $d_1R - C_1 - I_1 - C_3 - K_1 < 0, C + G - R_1 > 0$, and $-(C + G - R_1) > d_1R - K_1 - C_1 - I_1 - C_3$, obtained by mathematical operations: $d_1R + G - C_1 - I_1 - C_3 < R_1 + K_1 - C$. That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken. When $y > y_0$, $F'(0) < 0$, then $x = 0$ is the military enterprise ESS. When $y < y_0$, $F'(1) < 0$, then $x = 1$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, which strategy the military enterprise will take is based on the strategic probability of civilian enterprise.

Condition 6. $d_1R - C_1 - I_1 - C_3 - K_1 < 0, C + G - R_1 > 0$, and $-(C + G - R_1) < d_1R - K_1 - C_1 - I_1 - C_3$, obtained by mathematical operations: $d_1R + G - C_1 - I_1 - C_3 > R_1 + K_1 - C$. That is to say, if the military enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. $\forall y \in [0,1]$, $F'(1) < 0$, then $x = 1$ is the military enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the civilian enterprise takes, the military enterprise will take a strategy of {continuing cooperation} based on limited rationality.

4.2. Stability Analysis of Collaborative Innovation Strategy for Civilian Enterprise. Derivation of $M(y)$ with respect to y results in the following derivative.

$$M'(y) = (1 - 2y)\left[G + C - C_f - R_2 + (d_2R - C_2 - I_2 - C_4 - K_2)\,x\right] \tag{6}$$

When $M'(y) < 0$, then y is an evolutionary stabilization strategy. Let

$$x_0 = \frac{R_2 + C_f - C - G}{d_2R - C_2 - I_2 - C_4 - K_2}. \tag{7}$$

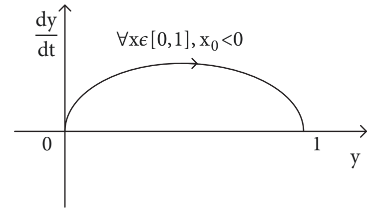

Figure 7: Phase diagram in Condition 1.

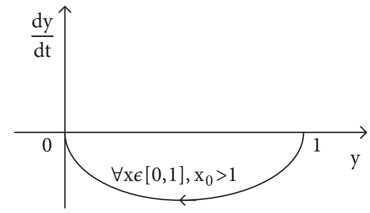

Figure 8: Phase diagram in Condition 2.

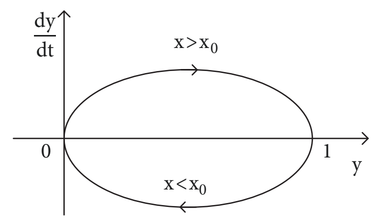

Figure 9: Phase diagram in Condition 3.

The following are discussions of the military enterprise's collaborative innovation strategy choices, with phase diagrams showing the dynamic changes of the strategy (Figures 7–12).

Condition 1. $d_2R - C_2 - I_2 - C_4 - K_2 > 0, G + C - C_f - R_2 > 0$, obtained by mathematical operations: $d_2R + G - C_2 - I_2 - C_4 - C_f > R_2 + K_2 - C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. $\forall x \in [0,1]$, $M'(1) < 0$, then $y = 1$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the military enterprise takes, the civilian enterprise will take a strategy of {continuing cooperation} based on limited rationality.

Condition 2. $d_2R - C_2 - I_2 - C_4 - K_2 > 0, G + C - C_f - R_2 < 0$, and $-(G + C - C_f - R_2) > d_2R - K_2 - C_2 - I_2 - C_4$, obtained by mathematical operations: $d_2R + G - C_2 - I_2 - C_4 - C_f < R_2 + K_2 - C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken. $\forall x \in [0,1]$, $M'(0) < 0$, then $y = 0$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the military enterprise takes, the civilian enterprise will take a strategy of {quit in the midway} based on limited rationality.

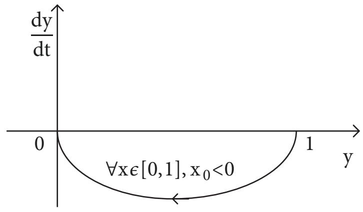

Figure 10: Phase diagram in Condition 4.

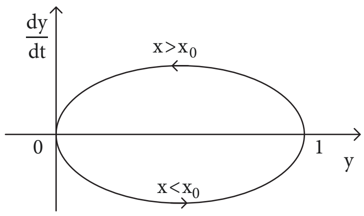

Figure 11: Phase diagram in Condition 5.

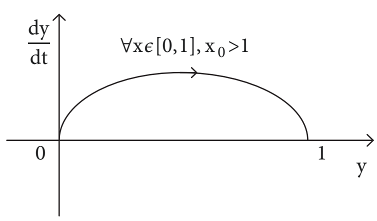

Figure 12: Phase diagram in Condition 6.

Condition 3. $d_2R-C_2-I_2-C_4-K_2>0, G+C-C_f-R_2<0$, and $-(G+C-C_f-R_2) < d_2R-K_2-C_2-I_2-C_4$, obtained by mathematical operations: $d_2R+G-C_2-I_2-C_4-C_f > R_2+K_2-C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. When $x > x_0$, $M'(1) < 0$, then $y = 1$ is the civilian enterprise ESS. When $x < x_0$, $M'(0) < 0$, then $y = 0$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, which strategy the civilian enterprise will take is based on the strategic probability of military enterprise.

Condition 4. $d_2R-C_2-I_2-C_4-K_2 < 0, G+C-C_f-R_2<0$, obtained by mathematical operations: $d_2R+G-C_2-I_2-C_4-C_f < R_2+K_2-C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken. $\forall x \in [0,1]$, $M'(0) < 0$, then $y = 0$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the military enterprise takes, the civilian enterprise will take a strategy of {quit in the midway} based on limited rationality.

Condition 5. $d_2R-C_2-I_2-C_4-K_2<0, G+C-C_f-R_2>0$, and $-(G+C-C_f-R_2) > d_2R-K_2-C_2-I_2-C_4$, obtained by mathematical operations: $d_2R+G-C_2-I_2-C_4-C_f < R_2+K_2-C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are lower than those when a strategy of {quit in the midway} is taken. When $x > x_0$, $M'(0) < 0$, then $y = 0$ is the civilian enterprise ESS. When $x < x_0$, $M'(1) < 0$, then $y = 1$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, which strategy the civilian enterprise will take is based on the strategic probability of military enterprise.

