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Research Article

Evolutionary Game of Vertical Cooperation and Innovation between Civilian and Military Enterprises: A Civilian-Military Integration Supply Chain System with Chinese Characteristics

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The establishment of a civil-military integration supply chain system is the cornerstone of China's strategic development in military-civilian integration. It is essential to explore cooperative innovation and development between upstream civilian enterprises and downstream military enterprises within the supply chain to optimise resource allocation and promote the sustainable use of civil-military resources. This exploration is a prerequisite for accelerating the formation of the civil-military integration supply chain system and holds significant importance for realising the internal synergy between the civilian industry and the military industry. However, utilizing the evolutionary game model as a foundation, this study delves into the impact of absorption capacity, transformation and integration capability, network synergy, and change and innovation capacity on the vertical cooperation and innovation behaviour within the supply chain of civil-military integration enterprises. Firstly, civilian enterprises are more cost-sensitive concerning collaborative innovation investments compared to military enterprises. Excessive costs can discourage collaboration between civilian and military entities. Secondly, strong exploratory and absorptive capabilities, along with network synergies, can enhance the benefits of cooperation and innovation among these enterprises, but they also introduce the risk of opportunistic "free-rider" behaviour. Thirdly, the dynamics of the technology and product chains are influenced by an excess supply for civilian enterprises, while the opposite is true for military enterprises. Finally, a strong capacity for transformation and integration fosters cooperative and innovative behaviours among enterprises, with civilian enterprises exhibiting greater responsiveness. This study brings new research perspectives to the forefront, exploring vertical cooperation and innovative development within supply chain enterprises, particularly through the lens of supply and demand dynamics. Additionally, it offers practical recommendations aimed at helping the government expedite the establishment of integrated military-civilian supply chains and foster the synergistic development of the two key sectors: the military and civilian economies.

1. Introduction

The 20th National Congress of the Communist Party of China (CPC) report puts forth the goal of "enhancing the resilience and security of the industrial and supply chains" and "strengthening the integrated national strategic system, civil-military integration, and core capabilities in strategic industries and scientific research to maximise national defence and economic benefits." Nowadays, the uncertain situation of a "negative-sum game" and increasing trade friction among big countries not only leads to the relocation and transfer of the global industrial chain but also carries the risk of industrial chain supply chain rupture and reconstruction [1]. This situation urgently demands the integration of advantageous resources within the industrial chain to compensate for the supply chain's deficiencies [2]. In the new era of armament construction, the stability and security of military supply chains are increasingly pivotal in determining the outcome of modern warfare and ensuring national defence. The strategy of deepening military-civilian integration can achieve the seamless integration of military and civilian resources, enhance the innovation capacity of national defence science and technology, elevate the resilience and security of the industrial supply chain, and maximise the benefits for both national defence and society. The integration of civilian enterprises into the military supply chain network can effectively stimulate the innovative vitality of military enterprises, reduce the production and manufacturing costs of weapons and equipment, and promote the synergistic development of the military and civilian economy, which is of great significance.

As the requirements of modern warfare continue to evolve, drones have shifted from being a supporting force to becoming a primary force in contemporary military operations. The primary advantage of military drones lies in their ability to reduce the risk of personnel loss and lower operational costs. The development and production of military UAVs, along with the need for innovation in response to the complexities of future warfare, demand close cooperation and joint innovation between upstream and downstream companies within the supply chain to optimise military UAV technology and enhance operational advantages. UAVs are also widely employed in civilian applications, such as geographic surveying and mapping, forest plant protection, and aerial photography. Civilian UAV technology and military UAV technology share commonalities in certain technical fields. Therefore, guiding advantageous civilian enterprises to participate in the strategy of civil-military integration can effectively promote resource utilization and industrial clusters. In the face of a complex and volatile international environment, the Chinese government places increased importance on the autonomous and controllable capabilities of the supply chain in the defence science and technology industry. This effort aims to foster joint innovation in both military and civilian technologies by promoting in-depth cooperation between military and civilian enterprises. The goal is to catch up with foreign advanced technologies and achieve breakthroughs in core technologies. AVIC Chengdu UAV Company and Guangwei Composite Materials serve as typical civil-military integration enterprises in the UAV field, playing pivotal roles in both the civil UAV supply chain and the military UAV supply chain.

With the in-depth development of China's civil-military integration strategy, the construction of China's civil-military integration supply chain network system has experienced continuous improvement. However, from the perspective of practical experience in China's civil-military integration, several issues persist in the development of China's civil-military integration supply chain. Civilian enterprises, when serving as suppliers of weapons and equipment, need to ensure that their product qualifications meet national regulations and standards. If civilian enterprises participate in military-civilian integration, their capacity constraints can significantly impact production allocation issues within both the military and civilian markets. In the process of military-civilian integration, the state's protection of intellectual property rights for civilian enterprises is still imperfect, and the property rights of jointly innovated technologies are not clearly defined. Additionally, the confidentiality of military technology, along with other special characteristics, affects fair cooperation between military and civilian enterprises, among other issues. To break down the barriers to civil-military integration and promote the formation of China's civil-military integration supply chain network system, both China's central and local governments have issued a series of policies and regulations. These measures aim to provide incentives for civilian enterprises to actively participate in civil-military integration, safeguard the lawful rights and interests of civilian enterprises involved in the process of civil-military integration, and ensure the security of military technology. Therefore, the study of the vertical cooperation and innovation behaviours of civil-military integration supply chain enterprises and their influencing factors holds far-reaching significance for national security as well as for sound economic and social development.

The rest of the paper is organised as follows. Section 2 provides a review of the current academic literature on the importance of civil-military integration and vertical cooperation in innovation. It also identifies the shortcomings of the research and highlights the innovations introduced in this paper. Section 3 models the evolutionary game by making assumptions about the research problem. Section 4 analyses the stabilisation strategies of the model developed in the previous section and examines the effect of parameters on the evolving system. Section 5 presents a numerical simulation to visualise the effect of parameters on the evolving system. Section 6 contains conclusions, theoretical contributions, and practical implications.

2. Literature Review

2.1. Vertical Cooperation and Innovation in the Supply Chain. While the supply chain vertical cooperation and innovation model is commonly adopted between upstream and downstream enterprises in the supply chain, there are relatively few academic studies on the vertical innovation model. It has been suggested that the probability of vertical cooperation and innovation in supply chains is much greater than the probability of horizontal cooperation and innovation [3]. Additionally, technological vertical cooperation can significantly enhance enterprises' innovation performance and social welfare [4], reduce carbon emissions, and lower retail prices [5], thus strengthening the competitive advantage of non-counterparts [6]. However, vertical cooperation among supply chain enterprises does not always enhance the overall profitability of the supply chain [7]. Some scholars have also examined profit distribution issues [8] arising from supply chain vertical cooperation innovation investment models [9] and cooperative R&D strategies [10], explored the impact of upstream and downstream enterprises' perceptions on cooperative innovation [11], and addressed equity issues related to innovation development [12]. Vertical cooperation and innovation in the supply chain can facilitate resource sharing, risk sharing, and information interoperability, thereby reducing costs, increasing efficiency for the supply chain network, and enhancing the output rate of research and development. This has significant practical importance and development value in terms of promoting China's economic development, bolstering enterprise competitiveness, advancing the implementation of the new development concept, and promoting progress in supply-side structural reform.

2.2. Civil-Military Integration. With the deepening development of China's civil-military integration and its increasing national strategic importance, the field of civil-military integration in academia has evolved from a blue ocean to a red ocean. In terms of qualitative analysis, many studies begin by considering China's national conditions to design a civil-military fusion development strategy that aligns with Chinese characteristics [13] and to establish China's civil-military fusion innovation system and innovation path [14]. Some research begins with Chinese civil-military fusion enterprises, examining the factors influencing the technical efficiency of civil-military fusion enterprises [15] and analysing the innovation mode and realisation path of civil-military fusion enterprises [16]. In quantitative analysis, scholars have extensively employed various types of game models to study the internal mechanisms of technological innovation in China's civil-military integration [17], cooperation stability [18], technology sharing, and benefit distribution [19]. Some studies have analysed the cooperative and innovative behaviours of military-civilian fusion industry-university-research institutes following the introduction of market mechanisms and government regulation [20], the stability strategy of civilian participation in the military within the context of local government support [21], and the impact of composite subsidy policies on the cooperative and innovative behaviours of military-civilian enterprises [22].