Condition 6. $d_2R-C_2-I_2-C_4-K_2<0, G+C-C_f-R_2>0$, and $-(G+C-C_f-R_2) < d_2R-K_2-C_2-I_2-C_4$, obtained by mathematical operations: $d_2R+G-C_2-I_2-C_4-C_f > R_2+K_2-C$. That is to say, if the civilian enterprise takes a strategy of {continuing cooperation}, the benefits obtained are higher than those when a strategy of {quit in the midway} is taken. $\forall x \in [0,1]$, $M'(1) < 0$, then $y = 1$ is the civilian enterprise ESS. The result of the game between the two sides is that, under this condition, no matter what strategy the military enterprise takes, the civilian enterprise will take a strategy of {continuing cooperation} based on limited rationality.

4.3. Stability Analysis of Collaborative Innovation Strategies of Game Sides. Above we analyzed the military and civilian enterprise's respective stability strategy under six conditions. By combining these conditions, two game sides can be divided into the following three situations:

In the first situation, both game sides do not affect each other in taking strategy, which meets military enterprise Condition 1 or Condition 2 or Condition 4 or Condition 6 and also meets civilian enterprise Condition 1 or Condition 2 or Condition 4 or Condition 6. There are 16 combinations in this situation.

In the second situation, when the two sides of the game take the strategy, only one side's strategic behavior is affected by the other side, which meets military enterprise Condition 1 or Condition 2 or Condition 4 or Condition 6; civilian enterprise Condition 3 or Condition 5; military enterprise Condition 3 or 5; and civilian enterprise Condition 1 or Condition 2 or Condition 4 or Condition 6. There are 16 combinations in this situation.

In the third situation, both sides of the game influence each other when taking a strategy, which meets military enterprise Condition 3 or Condition 5 and meets civilian enterprise Condition 3 or Condition 5. There are 4 combinations in this situation.

We use the local stability of the Jacobian matrix to verify the evolutionary stability strategy combinations that may exist in the three situations. The partial derivatives of $F(x)$ and $M(y)$ are, respectively, taken for $\boldsymbol{x}$ and $\boldsymbol{y}$, and the Jacobian matrix is as follows.

Table 2: Evolutionary stable point under conditions combination of military-civilian.

Combination		Military Enterprise Condition 1	2	3	4	5	6
Civilian Enterprise Condition	1	(1,1)	(0,1)	(1,1)	(0,1)	(0,1)	(1,1)
	2	(1,0)	(0,0)	(0,0)	(0,0)	(1,0)	(1,0)
	3	(1,1)	(0,0)	(1,1) (0,0)	(0,0)	null	(1,1)
	4	(1,0)	(0,0)	(0,0)	(0,0)	(1,0)	(1,0)
	5	(1,0)	(0,1)	null	(0,1)	(0,1) (1,0)	(1,0)
	6	(1,1)	(0,1)	(1,1)	(0,1)	(0,1)	(1,1)

$$J = \begin{pmatrix} (1-2x)\left[C+G-R_1+\left(d_1R-C_1-I_1-C_3-K_1\right)y\right] & (1-x)\left(d_1R-C_1-I_1-C_3-K_1\right)x \\ (1-y)\left(d_2R-C_2-I_2-C_4-K_2\right)y & (1-2y)\left[G+C-C_f-R_2+\left(d_2R-C_2-I_2-C_4-K_2\right)x\right] \end{pmatrix} \quad (8)$$

It can be seen from Table 2 that whether it is situation 1, situation 2, or situation 3, after long-term evolution, there are four combinations of evolutionary stability strategies, ***(1,1), (1,0), (0,1), (0,0)***. The final specific evolution direction mainly depends on the factors of military-civilian collaborative innovation cooperation evolution game matrix and the initial state of the system.

Further analysis of Table 2 shows that under the 36 condition's combinations, the cooperation of military-civilian collaborative innovation under 27 combinations is broken. Under 8 combinations, there is the only evolutionary stability point ***(1,1)***; that is, both the game sides take a strategy of {continuing cooperation}, and the cooperation between the military and civilian enterprise has continued to be maintained. There is only one combination, and the long-term evolutionary stable points are combined into ***(1,1)*** and ***(0,0)***.

According to the above analysis, the reason for the termination of the military-civilian collaborative innovation cooperation process is as follows: the total income earned by one or both sides of the game is lower than the total income obtained when the game is withdrawn. From the perspective of income, the cooperation income of two game sides does not reach the expected income or the income distribution is uneven; that is, the allocation of $\boldsymbol{d_1}$, $\boldsymbol{d_2}$ is unreasonable, or the cooperative income is lower than the independent R&D profit. The betrayal benefits brought about by the game side's breach of contract also increase the risk of cooperation failure. The incentives given by the government need to be further increased with targeted and differentiated rewards for different game sides. From the perspective of cost, the R&D cost, information communication cost, and technology secondary conversion cost invested by both game sides exceed the budget. Due to the high market risk, the losses incurred by one side are too high. In addition, liquidated damages are set too low, resulting in reduced binding and a reduced probability of successful cooperation.

The long-term evolution of the system contains a total of 9 combinations of conditions at point (1,1). Among them, under 8 combinations, when the game side takes a strategy of {continuing cooperation} and the return is greater than the net income obtained taking a strategy of {quit in the midway}, there is a unique game equilibrium state (1,1). According to the 9 combinations, the common conditions can be obtained, as shown in formula (9); the basic criteria for government incentive selection are calculated by this formula.

$$\begin{aligned} d_1R + G - C_1 - I_1 - C_3 &> R_1 + K_1 - C \\ d_2R + G - C_2 - I_2 - C_4 - C_f &> R_2 + K_2 - C \end{aligned} \quad (9)$$

We solve the basic standard of G: $G > R_1 + K_1 - C - (d_1R - C_1 - I_1 - C_3)$ and $G > R_2 + K_2 - C - (d_2R - C_2 - I_2 - C_4 - C_f)$.

The basic standards show that under the conditions of basic R&D income, cooperation income, betrayal income, liquidated damages, R&D and communication costs, technology secondary conversion cost, and cooperation risk, the intensity of government incentives must at least compensate for the difference between the benefits of the continued cooperation strategy and the gains from the withdrawal, and then the military-civilian collaborative innovation cooperation is likely to continue, so that the entire game system will eventually move toward a stable state of cooperation.

The situation in which the military-civilian collaborative innovation evolutionary stability point is ***(1,1), (0,0)*** is the combination of military enterprise's Condition 3 and civilian enterprise's Condition 3. Under this combination, it can be obtained from the local stability analysis of the Jacobian matrix that ***(1,0)*** and ***(0,1)*** are the unstable points of the long-term evolution game; if $\det(J)|(x_0, y_0) < 0$ and

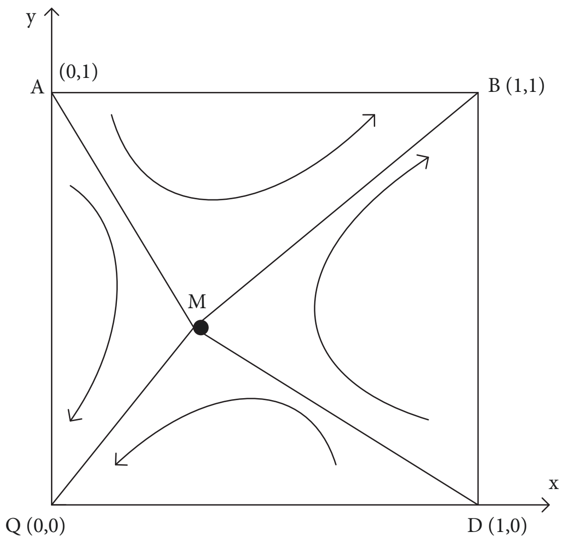

Figure 13: Phase diagram of the military-civilian collaborative innovation evolution.

$\mathrm{tr}(J)|(x_0, y_0) = 0$, then (x_0, y_0) is the saddle point $\boldsymbol{M}$, which is the critical point of evolutionary stability results. Putting Figures 3 and 9 on the same coordinate plane, we can get the dynamic phase diagram of the military-civilian collaborative innovation evolution, as shown in Figure 13.

4.4. Analysis of the Factors Affecting Military-Civilian Collaborative Innovation Strategy. We explore stability problem in the process of military-civilian collaborative innovation; that is, the process of ***(x,y)*** tends to ***(1,1)***. To analyze the factors affecting cooperative stability between two game sides, we choose the evolutionary stability point ***(1,1), (0,0)***.

According to Figure 13, the final evolutionary stability of military-civilian collaborative innovation cooperation game is as follows: two sides take a strategy of {continuing cooperation}, and two sides take a strategy of {quit in the midway}. The long-term evolutionary stability strategy has a dependence on initial state, and when initial state is near the saddle point ***M***, the small changes in initial state will affect final evolution of the cooperative game of military-civilian collaborative innovation. When initial state is in the ***AMDQ*** polyline area, military-civilian collaborative innovation cooperative game system will converge to ***Q(0,0)*** steady state; that is, the two sides take a strategy of {quit in the midway}. When initial state is in the ***AMDB*** polyline area, the military-civilian collaborative innovation cooperative game system will converge to ***B(1,1)*** steady state; that is, the two sides take a strategy of {continuing cooperation}, and collaborative innovation activities will continue. Therefore, the final evolutionary stability results of the military-civilian collaborative innovation and evolution system may continue to cooperate with the initial point or may be the termination of cooperation. Therefore, with the difference of initial points, the final evolutionary stability of the military-civilian collaborative innovation and evolution system may be the result of {continuing cooperation} or may be {quit in the midway}, whose evolutionary state tends to depend on the regional ***AMDQ*** area $\boldsymbol{S_1}$ and regional ***AMDB*** area $\boldsymbol{S_2}$**.** When $\boldsymbol{S_1} > \boldsymbol{S_2}$, the state of collaborative innovation and evolution system tends to collide with cooperation; when $\boldsymbol{S_2} > \boldsymbol{S_1}$, the collaborative innovation and evolution system tends to continue the cooperation between two sides. We explore the factors affecting the cooperative stability of military-civilian collaborative innovation, that is, analyze the factors affecting the $\boldsymbol{S_2}$ area.

Table 3: Analysis of the factors affecting military-civilian collaborative innovation strategy.

Influencing factor	Partial derivative	Impact on S_2
R	+	↑
R_1, R_2	−	↓
G	+	↑
K_1, K_2	−	↓
d_1, d_2	?	?
C	+	↑
C_1, C_2, C_3, C_4	−	↓
C_f	−	↓
$I_1, I_2,$	−	↓

$$S_2 = 1 - \frac{1}{2}\left(\frac{R_2 + C_f - C - G}{d_2 R - C_2 - I_2 - C_4 - K_2} + \frac{R_1 - C - G}{d_1 R - C_1 - I_1 - C_3 - K_1}\right) \tag{10}$$

From this formula, the factors affecting the $\boldsymbol{S_2}$ area can be divided into two categories: the income category

$$R, R_1, R_2, G, K_1, K_2, d_1, d_2 \tag{11}$$

and the cost category

$$C, C_1, C_2, C_3, C_4, C_f, I_1, I_2. \tag{12}$$

$\boldsymbol{S_2}$ is used to obtain partial derivatives for the above parameters, as shown in Table 3.

It can be seen from Table 3 that $\boldsymbol{R}$ is cooperation benefit in the process of military-civilians collaborative innovation. When it grows, the saddle point ***M*** moves to the ***Q*** point, and the regional ***AMDB*** area $\boldsymbol{S_2}$ increases. After long-term evolution, both game sides are more likely to trend toward ***B (1,1)*** point; that is, two game sides take a strategy of {continuing cooperation}. However, if the basic income $\boldsymbol{R_1}$, $\boldsymbol{R_2}$ of two game sides continues to grow, even exceeding the cooperative income, game sides tend to take a strategy of {quit in the midway} due to the consideration of optimal input-output ratio. The betrayal gain $\boldsymbol{K_1}$, $\boldsymbol{K_2}$ is negatively correlated with the stability of collaborative innovation. In particular, if the cooperative income R does not meet expectations and the betrayal income $\boldsymbol{K_1}$, $\boldsymbol{K_2}$ grows to a certain extent, then both game sides tend to take a strategy of {quit in the midway} based on interest considerations to avoid more losses.

To mobilize the enthusiasm of the military-civilian enterprises to participate in collaborative innovation, the government gives positive incentives ***G*** to game sides who maintain collaborative innovation cooperative stability. Since G is a part of the income of both game sides, when G exceeds the basic standard, it can promote evolution path of military-civilian cooperation to point B and improve the stability of collaborative innovation.

Since the monotonicity of S_2 to d_1 is uncertain, S_2 performs second-order derivation on d_1, and the second derivative is less than 0, indicating that S_2 has a maximum value for d_1. Similarly, S_2 also has a maximum value for d_2. That is to say, there is an optimal distribution coefficient for military-civilian collaborative innovation, which makes the military and civilian enterprises tend to take a strategy of {continuing cooperation}, which is conducive to a win-win situation.