2.3. Vertical Cooperation and Innovation in the Civil-Military Integration Supply Chain. Vertical cooperation and innovation in the military-civilian integration supply chain refer to the innovative structure formed by the correlation, matching, or fusion of upstream and downstream technologies within the industrial chain. This occurs when parts (or products) from different links in the upstream and downstream segments of the industrial supply chain are being researched, developed, transformed, or innovated during the integration of military technology, equipment, experience, and the production capacity, technical level, market channels, and other resources of civilian enterprises [23]. Vertical cooperation and innovation can facilitate resource sharing and technology complementarity between civilian and military enterprises. This, in turn, reduces research and development costs and enhances scientific research and innovation capabilities. Such cooperation can ensure the wartime requirements of the country, meeting the intense competitive demands of society. It also promotes the common development of socioeconomic development and national defence construction. There are relatively few studies on vertical cooperation and innovation in the civil-military integration supply chain. Some scholars have explored the construction of innovative logistics for civil-military integration from a supply chain perspective [24], the innovative selection of logistics suppliers, the distribution of benefits among upstream and downstream enterprises [25], resource allocation [26], and government regulation [27]. Additionally, some scholars have examined the overall impact of risk attitudes and incentive strategies for different types of civil-military suppliers on collaborative innovation strategies [28]. Vertical cooperation and innovation can fully leverage the advantages of civil-military integration. It enables civil-military resource sharing, complementary advantages, and synergistic development, facilitating the transformation and application of military technology, upgrading and optimising the industrial structure, and enhancing China's economic strength and national defence capabilities.

Based on the above literature, the current research on vertical cooperation and innovation in the civil-military integration supply chain has the following limitations. (1) Most of the existing literature is confined to qualitative research on the construction and innovation management aspects of the civil-military integration supply chain. There are relatively fewer relevant studies on the quantitative aspects of the model. (2) Most discussions regarding cooperative innovation among civil-military integration suppliers originate from horizontal cooperative innovation within the supply chain. They primarily focus on studying the distribution of benefits, resource allocation, and government regulation. However, there is a lack of exploration into the role of vertical cooperative innovation within the supply chain in civil-military integration. (3) Existing literature fails to investigate the supply and demand relationship between upstream and downstream enterprises in the civil-military integration supply chain and the impact of trust between enterprises on cooperation and innovation.

In summary, to further explore and elucidate the intrinsic mechanism of cooperation and innovation between upstream civilian enterprises in the supply chain and downstream military enterprises in the supply chain, this paper takes the upstream civilian enterprises and the downstream military enterprises in the supply chain as the two main subjects of the military-civilian integration supply chain network system to conduct evolutionary game modelling. In this paper, we consider the following aspects in the payment-benefit matrix. (1) We begin by examining the vertical perspective of the supply chain, focusing on how the capacity situations in both the military and civilian markets affect upstream civilian enterprises. We also analyse the product demand of military enterprises downstream in the supply chain. These factors play a crucial role in shaping decisions related to cooperation and innovation among enterprises. (2) In addition, we investigate the influence of the proportion of civilian technology utilized for the conversion and integration of military enterprise technology by civilian enterprises, taking into account the confidentiality of military technology. This analysis provides insights into the choices made regarding cooperation and innovation among civil-military fusion enterprises. (3) Furthermore, we consider the perspective of inter-enterprise trust and its impact on the development of cooperation and innovation among civil-military fusion enterprises. Additionally, we explore the potential effects of "free-riding" on these processes. We also establish the relationship between the behavioural evolution of upstream civilian enterprises and downstream military enterprises in the civil-military integration supply chain system. We use numerical simulation to explore their stability strategies. This paper argues that the research content can assist the Chinese government in providing a scientific basis for promoting the active participation of civilian enterprises in the construction of China's civil-military integration, as well as for improving the performance of the civil-military integration supply chain and introducing relevant policies.

3. Modelling the Evolutionary Game

3.1. Background. In recent years, the demand for drones has significantly increased in both the civilian and military sectors. This need became particularly pronounced after the Russian-Ukrainian war, emphasising the importance of military drones. Currently, most of China's civilian UAV companies and military UAV enterprises adopt an independent R&D model based on their market positioning. Civilian drones prioritise aspects such as product appearance, safety, and service life, while military drones emphasise range, stealth, and stability. However, military drones and civilian drones share commonalities along with their distinctive characteristics. Therefore, collaboration in R&D between civilian enterprises and military enterprises can enhance R&D efficiency and reduce R&D costs. However, the special characteristics of military involvement pose significant barriers for civilian enterprises wishing to enter this sector. These barriers include military qualification certification, technical product quality requirements, market-qualified supplier lists, lengthy development cycles, substantial R&D investments, and financial risks. The decision of whether or not to cooperate between upstream civilian enterprises and downstream military enterprises has a profound impact on the technological capabilities, profitability, and innovation development of these enterprises. Therefore, studying vertical cooperation and innovation within the supply chain of military and civilian integration enterprises can help reduce the duplication of resources, lower military expenditure, and promote the shared development of military and civilian industrial clusters.

This paper adopts an evolutionary game model to quantitatively analyse the evolutionary process of vertical collaborative innovation in supply chains across four dimensions: exploratory absorptive capacity [29], transformational and integrative capacity [15], transformational and innovative capacity [30], and network synergistic capacity [31]. The game model in this paper involves two game subjects: the civilian enterprise in the upstream of the supply chain and the military enterprise in the downstream of the supply chain. Each subject has two strategies to choose from: positive and negative cooperation. Due to the multifactor uncertain cooperative innovation environment, information asymmetry, and differences in the level of technological capabilities, both the military-industrial enterprise and civilian enterprise cannot fully control all the information about cooperative innovation in the integration process. As a result, both subjects have limited rationality. By studying the evolutionary game model of vertical cooperation and innovation in the supply chain, we can predict the stability of enterprise cooperation and the outcomes of cooperation. This study can serve as a reference for upstream and downstream military and civilian enterprises in the supply chain, helping them make the most favourable decisions in various situations during the process of military-civilian integration.

3.2. Model Assumptions. The real problem is abstracted and simplified to facilitate the development and calculation of the evolutionary game model. The research in this paper is based on the following assumptions:

Hypothesis 1: The probability that a civilian enterprise in the upstream of the supply chain chooses the "positive cooperation" strategy is denoted as x, while the probability that it chooses the "negative cooperation" strategy is $1 - x$, with x ranging from 0 to 1. Similarly, the probability that a downstream military enterprise in the supply chain chooses the "positive cooperation" strategy is represented by y, and the probability that it selects the "negative cooperation" strategy is $1 - y$, with y also within the range of 0 to 1. The civilian enterprise itself has a basic return denoted as π_1, while the military enterprise itself has a basic return of π_2. When enterprises choose the "positive cooperation" strategy, they will incur various costs, including R&D costs, information communication costs, and labour costs, among others. We refer to these costs as the total costs incurred in the process of cooperation and innovation, which are denoted as C_1 for the civilian enterprise and C_2 for the military-industrial enterprise. Notably, in China, C_1 is smaller than C_2, primarily due to the government's subsidy. This discrepancy arises from the military-industrial enterprise being less sensitive to the cost of technological development when compared to the civilian enterprise.

Hypothesis 2: The technical outcomes of the main cooperation will eventually be transformed into products, and how the market size of these products impacts the earnings of both parties. The civilian enterprise operates at the front end of the supply chain, and its technology and products are supplied to both the civilian market and the military-industrial market. Therefore, the amount of market supply size of the civilian enterprise (m_1) is greater than the amount of market demand size for the military enterprise (m_2), with m_1 being larger than m_2.

When upstream and downstream enterprises establish a strategic supply relationship through positive cooperation and innovation, they come to an agreement on the supply price. This agreement results in the formation of a supply price discount, which is represented as γ, and γ falls within the range of 0 to 1.

Hypothesis 3: We employ the dimension of transformational integration capability to illustrate the process of transferring new technologies obtained through collaborative innovation between upstream and downstream supply chain enterprises into valuable products or technologies [15]. The innovations resulting from positive cooperation between these entities typically involve military technology, characterised by its confidentiality and lack of standardization. To make these technologies accessible to the civilian market, they must undergo a transformation from confidential to non-confidential and from non-standard to standardized, among other aspects. Therefore, we define the rate of transfer and transformation of new technology, which results from technical cooperation and is applied to the civilian enterprise market as α [32]. Additionally, we use μ_1 to represent the earning capacity coefficient for the transformation of new technology applied to civilian products and μ_2 to represent the earning capacity coefficient for the transformation of new technology applied to military products.

In this paper, the civilian enterprise can derive benefits as follows: $\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2$. Conversely, the military enterprise can obtain benefits equal to $\mu_2 m_2$, where $(m_1 - m_2)$ represents the quantity of supply scale in the civilian market of the civilian enterprise.

Hypothesis 4: We employ the concept of network synergy capability to illustrate the resource complementarity between upstream and downstream enterprises within the supply chain, with the aim of maximising economic benefits [31]. In the context of technological cooperation, the non-competitive and partially exclusive nature of technology often results in the creation of "technological spillovers" with positive externalities [33]. This, in turn, allows inter enterprises to harness network synergies for accessing externally shared technological resources [34]. To provide a baseline, we assume that the technological capability of the civilian enterprise before engaging in technological cooperation is represented by L_1, while the military enterprise's technological capability is represented by L_2.

Hypothesis 5: We employ exploratory absorptive capacity to describe the ability of both upstream and downstream enterprises in the supply chain to acquire resources effectively [29]. The military-industrial enterprise and civilian enterprise adopt the "positive cooperation" strategy, leveraging the complementary nature of their technologies [35]. This allows them to capitalize on each other's technology "spillover effects," ultimately enhancing their respective technological capabilities. Specifically, we use the absorptive capacity coefficient λ_1 to represent the civilian enterprise's ability to absorb technological spillovers from the military-industrial enterprise. Similarly, λ_2 represents the military-industrial enterprise's capacity to absorb technological spillovers from the civilian enterprise. Additionally, we employ k_1 to indicate the transformation coefficient for the civilian enterprise, converting absorbed technological capabilities from the military-industrial enterprise into earning capabilities. In the case of the military-industrial enterprise, k_2 serves as the transformation coefficient for converting absorbed technological capabilities from the civilian enterprise into earning capabilities.

Hypothesis 6: We employ the concept of "change innovation capability" to evaluate the cooperative and innovative capacities of both upstream and downstream supply chain enterprises. This assessment equips them to effectively respond to the challenges presented by the competitive market environment [30]. In the current competitive market landscape, both enterprises opt for the "positive cooperation" strategy, which holds the potential to yield innovation outcomes and enhance their technical capabilities, ultimately translating into increased revenue. Our assumptions consider the level of technological capability for these innovations, denoted as L_3, and the coefficient responsible for enhancing revenue, represented by β. This enhancement in technological capability leads to gains for both the civilian enterprise $(\beta k_1 L_3)$ and the military enterprise $(\beta k_1 L_3)$.

Hypothesis 7: The trust mechanism within the supply chain, linking upstream and downstream enterprises, is characterised by goodwill and fosters extensive information sharing, thereby enhancing overall supply chain integration performance [36]. When an entity involved in innovation chooses the "positive cooperation" strategy, it commits specific human and material resources, along with its technological capabilities, to engage in transparent collaboration with its counterpart. Conversely, when the entity opts for the "negative cooperation" strategy, it leverages the technological spillover resources of the other party to bolster its own technological capabilities, effectively engaging in a "free-riding" behaviour. The benefits reaped by the civilian enterprise are denoted as $r\lambda_1 k_1 L_2$, while the military enterprise accrues benefits equivalent to $r\lambda_2 k_2 L_1$. When $r = 1$, it signifies that both entities opt for the "positive cooperation" strategy, harnessing technological complementarities to enhance their respective technological capabilities. In contrast, when $r = 0$, it implies that only one party chooses the "positive cooperation" strategy. The entity selecting the "negative cooperation" strategy enjoys the benefits of technological spillovers ("free-riding") but is also subject to penalties imposed by government regulators in the form of θD, where θ represents the intensity of government regulation [37] and D signifies the government-imposed penalty.

Hypothesis 8: In the scenario where both parties opt for the "positive cooperation" strategy, the outcomes of their collaborative innovation efforts become shared assets, introducing potential risks associated with investment gains and losses. These risks stem from the potential breaches in confidentiality agreements and the disclosure of intellectual property rights [38]. We denote the investment profit and loss for the civilian enterprise as εA_1 and for the military enterprise as εA_2. Here, ε represents the investment profit and loss obstacle factor, with a value range of $\varepsilon \in [0, 1]$. This factor indicates the extent to which various risks, including those related to breaches and the disclosure of intellectual property rights, hinder investment gains and losses. When $\varepsilon = 0$, it signifies that the investment profit and loss factor has no inhibitory effect on these risks, whereas when $\varepsilon = 1$, it implies that these risks can completely obstruct investment profit and loss. The variable A denotes the specific value of investment profit and loss.

3.3. Constructing the Evolutionary Game Payment Matrix. Based on the eight assumptions described above, the evolutionary game payment matrix is constructed as depicted in Table 1.

3.4. Dynamic Formula. The civilian enterprise selects the "positive cooperation" strategy to receive π_{11} and the "negative cooperation" strategy to obtain π_{12}. The average expected return $\overline{\pi_1}$, which can be calculated from the returns of the two strategies, is presented in equations (1)–(3):

$$\begin{aligned}\pi_{11} &= y\left[\alpha\mu_1\left(m_1 - m_2\right) + \mu_1\gamma m_2 + \lambda_1 k_1 L_2 + \beta k_1 L_3 + \pi_1 - C_1 - \varepsilon A_1\right] + (1-y)\left[\pi_1 - C_1 - \varepsilon A_1\right] \\ &= y\alpha\mu_1\left(m_1 - m_2\right) + y\mu_1\gamma m_2 + y\lambda_1 k_1 L_2 + y\beta k_1 L_3 + \pi_1 - C_1 - \varepsilon A_1,\end{aligned} \tag{1}$$

$$\begin{aligned}\pi_{12} &= y\left[\pi_1 + r\lambda_1 k_1 L_2 - \theta_1 D\right] + (1-y)\pi_1 \\ &= yr\lambda_1 k_1 L_2 - y\theta D + \pi_1,\end{aligned} \tag{2}$$

$$\begin{aligned}\overline{\pi_1} &= x\pi_{11} + (1-x)\pi_{12} \\ &= \mathrm{xy}\left[\alpha\mu_1\left(m_1 - m_2\right) + \mu_1\gamma m_2 + \lambda_1 k_1 L_2 + \beta k_1 L_3 + \theta D - r\lambda_1 k_1 L_2\right] + y\lambda_1 k_1 L_2 \\ &\quad + yr\lambda_1 k_1 L_2 + \pi_1 - xC_1 - x\varepsilon A_1 - y\theta D.\end{aligned} \tag{3}$$

The equation describing the replication dynamics of the civilian enterprise is presented in the following equation:

$$\begin{aligned}S(x) &= \frac{\mathrm{dx}}{\mathrm{dt}} \\ &= x\left(\pi_{11} - \overline{\pi_1}\right) \\ &= x(1-x)\left(\pi_{11} - \pi_{12}\right) \\ &= x(1-x)\left[y\alpha\mu_1\left(m_1 - m_2\right) + y\mu_1\gamma m_2 + y(1-r)\lambda_1 k_1 L_2 \right.\\ &\quad \left. + y\beta k_1 L_3 - C_1 - \varepsilon A_1 + y\theta D\right].\end{aligned} \tag{4}$$

The military enterprise selects the "positive cooperation" strategy to obtain π_{21} and the "negative cooperation" strategy to receive π_{22}. The average expected return $\overline{\pi_2}$, which can be calculated from the returns of the two strategies, is presented in equations (5)–(7):

Table 1: Payoff matrix of military and civilian enterprises' cooperative innovation evolution game.