C_1, C_2, C_3, C_4, I_1, I_2 are the cooperative costs of collaborative innovation invested by both military and civilian enterprises. When these costs increase, the regional $AMDB$ area S_2 decreases, indicating that the probability of the game sides taking a strategy of {continuing cooperation} becomes smaller, which may lead to the breakdown of cooperation. The reasonable explanation for this is that after the investment in R&D costs and technology secondary conversion costs exceed the budget, the military and civilian enterprise increase the communication cost due to the difference in the management mechanism system; in the end, the cooperative income did not reach the expected basic income of the game sides or even a lower value, and then the collaborative innovation cooperation relationship was terminated. C indicates penalty costs in the cooperative process, and the penalty costs are positively correlated with the area of S_2. This means that both the military and civilian enterprises are more inclined to take a strategy of {continuing cooperation} under the effective and strict restraint mechanism, reducing the moral hazard and thus improving the collaborative innovation cooperative stability. Above discussion on the costs is based on the premise shared by both the military and civilian enterprises. Compared with the military enterprises, the market risk brings a large cost loss C_f to the civilian enterprises. When C_f is getting bigger and bigger, beyond the risk estimation of the civilian enterprises, the process of collaborative innovation is difficult to maintain or even the relationship is broken. In combination with the actual situation, the market risk is dynamic. Whether it is for the military or civilian enterprises, the risk loss is a hidden danger worthy of attention, and dynamic risk management is necessary.

In summary, in the process of military-civilian collaborative innovation, the cooperative stability of cooperation between two game sides is affected by their respective basic income, cooperation revenue, betrayal income, government incentives, various costs of investment, liquidated damages, optimal distribution coefficient, etc.

5. Numerical Analysis

Based on the above analysis of evolutionary stability of both game sides under different conditions, we take the military and civilian enterprises in satellite industry as examples, assign values to each parameter, perform numerical evolution and simulation analysis, and then use ***Matlab*** software to simulate the dynamics evolution process of strategic selection between the military and civilian enterprises. To visually demonstrate and verify the influence of relevant factors and initial state on the stability of military-civilian collaborative innovation cooperation process, the evolutionary game stability strategy of both sides is selected to simulate the ***(1,1)*** condition combination state.

The characteristics of satellite industry are that development of the military industry and technological breakthroughs can promote simultaneous development of the civilian industry, and technological advancement of the civilian industry will drive the growth of the military industry in turn. The two sides promote each other and depend on each other to form a symbiotic relationship of synergy and common growth. From the perspective of technical attributes, the technology of satellite industry can be transferred between the military and civilian industry. Moreover, satellite industry is an industry with a blurred border of military-civilian and a high degree of common assets. The products and business levels are relatively similar, and boundaries will become increasingly blurred. That is, the status of military-civilian collaborative innovation in these industries has a certain foundation, and industrial barriers are relatively easy to break; at the same time, it has very large market potential.

Based on the above-mentioned satellite industry's development status and future market potential, combined with the evolutionary game model of military-civilian collaborative innovation, we should consider the following basic conditions when assigning values to the parameters: the cooperative benefits of the joint innovation between the game sides must exceed their respective basic benefits; based on the higher investment cost and basic technology advantages, military enterprise's income distribution coefficient, basic income, betrayal income, and research and development costs are higher than the civilian enterprise. The initial assignment of each parameter is as follows (unit: million ***RMB***, except $d_1, d_2 (d_1 + d_2 = 1)$).

$$
\begin{aligned}
d_1 &= 0.6,\\
R &= 70,\\
R_1 &= 25,\\
C_1 &= 10,\\
I_1 &= 6,\\
K_1 &= 14,\\
C_3 &= 7,\\
C &= 10\\
d_2 &= 0.4,\\
R_2 &= 20,\\
C_2 &= 5,\\
I_2 &= 6,\\
K_2 &= 7,
\end{aligned}
$$

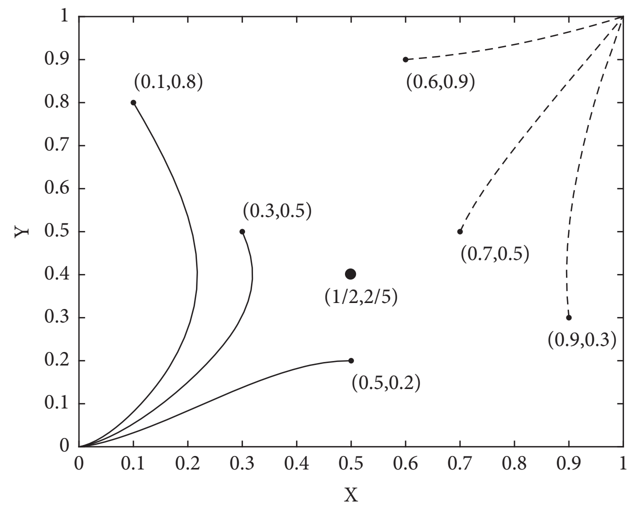

Figure 14: The dynamic evolution process of military-civilian strategies in different initial states.

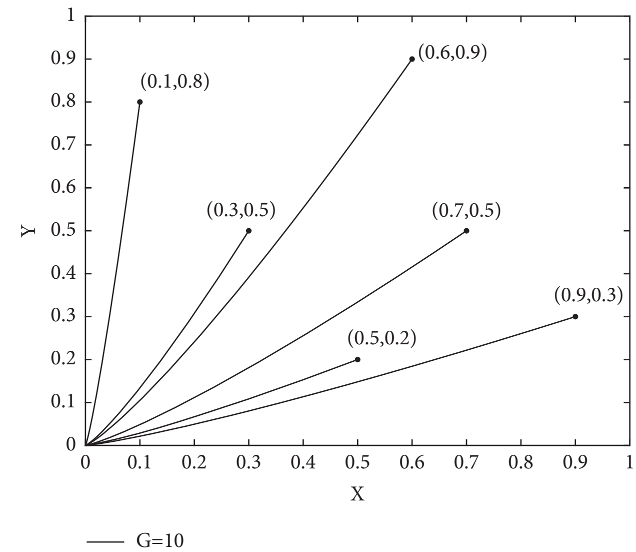

Figure 15: The dynamic evolution process of military-civilian strategies at G=10.

$$C_4 = 4,$$
$$C_f = 6,$$
$$G = 13 \tag{13}$$

According to the set parameter values, the saddle point ***M*** is calculated as ***(1/2, 2/5)***. Randomly set the initial six initial states of the military-civilian cooperation ***(0.1, 0.8), (0.3, 0.5), (0.5, 0.2), (0.9, 0.3), (0.7, 0.5), (0.6, 0.9)***. Through ***Matlab*** simulation, the dynamic evolution process of game strategies after long-term evolution is predicted, as shown in Figure 14.

It can be seen from Figure 14 that when ***(x, y)*** falls in the ***AMDB*** region, it gradually converges to ***(1, 1)***, and when ***(x, y)*** falls in the ***AMDQ*** region, it gradually converges to ***(0, 0)***, which verifies that the stability of civil-military collaborative innovation process is related to initial state of the system.