Military enterprise Civilian enterprise	Positive cooperation (y)	Negative cooperation $(1-y)$
Positive cooperation(x)	$\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+k_1\lambda_1L_2+\beta k_1L_3+\pi_1-C_1-\varepsilon A_1$ $\mu_2m_2+k_2\lambda_2L_1+\beta k_2L_3+\pi_2-C_2-\varepsilon A_2$	$\pi_1-C_1-\varepsilon A_1$ $\pi_2+r\lambda_2k_2L_1-\theta D$
Negative cooperation $(1-x)$	$\pi_1+rk_1\lambda_1L_2-\theta D$ $\pi_2-C_2-\varepsilon A_2$	π_1 π_2

$$\begin{aligned}\pi_{21} &= x\left[\mu_2m_2+\lambda_2k_2L_1+\beta k_2L_3+\pi_2-C_2-\varepsilon A_2\right]+(1-x)\left(\pi_2-C_2-\varepsilon A_2\right)\\ &= x\mu_2m_2+x\lambda_2k_2L_1+x\beta k_2L_3+\pi_2-C_2-\varepsilon A_2,\end{aligned}\tag{5}$$

$$\begin{aligned}\pi_{22} &= x\left[\pi_2+r\lambda_2k_2L_1-\theta_2D\right]+(1-x)\pi_2\\ &= xr\lambda_2k_2L_1+xN_2+\pi_2-x\theta D,\end{aligned}\tag{6}$$

$$\begin{aligned}\overline{\pi_2} &= y\pi_{21}+(1-y)\pi_{22}\\ &= \mathrm{xy}\left[\mu_2m_2+\lambda_2k_2L_1+\beta k_2L_3+\theta D-r\lambda_2k_2L_1\right]+xr\lambda_2k_2L_1+x\lambda_2k_2L_1+\pi_2-yC_2-y\varepsilon A_2-x\theta D.\end{aligned}\tag{7}$$

The equation describing the replication dynamics of the military enterprise is presented in the following equation:

$$\begin{aligned}M(y) &= \frac{\mathrm{dy}}{\mathrm{dt}}\\ &= y\left(\pi_{21}-\overline{\pi_2}\right)\\ &= y(1-y)\left(\pi_{21}-\pi_{22}\right)\\ &= y(1-y)\left[x\mu_2m_2+x(1-r)\lambda_2k_2L_1+x\beta k_2L_3-C_2-\varepsilon A_2+x\theta D\right].\end{aligned}\tag{8}$$

4. Analysis of Stabilisation Strategies

4.1. Analysis of Local Stabilisation Strategies. Based on the aforementioned assumptions and the replicated dynamic equations, we can proceed to analyse the stabilisation strategies of the two enterprises. This analysis is based on the stability theorem of differential equations. An equilibrium point, denoted as x, is considered asymptotically stable when $S'(x)<0$, while an equilibrium point y is deemed asymptotically stable when $M'(y)<0$. Furthermore, we perform a comprehensive Jacobian matrix analysis to assess the local stability of strategy combinations and determine whether they qualify as ESSs (evolutionarily stable strategies). This detailed analysis also allows us to understand the impact of each parameter on the selection of strategies.

4.1.1. The Asymptotic Stability Strategy of the Civilian Enterprise. If $S(x)=0$ and $S'(x)<0$, it indicates that x represents an asymptotically stable strategy for the civilian enterprise. Consequently, we can calculate the partial derivatives:

$$S'(x)=(1-2x)\left[y\alpha\mu_1\left(m_1-m_2\right)+y\mu_1\gamma m_2+y(1-r)\lambda_1k_1L_2+y\beta k_1L_3-C_1-\varepsilon A_1+y\theta D\right].\tag{9}$$

For the sake of clarity, we define $H=-C_1-\varepsilon A_1$ and $F=\alpha\mu_1\left(m_1-m_2\right)+\mu_1\gamma m_2+(1-r)\lambda_1k_1L_2+\beta k_1L_3+\theta D$. This definition facilitates the derivation of the following equation:

$$S'(x)=(1-2x)(\mathrm{yF}+H).\tag{10}$$

In the following three cases, the impact of the relationship between F and H on the stability strategy is discussed.

Case 1: $F>0, H<0$ and $F+H=\alpha\mu_1\left(m_1-m_2\right)+\mu_1\gamma m_2+(1-r)\lambda_1k_1L_2+\beta k_1L_3+\theta D-C_1-\varepsilon A_1>0$.

Then,

$$\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \lambda_1 k_1 L_2 + \beta k_1 L_3 - C_1 - \varepsilon A_1 > r\lambda_1 k_1 L_2 - \theta D. \tag{11}$$

Indication: From equation (11), we can observe that the total profit of the civilian enterprise is greater when they choose the "positive cooperation" strategy compared to when they choose the "negative cooperation" strategy. In this case, when yF + $H > 0$ for all y within the range $[0, 1]$, $\exists S'(x) < 0$, $x = 1$ is the point at which the stabilisation strategy of the civilian enterprise evolves. In other words, the "positive cooperation" strategy becomes the stabilisation strategy for the civilian enterprise.

Case 2: $F > 0$, $H < 0$, and $F + H = \alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + (1 - r)\lambda_1 k_1 L_2 + \beta k_1 L_3 + \theta D - C_1 - \varepsilon A_1 < 0$.

Then,

$$\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \lambda_1 k_1 L_2 + \beta k_1 L_3 - C_1 - \varepsilon A_1 < r\lambda_1 k_1 L_2 - \theta D. \tag{12}$$

Indication: From equation (12), we can determine that the total profit of the civilian enterprise is smaller when it chooses the "positive cooperation" strategy compared to when it chooses the "negative cooperation" strategy. In this case, when yF + $H < 0$, $x = 0$ is the stabilisation point of the evolutionary strategy for the civilian enterprise, meaning that the "negative cooperation" strategy is the stabilisation strategy of the civilian enterprise. However, when yF + $H > 0$, $x = 1$ is the point at which the stabilisation strategy for the civilian enterprise evolves, indicating that the "positive cooperation" strategy becomes the stabilisation strategy for the civilian enterprise.

Case 3: $F < 0$, $H > 0$, and $F + H = \alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + (1 - r)\lambda_1 k_1 L_2 + \beta k_1 L_3 + \theta D - C_1 - \varepsilon A_1 < 0$.

Then,

$$\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \lambda_1 k_1 L_2 + \beta k_1 L_3 - C_1 - \varepsilon A_1 < r\lambda_1 k_1 L_2 - \theta D. \tag{13}$$

Indication: From equation (13), we can conclude that the total profit of the civilian enterprise choosing the "positive cooperation" strategy is smaller than the total profit of the civilian enterprise selecting the "negative cooperation" strategy. This outcome is only possible if the civilian enterprise opts for the "positive cooperation" strategy, which entails higher innovation input costs and investment gains and losses. In this case, yF + $H < 0$. So, for all y in the range of $[0, 1]$, there exists $F'(x) < 0$ and $x = 0$ is the stable point of the evolutionary strategy of the civilian enterprise, meaning that the "negative cooperation" strategy is the stable strategy for the civilian enterprise.

4.1.2. The Asymptotic Stability Strategy of the Military Enterprise. If $M(y)$ and $M'(y) < 0$, it follows that y is an asymptotically stable strategy for the military enterprise. Thus, we can calculate the partial derivatives:

$$M'(y) = (1 - 2y)\left[x\mu_2 m_2 + x(1 - r)\lambda_2 k_2 L_1 + x\beta k_2 L_3 - C_2 - \varepsilon A_2 + x\theta D\right]. \tag{14}$$

For clarity, we define $R = -C_2 - \varepsilon A_2$ and $E = \mu_2 m_2 + (1 - r)\lambda_2 k_2 L_1 + \beta k_2 L_3 + \theta D$ which enables us to derive equation (12).

$$M'(y) = (1 - 2y)(\mathrm{x}E + R). \tag{15}$$

In the following three cases, the impact of the relationship between E and R on the stability of the strategy is discussed.

Case 1: $E > 0$, $R < 0$, and $E + R = \mu_2 m_2 + (1 - r)\lambda_2 k_2 L_1 + \beta k_2 L_3 + \theta D - C_2 - \varepsilon A_2 > 0$.

Then,

$$\mu_2 m_2 + \lambda_2 k_2 L_1 + \beta k_2 L_3 - \varepsilon A_2 - C_2 > r\lambda_2 k_2 L_1 - \theta D. \tag{16}$$

Indication: From equation (16), we can conclude that the total profit of the military-industrial enterprise choosing the "positive cooperation" strategy is greater than the total profit of the military-industrial enterprise selecting the "negative cooperation" strategy. In this case, $\mathrm{x}E + R > 0$. Therefore, for all x in the range of $[0, 1]$, there exists $M'(y) < 0$, and $y = 1$ is the stable strategy evolution point for the military-industrial enterprise, indicating that the "positive cooperation" strategy is the stable strategy for the military-industrial enterprise.

Case 2: $E > 0$, $R < 0$, and $E + R = \mu_2 m_2 + (1 - r)\lambda_2 k_2 L_1 + \beta k_2 L_3 + \theta D - C_2 - \varepsilon A_2 < 0$.

Then,

$$\mu_2 m_2 + \lambda_2 k_2 L_1 + \beta k_2 L_3 - \varepsilon A_2 - C_2 < r\lambda_2 k_2 L_1 - \theta D. \tag{17}$$

Indication: From equation (17), we can conclude that the total profit of the military-industrial enterprise choosing the "positive cooperation" strategy is smaller than the total profit of the military-industrial enterprise selecting the "negative cooperation" strategy. In this case, $\mathrm{x}E + R < 0$. As a result, $y = 0$ is the stable point of the evolutionary strategy for the military-industrial enterprise, meaning that the "negative cooperation" strategy is the stable strategy for the military-industrial enterprise. However, when $\mathrm{y}E + H > 0$, $x = 1$ is the stable point of the evolutionary strategy for the military-industrial enterprise, indicating that the "positive cooperation" strategy is the stable strategy for the military-industrial enterprise.

Case 3: $E < 0$, $R < 0$, and $E + R = \mu_2 m_2 + (1 - r)\lambda_2 k_2 L_1 + \beta k_2 L_3 + \theta D - C_2 - \varepsilon A_2 < 0$.

Then,

$$\mu_2 m_2 + \lambda_2 k_2 L_1 + \beta k_2 L_3 - \varepsilon A_2 - C_2 < r\lambda_2 k_2 L_1 - \theta D. \tag{18}$$

Indication: From equation (18), we can conclude that the total profit of the military-industrial enterprise choosing the "positive cooperation" strategy is smaller than the total profit of the military-industrial enterprise selecting the "negative cooperation" strategy. This is only possible if the military-industrial enterprise chooses the "positive cooperation" strategy, which entails higher innovation input costs and investment gains and losses. In this case, $\mathrm{x}E + R < 0$. Therefore, for all x in the range of $[0, 1]$, there exists $M'(y) < 0$, and $y = 0$ is the stable point of the evolutionary strategy of the military-industrial enterprise, meaning that the "negative cooperation" strategy is a stable strategy for the military-industrial enterprise.

4.2. Eigenvalue Analysis of the Jacobian Matrix. By taking partial derivatives with respect to x and y for the replicated dynamic equations $S(x)$ and $M(y)$ mentioned above, we can construct Jacobian matrices.

$$\begin{aligned}
J &= \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix},\\
a_{11} &= (1 - 2x)\left[y\alpha\mu_1(m_1 - m_2) + y\mu_1\gamma m_2 + y(1 - r)\lambda_1 k_1 L_2 + y\beta k_1 L_3 - C_1 - \varepsilon A_1 + y\theta D\right],\\
a_{12} &= x(1 - x)\left[\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + (1 - r)\lambda_1 k_1 L_2 + \beta k_1 L_3 + \theta D\right],\\
a_{21} &= y(1 - y)\left[(1 - r)\lambda_2 k_2 L_1 + \beta k_2 L_3 + \theta D\right],\\
a_{22} &= (1 - 2y)\left[x\mu_2 m_2 + x(1 - r)\lambda_2 k_2 L_1 + x\beta k_2 L_3 - C_2 - \varepsilon A_2 + x\theta D\right].
\end{aligned} \tag{19}$$

Let $S(x) = 0$ and $M(y) = 0$; there exist five local equilibrium points of $O(0, 0)$, $A(1, 0)$, $B(1, 1)$, $C(0, 1)$, and $D(x^*, y^*)$ between the two sides of the game subjects on $R = \{(x, y) \mid 0 \le x \le 1, 0 \le y \le 1\}$, which are obtained:

$$\begin{aligned}
x^* &= \frac{C_2 + \varepsilon A_2}{\mu_2 \mathrm{m}_2 + \beta k_2 L_3 + \theta D + (1 - r)\lambda_2 k_2 L_1},\\
y^* &= \frac{C_1 + \varepsilon A_1}{\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1 - r)\lambda_1 k_1 L_2}.
\end{aligned} \tag{20}$$

When the Jacobian matrix satisfies $\mathrm{Det}(J) > 0$ and $\mathrm{Tr}(J) < 0$, there are five local equilibrium points in the system, $O(0, 0)$, $A(1, 0)$, $B(1, 1)$, $C(0, 1)$, and $D(x^*, y^*)$. The specific values are shown in Table 2. A local equilibrium point becomes stable if it meets the conditions of $\mathrm{Tr}(J)$ and $\mathrm{Det}(J)$ as follows:

Table 2: Eigenvalues of the Jacobian matrix at each equilibrium point.

Balance point	a_{11}	a_{12}	a_{21}	a_{22}
$O(0,0)$	$-C_1-\varepsilon A_1$	0	0	$-C_2-\varepsilon A_2$
$A(1,0)$	$C_1+\varepsilon A_1$	0	0	$\mu_2 m_2+(1-r)\lambda_2 k_2 L_1+\beta k_2 L_3-C_2-\varepsilon A_2+\theta D$
$B(1,1)$	$-\alpha\mu_1(m_1-m_2)-\mu_1\gamma m_2-(1-r)\lambda_1 k_1 L_2-\beta k_1+C_1+\varepsilon A_1-y\theta D$	0	0	$-\mu_2 m_2-(1-r)\lambda_2 k_2 L_1-\beta k_2 L_3+C_2+\varepsilon A_2-\theta D$
$C(0,1)$	$\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+(1-r)\lambda_1 k_1 L_2+\beta k_1 L_3-C_1-\varepsilon A_1+\theta D$	0	0	$C_2+\varepsilon A_2$
$D(x^*,y^*)$	0	K	Z	0

(1) $a_{11}+a_{22}<0$ $(\mathrm{Tr}(J))$

(2) $\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22}-a_{12}a_{21}>0$ $(\mathrm{Det}(J))$

$$K=\frac{C_2+\varepsilon A_2}{\mu_2 m_2+\beta k_2 L_3+\theta_2 D+(1-r)\lambda_2 k_2 L_1}\left(1-\frac{C_2+\varepsilon A_2}{\mu_2 m_2+\beta k_2 L_3+\theta D+(1-r)\lambda_2 k_2 L_1}\right)\cdot\left[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+(1-r)\lambda_1 k_1 L_2+\beta k_1 L_3+\theta D\right],$$
$$Z=\frac{C_1+\varepsilon A_1}{\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1 L_3+\theta D+(1-r)\lambda_1 k_1 L_2}\cdot\left(1-\frac{C_1+\varepsilon A_1}{\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1 L_3+\theta D+(1-r)\lambda_1 k_1 L_2}\right)\left[\mu_2 m_2+(1-r)\lambda_2 k_2 L_1+\beta k_2 L_3-C_2-\varepsilon A_2+\theta D\right]. \tag{21}$$

(1) At point $O(0,0)$, we have the following conditions: $\mathrm{trJ}=a_{11}+a_{22}=-C_1-C_2-\varepsilon(A_1+A_2)<0$ and $\det J=a_{11}a_{22}-a_{12}a_{21}=(-C_1-\varepsilon A_1)\quad(-C_2-\varepsilon A_2)>0$, making point $O(0,0)$ a focal point for the system's evolutionarily stable strategy (ESS), which is characterised by {negative cooperation, negative cooperation}.

(2) At point $A(1,0)$, we have the following conditions: $\mathrm{trJ}=a_{11}+a_{22}=C_1+\varepsilon A_1+\mu_2 m_2+(1-r)\lambda_2 k_2 L_1+\beta k_2 L_3-C_2-\varepsilon A_2+\theta D>0$ and $\det J=a_{11}a_{22}-a_{12}a_{21}=(C_1+\varepsilon A_1)[\mu_2 m_2+(1-r)\lambda_2 k_2 L_1+\beta k_2 L_3-C_2-\varepsilon A_2+\theta D]>0$. Consequently, point $A(1,0)$ represents an unstable point in the evolution of the system.

(3) At point $B(1,1)$, we have the following conditions: $\mathrm{trJ}=a_{11}+a_{22}=-\alpha\mu_1(m_1-m_2)-\mu_1\gamma m_2-(1-r)\lambda_1 k_1 L_2-\beta k_1+C_1+\varepsilon A_1-y\theta D-\mu_2 m_2-(1-r)\lambda_2 k_2 L_1-\beta k_2 L_3+C_2+\varepsilon A_2-\theta D<0$ and $\det J=a_{11}a_{22}-a_{12}a_{21}=[-\alpha\mu_1(m_1-m_2)-\mu_1\gamma m_2-(1-r)\lambda_1 k_1 L_2-\beta k_1+C_1+\varepsilon A_1-y\theta D][-\mu_2 m_2-(1-r)\lambda_2 k_2 L_1-\beta k_2 L_3+C_2+\varepsilon A_2-\theta D]>0$ are met. As a result, point $B(1,1)$ represents the evolutionary stable strategy (ESS) for the system, characterised by {positive cooperation, positive cooperation}.