By the initial assignment of the above parameters, the value of the government incentive ***G*** is changed to visually demonstrate the impact of government incentives on the military-civilian collaborative innovation cooperative stability. In order to make military-civilian collaborative innovation in the initial state tend to be stable, according to the basic standard formula of ***G, G***>***10*** is calculated.

When ***G=10,*** as shown in Figure 15, military-civilian collaborative innovation cooperation in the six randomly selected states tends to ***(0,0)*** in the long-term evolution process. This shows that when government incentive G does not reach the basic standard, one of two game sides fails to meet the expected total income of cooperation, willingness to cooperate with collaborative innovation will decrease with time, and the state of cooperation between two game sides will be unstable or even ruined.

When ***G=13,14***, as shown in Figure 16, the initial state of ***(0.1,0.8), (0.3,0.5), (0.5,0.2)*** military-civilian collaborative innovation has changed from failure to stable cooperation, because government incentive ***G*** is higher than the basic standard, compensating for the difference between military and civilian enterprises losses and enhancing the confidence of collaborative innovation cooperation; that is, ***G*** plays a positive role in the stability of game system. When initial state of is ***(0.9, 0.3), (0.7, 0.5), (0.6, 0.9)***, steady state has been reached under the condition of ***G=13***, and when ***G*** is increased to ***14***, this does not significantly improve civil-military cooperation the two sides which tends to be ***(1,1)***. The explanation is that government incentives may have marginal effects, and further research is needed to get the scope of implementation of government incentives.

We then select representative factors and analyze their impact on the dynamic evolution process of military-civilian collaborative innovation. Taking ***C***, I_2, and C_3 as examples, the dynamic process of strategic evolution between two game sides is visually demonstrated. The specific process is as follows.

5.1. Liquidated Damages ***C***. Except for ***C***, the values of other factors are consistent with the initial settings of the parameters. When ***C=8, 10, 12***, and initial state is ***(0.1, 0.8), (0.3, 0.5), (0.7, 0.5), (0.9,0.3)***, the dynamic evolution process of two game sides strategies is shown in Figure 17. With the increase of liquidated damages ***C***, the strategic evolution direction of both game sides gradually evolved from the unstable state ***(0,0)*** to the stable state ***(1,1)***. This shows that liquidated damages have a positive effect on the stability of the process of military-civilian collaborative innovation; that is, the higher the liquidated damages, the more likely that the two game sides tend to take a strategy of {continuing cooperation}, which is in line with the actual situation.

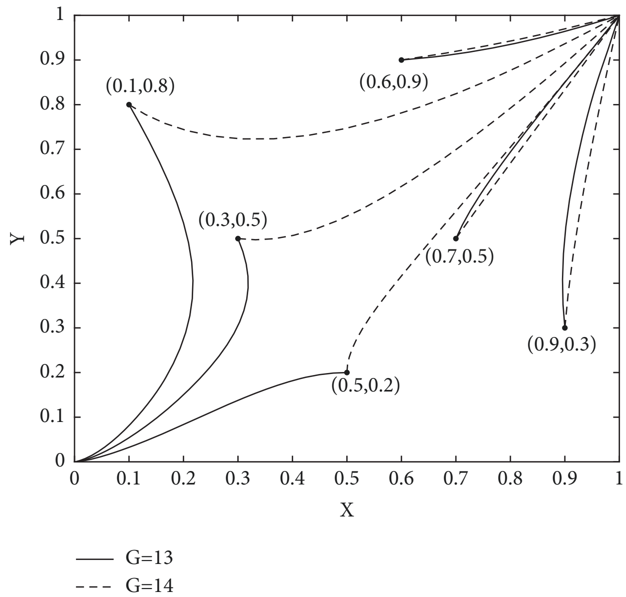

Figure 16: The dynamic evolution process of military-civilian strategies at G=13,14.

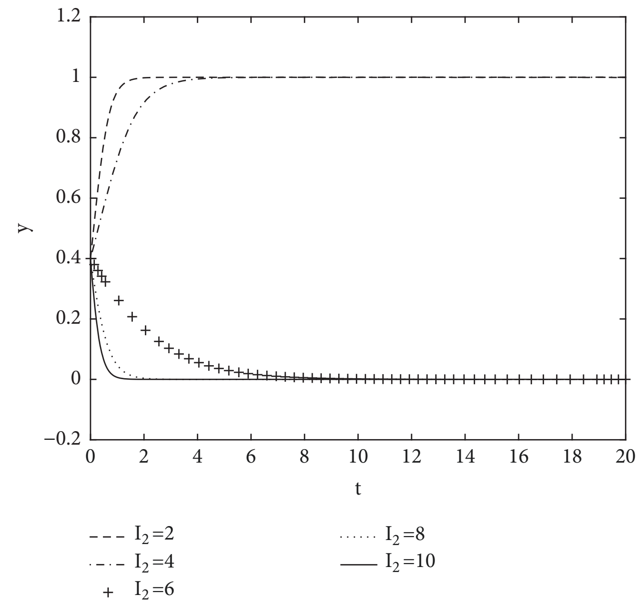

Figure 18: The dynamic evolution process of civilian strategies at I_2*=2, 4, 6, 8, 10*.

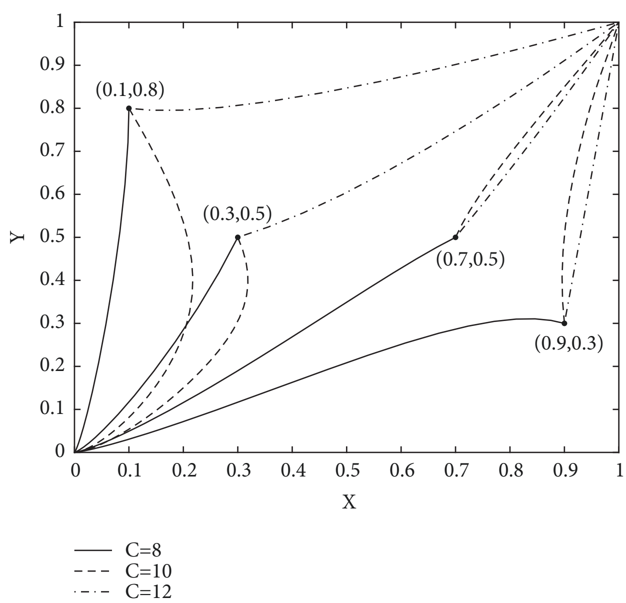

Figure 17: The dynamic evolution process of military-civilian strategies at *C=8, 10, 12*.