(4) At point $C(0,1)$, we have the following conditions: $\mathrm{trJ}=a_{11}+a_{22}=[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+(1-r)\lambda_1 k_1 L_2+\beta k_1 L_3-C_1-\varepsilon A_1+\theta D]+C_2+\varepsilon A_2>0$ and $\det J=a_{11}a_{22}-a_{12}a_{21}=[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+(1-r)\lambda_1 k_1 L_2+\beta k_1 L_3-C_1-\varepsilon A_1+\theta D][C_2+\varepsilon A_2]>0$ exist. Consequently, point $C(0,1)$ is an unstable point in the evolution of the system.

(5) At point $D(x^*,y^*)$, we have the following conditions: $\mathrm{trJ}=a_{11}+a_{22}=0$ and $\det J=a_{11}a_{22}-a_{12}a_{21}=-\mathrm{KZ}<0$. This categorises point $D(x^*,y^*)$ as a saddle point.

By performing stability analysis on the five equilibrium points mentioned earlier, we can derive the data presented in Table 3. Subsequently, we utilize the information in Table 3 to construct a simulated game phase diagram, vividly illustrating the system's evolutionary trends, as depicted in Figure 1.

As shown in Figure 1, regardless of the initial decisions made by the two subjects, the evolutionary system will eventually evolve towards either point $B(1,1)$ {positive cooperation, positive cooperation} or point $O(0,0)$ {negative cooperation, negative cooperation} after continuous evolutionary gameplay. The final evolution strategy chosen by both subjects in the game depends on the relative sizes of S_{AOCD} and S_{ABCD}. The system's evolution direction is analysed based on the impact of parameter changes on the relative area of the quadrilateral to make predictions about on the system's evolution direction.

Table 3: Results of local stability analysis.

Balance point	Det J	Tr J	Local stability
$O(0,0)$	+	−	ESS
$A(1,0)$	+	+	unstable point
$B(1,1)$	+	−	ESS
$C(0,1)$	+	+	unstable point
$D(x^*, y^*)$	−	0	Saddle point

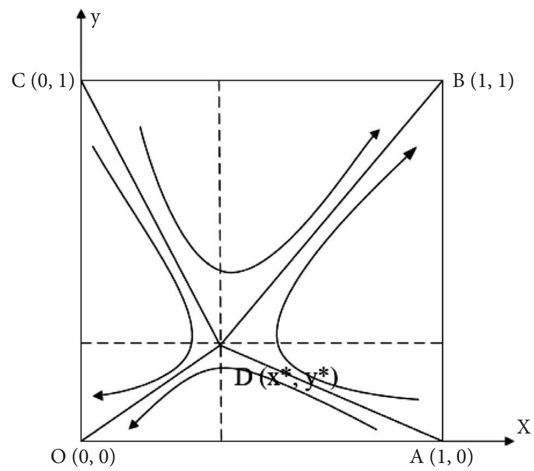

Figure 1: Phase diagram of the evolutionary game.

$$S_{\mathrm{AOCD}} = \frac{1}{2}\left(x^* + y^*\right) = \frac{1}{2}\left[\frac{C_2 + \varepsilon A_2}{\mu_2 m_2 + \beta k_2 L_3 + \theta D + (1-r)\lambda_2 k_2 L_1} + \frac{C_1 + \varepsilon A_1}{\alpha\mu_1\left(m_1 - m_2\right) + \mu_1 \gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2}\right]. \tag{22}$$

4.3. Impact of Parameters on Evolutionary Stabilisation Strategies

Proposition 1. *In a market mechanism, as the associated costs increase, the probability of game participants choosing the "positive cooperation" strategy decreases.*

Proof. According to $(\partial S_{\mathrm{AOCD}}/\partial C_1) = (1/2[\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2])$, due to the alignment of x^* and y^* within the plane of $R = \{(x,y) \mid 0 \le x \le 1,\ 0 \le y \le 1\}$, both $(\partial S_{\mathrm{AOCD}}/\partial C_1) > 0$ and, similarly, $(\partial S_{\mathrm{AOCD}}/\partial C_2) > 0$ exhibit similar trends. This behaviour extends to S_{AOCD}, which becomes a monotonically increasing function based on C_1, and C_2, respectively. Moreover, as C_1 and C_2 increase, the area of S_{AOCD} expands, while the area of S_{ABCD} contracts with higher values of C_1 and C_2. Additionally, S_{ABCD} diminishes as the innovation input cost increases in positive cooperation between the two entities in the game. In this context, the probability of the system advancing to point $O(0,0)$ rises, leading the two entities within the game to lean towards adopting a "negative cooperation" strategy.

Proposition 2. *In the context of a market mechanism, when there is a lower obstacle factor for investment gain or loss, it increases the likelihood that both participants in the game will opt for the "positive cooperation" strategy.*

Proof. Based on the derivative $(\partial S_{\mathrm{AOCD}}/\partial \varepsilon) = (1/2)\{(A_2/\mu_2 m_2 + \beta k_2 L_3 + \theta D + (1-r)\lambda_2 k_2 L_1) + A_1/\alpha\mu_1 (m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 \quad L_2\} > 0$, when we consider the positions of x^* and y^* within the framework of $R = \{(x,y) \mid 0 \le x \le 1, 0 \le y \le 1\}$, we find that S_{AOCD} becomes a monotonically increasing function of ε, while S_{ABCD} transforms into a monotonically decreasing function of ε. As ε increases, the area of S_{ABCD} gradually contracts, thus increasing the likelihood of the system progressing towards point $O(0,0)$. In this context, the predominant inclination of the game's key players is to lean towards the "negative cooperation" strategy. It is important to note that the adoption of a "negative cooperation" strategy by the game's participants stems from a range of factors. Factors such as the disclosure of relevant confidentiality agreements, the potential leakage of intellectual property rights, and the extent to which both companies uphold the essence of their contract all contribute to hindering the generation of investment gains and losses. However, when these companies choose the path of "positive cooperation," their mutual trust deepens. Their commitment to honouring the contractual spirit and adhering to legal regulations mitigates the factor of investment loss. As a result, the expanse of S_{ABCD} expands, the likelihood of the system advancing to point $B(1,1)$ increases, and the two participants in the game become more likely to adopt the "positive cooperation" strategy.

Proposition 3. *In the context of the market mechanism, when upstream and downstream enterprises within the supply chain strengthen their collaboration, the civilian enterprise is inclined to provide more significant product discounts. This results in an expansion of the demand scale for military enterprises. As a consequence, the likelihood of both sides of the game choosing the "positive cooperation" strategy increases.*

Proof. Given the premise $(\partial S_{AOCD}/\partial\gamma) = -1/4(\mu_1 m_2 (C_1 + \varepsilon A_1)/[\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2]^2) < 0$, we can conclude that S_{AOCD} behaves as a monotonically decreasing factor concerning γ. As γ increases, S_{AOCD} gradually decreases. Thus, S_{AOCD} is established as a monotonically decreasing function linked to γ. With an increase in, S_{ABCD} similarly increases. This impact elevates the probability of the system evolving towards point $B(1,1)$, encouraging the primary entities within the game to lean towards adopting the "positive cooperation" strategy. It is crucial to note that the depth of the relationship between the two enterprises significantly influences this dynamic. A stronger connection heightens the likelihood of both enterprises embracing the "positive cooperation" strategy. Furthermore, the extent of product discounts offered by the civilian enterprise to their military counterparts directly impacts the relative profits achievable by the military enterprise. This, in turn, strengthens the military enterprise's inclination to opt for the "positive cooperation" strategy.

Proposition 4. *Within the context of the market mechanism, as the absorptive capacity and network synergy of both upstream and downstream supply chain enterprises strengthen, the probability of the game's central participants choosing the "positive cooperation" strategy increases.*

Proof. Starting from $(\partial S_{AOCD}/\partial\lambda_1) = -(1/4)((1-r)k_1 L_2(C_1 + \varepsilon A_1)/\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2) < 0$, there exists a relationship: $(\partial S_{AOCD}/\partial\lambda_2) = -(1/4)((1-r)k_2 L_1(C_2 + \varepsilon A_2)/\mu_2 m_2 + \beta k_2 L_3 + \theta D + (1-r)\lambda_2 k_2 L_1) < 0$. Similarly, another relationship follows: $(\partial S_{AOCD}/\partial\lambda_1) < 0$ and $(\partial S_{AOCD}/\partial\lambda_2) < 0$, and these are linked to S_{AOCD} as monotonically decreasing functions associated with λ_1, λ_2, μ_1, and μ_2, respectively. In fact, S_{AOCD} decreases monotonically with respect to λ_1, λ_2, μ_1, and μ_2. As λ_1, λ_2, μ_1, and μ_2 increase, the value of S_{AOCD} experiences a gradual reduction. In contrast, S_{ABCD} behaves as a monotonically increasing function linked to λ_1, λ_2, μ_1, and μ_2. As λ_1, λ_2, μ_1, and μ_2 increase, S_{ABCD} gradually grows. This shift amplifies the likelihood of the system advancing towards point $B(1,1)$, leading to a stronger inclination among the key parties in the game to adopt the "positive cooperation" strategy. Moreover, within an appropriate supply and demand scale, this dynamic's potency deepens. Enhanced absorptive capacity and the ability to transform revenue, possessed by both upstream and downstream supply chain enterprises, result in higher revenue potential for both entities. As a result, the tendency to adopt the "positive cooperation" strategy becomes more pronounced within their evolutionary strategy.

Proposition 5. *In the context of the market mechanism, it becomes intriguing when one party chooses the "positive cooperation" strategy, as it raises the question of whether this choice influences the likelihood of both parties adopting the same strategy. Notably, this probability tends to increase when the party initially opting for "positive cooperation" exhibits lower levels of trust.*

Proof. Given $(\partial S_{AOCD}/\partial r) = (1/4)\{(\lambda_2 k_2 L_1(C_2 + \varepsilon A_2)/[\mu_2 m_2 + \beta k_2 L_3 + \theta D + (1-r)\lambda_2 k_2 L_1]^2) + (\lambda_1 k_1 L_2(C_1 + \varepsilon A_1)/[\alpha\mu_1 (m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2]^2)\} > 0$, it becomes evident that S_{AOCD} exhibits a monotonically increasing trend concerning r. As r increases, S_{AOCD} also grows, thereby increasing the likelihood of the system progressing towards point $O(0,0)$. In contrast, S_{ABCD} follows a monotonically decreasing pattern concerning r. As r experiences an increment, S_{ABCD} gradually diminishes, resulting in a decreased probability of the system advancing to point $B(1,1)$. This scenario often prompts enterprises to consider adopting a "negative cooperation" strategy, capitalizing on the significant benefits of technological spillover opportunities. On the other hand, those opting for a "positive cooperation" strategy incur substantial costs and heightened risks. Therefore, enterprises planning to engage in positive collaborative innovation should exercise caution, maintaining a prudent level of trust in other enterprises. It is imperative for enterprises to remain vigilant and exercise restraint in trusting other entities before embarking on collaborative innovation efforts.

Proposition 6. *Within the market mechanism, a notable trend emerges: as the supply scale of upstream civilian enterprises expands and the demand scale of downstream military enterprises grows, the likelihood of both parties opting for the "positive cooperation" strategy increases. Furthermore, it is observed that the sensitivity of civilian enterprises' supply scale outweighs that of the military enterprise's demand scale.*

Proof. Since $(\partial S_{AOCD}/\partial m_1) = -(1/4)((C_1 + \varepsilon A_1)\alpha\mu_1/[\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2]^2) < 0$ and $(\partial S_{AOCD}/\partial m_2) = -(1/4)\{((C_2 + \varepsilon A_2)\mu_1/[\mu_2 m_2 + \beta k_2 L_3 + \theta D + (1-r)\lambda_2 k_2 L_1]^2) + ([\mu_1(\gamma - \alpha)](C_1 + \varepsilon A_1)/[\alpha\mu_1(m_1 - m_2) + \mu_1\gamma m_2 + \beta k_1 L_3 + \theta D + (1-r)\lambda_1 k_1 L_2]^2)\} < 0$ both exhibit a similar trend, let us consider S_{AOCD} as a function that decreases concerning either m_1 or m_2. As m_1 or m_2

increases, S_{AOCD} demonstrates a corresponding decrease. On the other hand, S_{ABCD} is a monotonically increasing function concerning m_1 or m_2. As m_1 or m_2 increases, S_{ABCD} consistently grows, leading to an enhanced likelihood of the system progressing to point $B(1,1)$. In practical terms, this implies that when the supply scale of civilian enterprises experiences growth or the demand scale of military enterprises rises, the probability of these entities opting for "positive cooperation" also experiences an upsurge. The military enterprise benefits from cost reduction through discounts, while the civilian enterprise can enhance its profits by increasing sales volume. This relationship is driven by $(\gamma-\alpha)\mu_1<\mu_1$. Furthermore, considering the relative slopes of the $(\partial S_{\mathrm{AOCD}}/\partial m_1)$ and $(\partial S_{\mathrm{AOCD}}/\partial m_2)$ functions, it becomes evident that $(\partial S_{\mathrm{AOCD}}/\partial m_1)$ experiences a steeper decline compared to $(\partial S_{\mathrm{AOCD}}/\partial m_2)$.In summary, the influence of the supply side of the civilian enterprise on the inclination towards "positive cooperation" surpasses that of the demand from the military enterprise. In other words, the civilian enterprise exhibits a stronger inclination towards adopting the "positive cooperation" strategy in contrast to the military enterprise. This preference is manifested through the practical implementation of the "positive cooperation" strategy, leading to elevated profitability for the civilian enterprise.

Proposition 7. *In the context of the market mechanism, when both civilian and military enterprises exhibit a heightened capability for adaptability and integration, it significantly increases the probability of both participants choosing a "positive cooperation" strategy.*

Proof. Given that $(\partial S_{\mathrm{AOCD}}/\partial k_1)=-(1/4)([(1-r)k_1+\beta L_3](C_1+\varepsilon A_1)/[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1L_3+\theta D+(1-r)\lambda_1k_1L_2]^2)<0$, $(\partial S_{\mathrm{AOCD}}/\partial\alpha)=-(1/2)(\mu_1(m_1-m_2)(C_1+\varepsilon A_1)/\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1L_3+\theta D+(1-r)\lambda_1k_1L_2)<0$, and similarly $(\partial S_{\mathrm{AOCD}}/\partial k_2)<0$, S_{AOCD} is function that decreases concerning α, k_1, or k_2. As α, k_1, or k_2 increases, S_{AOCD} also exhibits a decreasing trend. On the other hand, S_{ABCD} is a monotonically increasing function of α, k_1, or k_2. As α, k_1, or k_2 increases, S_{ABCD} will steadily rise, subsequently increasing the likelihood of the system progressing to point $B(1,1)$. As both upstream and downstream enterprises within the supply chain enhance their transformative and integrative capacities, the probability of these two enterprises opting for the "positive cooperation" strategy also amplifies.

Proposition 8. *In the context of the market mechanism, when government regulations are more stringent and the fines imposed by the government are higher, it significantly raises the probability of both parties engaged in the game choosing a "positive cooperation" strategy.*

Proof. Through $(\partial S_{\mathrm{AOCD}}/\partial\theta)=-(1/4)(D(C_1+\varepsilon A_1)/[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1L_3+\theta D+(1-r)\lambda_1k_1L_2]^2)-(1/4)(D(C_2+\varepsilon A_2)/[\mu_2m_2+\beta k_2L_3+\theta D+(1-r)\lambda_2k_2L_1]^2)<0$ and $(\partial S_1/\partial D)=-(1/4)\{(\theta(C_2+\varepsilon A_2)/[\mu_2m_2+\beta k_2L_3+\theta D+(1-r)\lambda_2k_2L_1]^2)+(\theta(C_1+\varepsilon A_1)/[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1L_3+\theta D+(1-r)\lambda_1k_1L_2]^2)\}<0$, it becomes evident that S_{AOCD} is a function that decreases with θ and D. As θ and D increase, S_{AOCD} exhibits a declining trend. On the other hand, S_{ABCD} consistently rises concerning the increasing values of θ and D. As θ and D grow, S_{ABCD} follows suit by gradually ascending. This, in turn, augments the likelihood of the system progressing towards point $B(1,1)$. The correlation between government regulation and fines, as well as the impact of stringent constraints on enterprises and elevated default costs, plays a crucial role. This interplay influences the strategic choices of enterprises. Particularly, as government regulation strengthens and fines become more substantial, the constraints imposed on enterprises intensify. Consequently, the cost of default rises. In response to these factors, enterprises lean towards adopting a "positive cooperation" strategy.