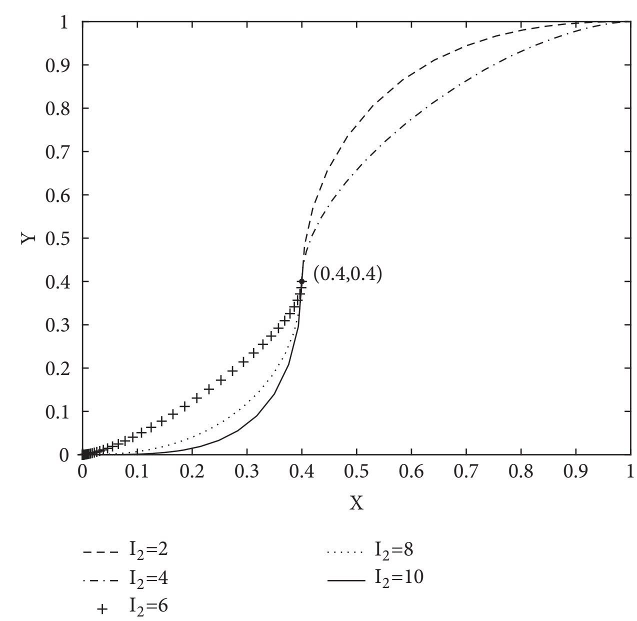

Figure 19: The dynamic evolution process of military-civilian strategies at I_2*=2, 4, 6, 8, 10*.

5.2. Information Communication Cost of Civilian Enterprise I_2. Except for I_2, the values of other factors are consistent with the initial settings of the parameters. When I_2*=2, 4, 6, 8, 10* and the initial state is *(0.4, 0.4)*, the dynamic evolution process of game sides strategies is shown in Figure 18. When I_2 continues to increase, the value of the civilian I_2 exceeds civilian enterprise's acceptable range, the civilian enterprise tends to take a strategy of {quit in the midway}, and, at the same time, the convergence rate is accelerated. Figure 19 also verifies that under same conditions, when the cost of information communication gradually increases and exceeds budget, the cooperative relationship of the military-civilian collaborative innovation is also shattered. This shows that the cooperative stability of military-civilian collaborative innovation will be negatively affected by I_2.

5.3. Technology Secondary Conversion Cost of Military Enterprise C_3. Except for C_3, the values of other factors are consistent with the initial settings of the parameters. When C_3*=3, 5, 6, 9, 11* and the initial state is *(0.4, 0.4)*, the dynamic evolution process of the game sides strategies is

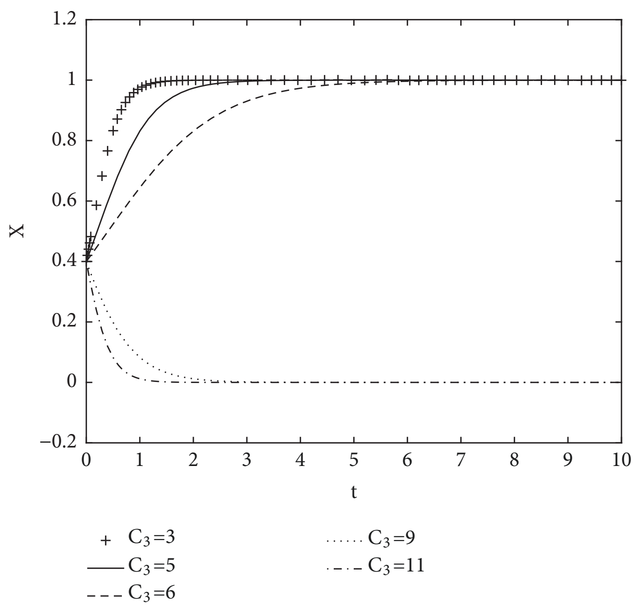

Figure 20: The dynamic evolution process of military strategies at C_3=3, 5, 6, 9, 11.

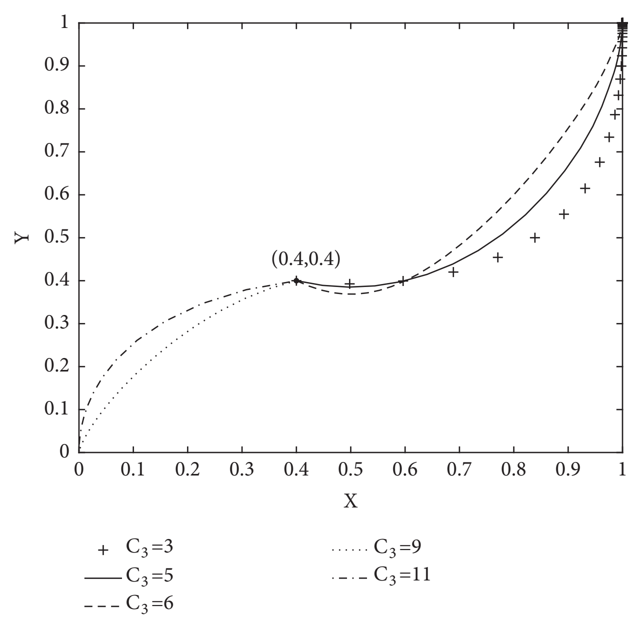

Figure 21: The dynamic evolution process of military-civilian strategies at C_3=3, 5, 6, 9, 11.

shown in Figure 20. When C_3 continues to increase, in order to avoid more losses, the military enterprise tends to take a strategy of {quit in the midway} and, at the same time, the convergence rate is accelerated. Figure 21 also verifies that under the same conditions, when secondary conversion cost gradually increases, the strategic evolution direction of both game sides gradually evolved from the state ***(1,1)*** to ***(0,0)***. This shows that the cooperative stability of military-civilian collaborative innovation will be negatively affected by C_3.

6. Main Conclusions and Management Implications

6.1. Main Conclusions. The long-term evolutionary game of military-civilian collaborative innovation in the satellite industry has four stable points, namely, ***(1,1), (1,0), (0,1), (0,0)***, and its evolution direction depends on the initial state and factor values of the military-civilian collaborative innovation evolutionary game system.

By analyzing the factors leading the military-civilian collaborative innovation in satellite industry to tend to stable state ***(1,1)***, the following conclusions are drawn: The higher the basic income, R&D cost, information communication cost, technology secondary conversion cost, and betrayal income, the higher the market risk and the more unfavorable the cooperative stability between the two sides, whereas the liquidated damages, government incentives, cooperative income, and reasonable income distribution coefficient are conducive to cooperative stability. At the same time, the article gives basic standards for government to promote the incentives for cooperation between military and civilian enterprises.

Based on the characteristics of China's satellite industry, we use ***Matlab*** to simulate the above conclusions, vividly demonstrate the dynamic evolution process of the military-civilian strategies, and verify the impact of relevant factors on the cooperative stability of military-civilian integration collaborative innovation.

6.2. Implications for Researchers. In the evolutionary game model, we have simplified the setting and classification of the relevant parameters in the model to facilitate the analysis and solution. The game set only two major participants: military enterprises and civilian enterprises. In the satellite industry military-civilian collaborative innovation network, there are many participants involved, and the parameters of the model are more complicated. The follow-up research can be extended to the situation of military-civilian collaborative innovation cooperation composed of multiple agent, such as third-party intermediaries or financing institutions and research institutes.

In Section 5, through the analysis of the characteristics of China's satellite industry, we have determined the evaluation criteria of the model parameters and assigned the relevant parameters. The simulation result shows the dynamic evolution process of the military-civilian integration collaborative innovation. In order to make the conclusion more scientific and accurate, the follow-up research can be verified by empirical research on military-civilian collaborative innovation in different industries, and the evaluation index system and evaluation method can be constructed to comprehensively and accurately assess the military-civilian collaborative innovation cooperative stability.

Although this paper explores the cooperative stability of the military-civilian collaborative innovation for China's satellite industry, it provides reference material and an extended example for other researchers to explore the collaborative innovation of military-civilian integration in different countries in terms of the assumption of evolutionary game model, the form of payment matrix, the solution and analysis of the model, and ***Matlab*** simulation analysis.

6.3. Implications for Government. From the perspective of promoting the cooperative stability of military-civilian collaborative innovation in China's satellite industry, the government needs to do top-level planning, strengthen top-level design functions, coordinate overall development, thoroughly study the structure and appeals of relevant stakeholders, and scientifically formulate and rigidly implement relevant policies and mechanisms to create environment and conditions that can encourage civilian enterprises to enter satellite industry or to start businesses in the satellite industry. The details are as follows:

Government's policy supports and guarantees. For instance, for enterprises that actively participate in the military-civilian collaborative innovation, especially civilian enterprises, government grants necessary tax incentives and financial subsidies, simplifies the civil-military coordination procedures, and offers low-interest loans to the satellite industry. At the same time, government can also simplify loan processes and standards and encourage large-scale defense groups to conduct in-depth cooperation with civilian enterprises through material subsidies and preferential policies.

Government should focus on improving relevant laws and regulations and intellectual property protection to enhance the security of the satellite industry's military-civilian collaborative innovation policy environment; meanwhile, government can also improve the relevant content in the strategic planning of military-civilian collaborative innovation from national defense law to local regulations, so as to suppress betrayal behavior and speculation through the improvement of the legal system. In addition, relevant technologies in the satellite industry should adopt national standards and industry standards and gradually realize the integration of military and civilian standards. Government is supposed to improve laws and regulations on the transformation of dual-use S&T achievements in the satellite industry, provide legal guarantees for the transformation, and promote the application of dual-use S&T achievements.

Government plays a guiding role in policy by strengthening market standardization management for its role of market regulation and enforcement. Government can also promote the two-way flow of powerful resources between the military and civilian enterprises and form a market mechanism with clear national defense and market demand. From the perspective of factors affecting cooperative stability of military-civilian collaborative innovation, it is recommended that the government take the lead in cooperating with authoritative and independent institutions to supervise the whole process of cooperation, ensuring that collaborative innovation and cooperation are carried out smoothly and efficiently, and derogatory behavior can be avoided.

The cooperative stability of military-civilian collaborative innovation can be maintained by using the Internet plus service model thinking to build a platform for information exchange and interaction between the military and the civilian enterprise through the big data, cloud computing, and other technologies, so as to enrich the information involved in collaborative innovation and improve the efficiency and accuracy of information communication. Establishing a platform for the transformation of dual-use S&T achievements in the satellite industry is recommended, such as the high-technology enterprise incubation center, in addition to developing third-party intermediary service organizations. Military-civilian intermediary service system and military-civilian information exchange system need to be improved to promote the application of civilized achievements in national defense technology and the application of militarized results of advanced civilian technologies.

6.4. Implications for Game Sides. For both sides of the game, maintaining a friendly cooperative relationship can proceed from the following aspects:

Promote a win-win situation and risk assessment mechanism. Build an effective competition mechanism, supervision mechanism, evaluation mechanism, and incentive system. Achieve the effect of one investment and two outputs based on mutual development. Regarding risk management, a professional evaluation committee composed of government departments, experts from scientific institutions, and representatives from the game sides will make detailed predictions and demonstrations on military-civilian cooperation projects in the satellite industry, coordinate development, effectively allocate resources, and implement risk sharing to avoid potential risks as much as possible.

Establish a reasonable proportion of cooperative income distribution. Interest is the direct driving force for cooperation between the two game sides, and the reasonable distribution of benefits can promote the cooperative stability. A third-party evaluation agency may be introduced to consider the cost, comprehensive contribution, and risk assumed by both sides in the process of cooperation and reasonably distribute the cooperative income in dynamic manner. While maximizing the benefits of cooperation, we should satisfy the interests of the game sides as much as possible and avoid income disputes in the system.

To increase the benefits of military-civilian collaborative innovation in the satellite industry, we encourage the diversification of cooperation forms, such as joint development and commissioned development. Bring into play the role of the enterprise's innovative main body, and carry out technical research with large-scale enterprises and scientific research institutions that have both scientific research and technical strength.

To improve the cooperative willingness of the game sides and adjust the cooperative status, a reasonable staged contract can be formulated or the contract can be continuously revised and improved, to avoid disputes in the cooperation process and help maintain the harmony of the game sides. Other participants can be introduced in capital and technology R&D, such as financial institutions, universities, and research institutes, to form new business models to solve the problems of high R&D costs, high cost of secondary technology conversion, and difficulty in research and development.

Data Availability

The simulation data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This research was funded by Projects of the National Social Science Foundation of China grant number [18BGL020]. Our research team is grateful to Ms. Stefania Ascarelli for professionally correcting the English of this manuscript, diligent proofreading, and suggesting improvements of style and structure.

References

[1] J. Yongfeng, "An empirical study on patent activities in China's high-tech industry: a case study of satellite industry," *Science & Technology Progress & Policy*, vol. 3, pp. 70–74, 2015.

[2] L.-Y. Sun, C.-L. Miao, and L. Yang, "Ecological-economic efficiency evaluation of green technology innovation in strategic emerging industries based on entropy weighted TOPSIS method," *Ecological Indicators*, vol. 73, pp. 554–558, 2017.

[3] P.-A. Balland, "Proximity and the evolution of collaboration networks: evidence from research and development projects within the global navigation satellite system (GNSS) industry," *Regional Studies*, vol. 46, no. 6, pp. 741–756, 2012.

[4] L.-Y. Wu, K.-Y. Chen, P.-Y. Chen, and P.-J. Tung, "Revisiting associations between specific asset investment and loyal and cooperative behavior: a complexity theory perspective," *Journal of Business Research*, vol. 69, no. 9, pp. 3545–3552, 2016.

[5] F. Chen, Q. Meng, and F. Li, "How resource information backgrounds trigger post-merger integration and technology innovation? A dynamic analysis of resource similarity and complementarity," *Computational and Mathematical Organization Theory*, vol. 23, no. 2, pp. 167–198, 2017.

[6] A. Parkhe, "Strategic alliance structuring: a game theoretic and transaction cost examination of interfirm cooperation," *Academy of Management Journal*, vol. 36, no. 4, pp. 794–829, 1993.

[7] M. Zeng and X.-P. Chen, "Achieving cooperation in multiparty alliances: a social dilemma approach to partnership management," *Academy of Management Review*, vol. 28, no. 4, pp. 587–605, 2003.

[8] J. D. Sanchez de Pablo Gonzalez del Campo, I. Peña García Pardo, and F. Hernández Perlines, "Influence factors of trust building in cooperation agreements," *Journal of Business Research*, vol. 67, no. 5, pp. 710–714, 2014.

[9] N. Myhr, "Business-to-business partnerships: an empirical examination in a supply chain context," *Canadian Journal of Chemical Engineering*, vol. 86, no. 3, pp. 347–355, 2008.

[10] K. Mignonac, O. Herrbach, and S. Guerrero, "The interactive effects of perceived external prestige and need for organizational identification on turnover intentions," *Journal of Vocational Behavior*, vol. 69, no. 3, pp. 477–493, 2006.

[11] D. Friedman, "Evolutionary games in economics," *Econometrica*, vol. 59, no. 3, pp. 637–666, 1991.

[12] S. N. Evans, A. Hening, and S. J. Schreiber, "Protected polymorphisms and evolutionary stability of patch-selection strategies in stochastic environments," *Journal of Mathematical Biology*, vol. 71, no. 2, pp. 325–359, 2015.

[13] S. Sati, A. Ippisch, and K. Graffi, "Dynamic replication control strategy for Opportunistic Networks," in *Proceedings of the International Conference on Computing, Networking and Communications (ICNC '17)*, pp. 1017–1023, IEEE, January 2017.

[14] T. Feng, S. Tai, C. Sun, and Q. Man, "Study on cooperative mechanism of prefabricated producers based on evolutionary game theory," *Mathematical Problems in Engineering*, vol. 2017, Article ID 1676045, 6 pages, 2017.

[15] W. He, "A dynamic evolutionary game model of modular production network," *Discrete Dynamics in Nature and Society*, vol. 2016, Article ID 6425158, 9 pages, 2016.

[16] Q. Shi, J. Zhu, and Q. Li, "Cooperative evolutionary game and applications in construction supplier tendency," *Complexity*, vol. 2018, Article ID 8401813, 13 pages, 2018.

[17] C. Pan and Y. Long, "Evolutionary game analysis of cooperation between microgrid and conventional grid," *Mathematical Problems in Engineering*, vol. 2015, Article ID 103206, 10 pages, 2015.

[18] C. Li, X. Li, and Y. Wang, "Evolutionary game analysis of the supervision behavior for public-private partnership projects with public participation," *Mathematical Problems in Engineering*, vol. 2016, Article ID 1760837, 8 pages, 2016.

[19] S.-H. Chen, "An evolutionary game model of knowledge workers' counterproductive work behaviors based on preferences," *Complexity*, vol. 2017, Article ID 3295436, 11 pages, 2017.

[20] Q. Sun and Z. Yao, "Evolutionary game analysis of competitive information dissemination on social networks: an agent-based computational approach," *Mathematical Problems in Engineering*, vol. 2015, Article ID 679726, 12 pages, 2015.

[21] T. E. Trainor, D. M. Brazil, and T. Lindberg, "Building knowledge from organizational experience: approaches and lessons learned from us army base camp workshops," *Engineering Management Journal*, vol. 20, no. 2, pp. 37–45, 2008.

[22] J. Brickey and S. Walczak, "A comparative analysis of professional forums in the United States army and hybrid communities of practice in the civilian sector," *International Journal of Strategic Studies*, vol. 35, no. 6, pp. 1–29, 2012.

[23] V. Merindol and D. W. Versailles, "Dual-use as knowledge-oriented policy: France during the 1990-2000s," *International Journal of Technology Management*, vol. 50, no. 1, pp. 80–98, 2010.

[24] L. Totimeh, "Application of knowledge management in a military-civilian organization focusing on naval sea systems case study," *Dissertations & Theses-Gradworks*, vol. 12, no. 4, pp. 117–130, 2010.

[25] J. Molas-Gallart and P. Tang, "Ownership matters: Intellectual property, privatization and innovation," *Research Policy*, vol. 35, no. 2, pp. 200–212, 2006.

[26] R. McIvor and P. Humphreys, "Early supplier involvement in the design process: Lessons from the electronics industry," *Omega* , vol. 32, no. 3, pp. 179–199, 2004.

[27] K.-I. Jeong, J.-D. Lee, and C. Lee, "Profitability gains of korean defense firms: technological progress or cost shifting?" *Asian Journal of Technology Innovation*, vol. 18, no. 2, pp. 219–239, 2010.

[28] Y. Zhikai, "A research on the scientific and technological intellectual property rights under the system of the military and

civilian union," *Scientific Management Research*, vol. 26, no. 3, pp. 107–110, 2008.

[29] C. M. Schnaubelt, *Towards a Comprehensive Approach: Integrating Civilian and Military Concepts of Strategy*, NATO Defense College, Rome, Italy, 2011.

[30] H. T. Kulve and W. A. Smit, "Civilian-military co-operation strategies in developing new technologies," *Research Policy*, vol. 32, no. 6, pp. 955–970, 2003.

[31] V. Yepes, E. Pellicer, L. F. Alarcon, and C. L. Correa, "Creative innovation in spanish construction firms," *Journal of Professional Issues in Engineering Education & Practice*, vol. 142, no. 1, Article ID 04015006, 2016.

[32] T. M. Lavallee, "Civil-military integration: the politics of outsourcing national security," *Bulletin of Science, Technology & Society*, vol. 30, no. 3, pp. 185–194, 2010.

[33] K. G. Ross, M. Wisecarver, C. A. Thornson, D. A. Peluso, and M. K. Roberts, *Development of a Competency Model for Civil-Military Teaming*, Springer International Publishing, 2017.

[34] L. Zhao, J. Sun, and H. Zhang, "An analysis of civil-military integration technology collaborative innovation behavior," *Science & Technology Progress & Policy*, vol. 32, no. 13, pp. 111–117, 2015.