Proposition 9. *In the market mechanism context, when both upstream and downstream enterprises in the supply chain embrace the "positive cooperation" strategy, an interesting pattern emerges. More notably, the stronger an enterprise's capacity for adaptability and innovation is, the higher the probability that both participants in this interaction will choose the "positive cooperation" strategy.*

Proof. Given the premise of $(\partial S_{\mathrm{AOCD}}/\partial L_3)=-(1/4)\{(\beta k_2(C_2+\varepsilon A_2)/[\mu_2m_2+\beta k_2L_3+\theta D+(1-r)\lambda_2k_2L_1]^2)+(\beta k_1(C_1+\varepsilon A_1)/[\alpha\mu_1(m_1-m_2)+\mu_1\gamma m_2+\beta k_1L_3+\theta D+(1-r)\lambda_1k_1L_2]^2)\}<0$, we observe that S_{AOCD} behaves as a decreasing function in relation to L_3. As L_3 increases, S_{AOCD} exhibits a corresponding decrease, thereby increasing the likelihood of the system progressing towards point $B(1,1)$. Similarly, S_{ABCD} experiences a continuous increase as a function of L_3. With the upward shift in L_3, S_{ABCD} demonstrates a gradual rise, further contributing to the likelihood of the system evolving to $B(1,1)$. In the context of enhanced cooperation and innovation outcomes among enterprises, combined with advances in technical prowess and improvements in product quality, the potential for significantly enhancing the economic benefits of these enterprises becomes evident. As a result, both upstream and downstream enterprises are inclined to opt for the "positive cooperation" strategy.

5. Simulation Analysis

Based on the parameter analysis provided in the previous section, it becomes clear that there exists a significant correlation between the evolutionary stabilisation strategy of both civilian and military enterprises and each parameter. This paper employs MATLAB 2023a to simulate and analyse these parameters within a two-party evolutionary game model. Through this method, we aim to gain a better understanding of how variations in key numerical parameters influence the outcomes of the two-party game evolution. The initial parameters, based on existing literature [9, 17, 18, 20–22] and research results, are set as follows:

$\alpha = 0.8$, $\mu_1 = 3$, $\mu_2 = 5$, $C_1 = 15$, $C_2 = 25$, $\theta = 0.5$, $D = 10$, $\gamma = 0.8$, $\varepsilon = 0.1$, $r = 0.8$, $\lambda_1 = 0.4$, $\lambda_2 = 0.6$, $\beta = 1.5$, $A_1 = 2$, $A_2 = 2$, $L_1 = 2$, $L_2 = 1$, $k_1 = 3$, $k_2 = 4$, $m_1 = 4$, and $m_2 = 2$. In our numerical simulations, we utilize the initial values (x, y), represented as $(0.3, 0.6)$, $(0.4, 0.5)$, $(0.5, 0.5)$, $(0.5, 0.6)$, $(0.6, 0.3)$, $(0.7, 0.2)$, $(0.7, 0.3)$, and $(0.8, 0.2)$. These simulations are illustrated in Figure 2, providing insights into how the strategies chosen by the two participants evolve over time.

As depicted in Figure 2, when the probabilities (x, y) assigned to the two participants in the evolutionary game have distinct initial values, the outcomes of the game evolution converge at specific points: $(0, 0)$ and $(1, 1)$, indicating scenarios of {negative cooperation, negative cooperation} and {positive cooperation, positive cooperation}, respectively. By utilizing MATLAB 2023a with the given initial value (x, y), we can determine the value of the saddle point $D((90/163), (760/1867))$, which is presented in Figure 1. It is noteworthy that when the initial value (x, y) falls within the quadrilateral AOCD region, convergence occurs at point $(0, 0)$, leading both participants to opt for the "negative cooperation" strategy. On the other hand, if the initial value of point A falls within the quadrilateral ABCD region, convergence leads to point $(1, 1)$, where both participants in the game select the "positive cooperation" strategy.

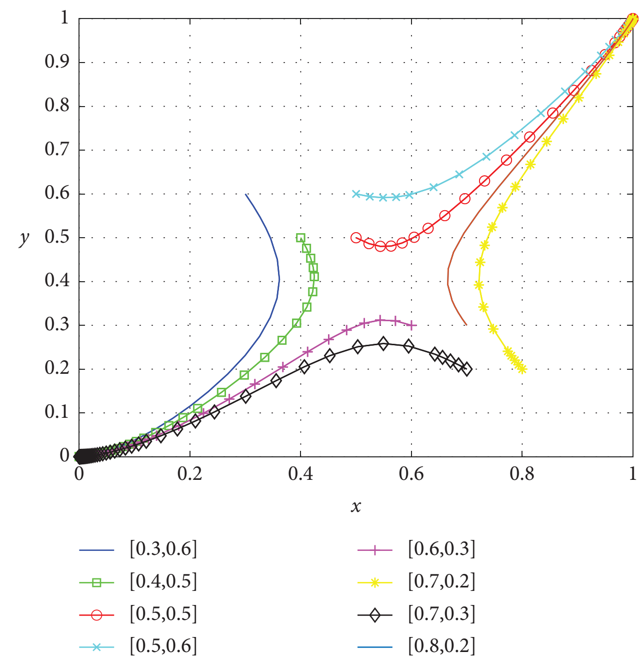

Figure 2: Map of evolutionary trends.

5.1. Impact of Input Costs of Civilian Enterprises. As depicted in Figures 3(a) and 3(b), when other parameters remain constant, changes in the cost input for the civilian enterprise, denoted as $C_1 \leq 18$, result in the convergence of data evolution curves for both the civilian and military enterprises towards point $(1, 1)$. This convergence signifies the adoption of the "positive cooperation" strategy by both types of enterprises. Notably, a lower input cost for the civilian enterprise leads to a swifter convergence of the curves towards 1. When the input cost is denoted as $C_1 \geq 19$, the evolution curves for both the civilian and military enterprises converge at point $(0, 0)$. This convergence signals that neither type of enterprise opts for the "positive cooperation" strategy. It is worth noting that a higher input cost for the civilian enterprise results in a quicker convergence of the curves towards 0.

Moving to Figure 3(b), when the input cost for the civilian enterprise is labelled as $C_1 = 10$, the civilian enterprise tends to approach 1 more rapidly compared to the rate of convergence of the military enterprise. Conversely, with an input cost denoted as $C_1 = 15$, the civilian enterprise tends to reach 1 at a slower pace than the military enterprise. Lastly, when the input cost is designated as $C_1 = 20$, the civilian enterprise tends to approach 0 more swiftly than the military enterprise.

This observation highlights that the civilian enterprise exhibits a greater sensitivity to increases in input costs associated with the "positive cooperation" strategy.

5.2. Impact of Input Costs of Military Enterprises. As demonstrated by Figures 4(a) and 4(b), under the condition of all other parameters remaining constant, the evolution curves for both the military and civilian enterprises converge towards point $(1, 1)$ when we make changes to the cost input for the military enterprise, represented as $C_2 \leq 25$. This convergence indicates the adoption of the "positive cooperation" strategy by both types of enterprises. It is important to note that this convergence trend is observed exclusively when the cost input for the military enterprise is set at $C_2 \leq 25$. This specific cost input leads to the most rapid convergence of both the military and civilian enterprises towards point $(1, 1)$.

In cases where the cost inputs are labelled as $C_2 = 10$ and $C_2 = 20$, the rates of convergence to the "positive cooperation" strategy are equal for both military and civilian enterprises. Conversely, when the input cost reaches $C_2 \geq 30$, the evolution curves for both types of enterprises converge at point $(0, 0)$, indicating the selection of the "negative cooperation" strategy.

Additionally, it is worth highlighting that a higher input cost for the civilian enterprise results in a quicker convergence of the curve towards 0. When we examine Figure 4, considering an input cost of $C_2 = 20$, we notice that the speed at which the military enterprise approaches convergence to 1 is slower compared to the civilian enterprise. However, around 0.2 seconds after convergence, the speeds at which both types of enterprises reach 1 become equal.

Further analysis of the remaining five sets of data reveals that military enterprises display a higher sensitivity to cost increases associated with the "positive cooperation" strategy.

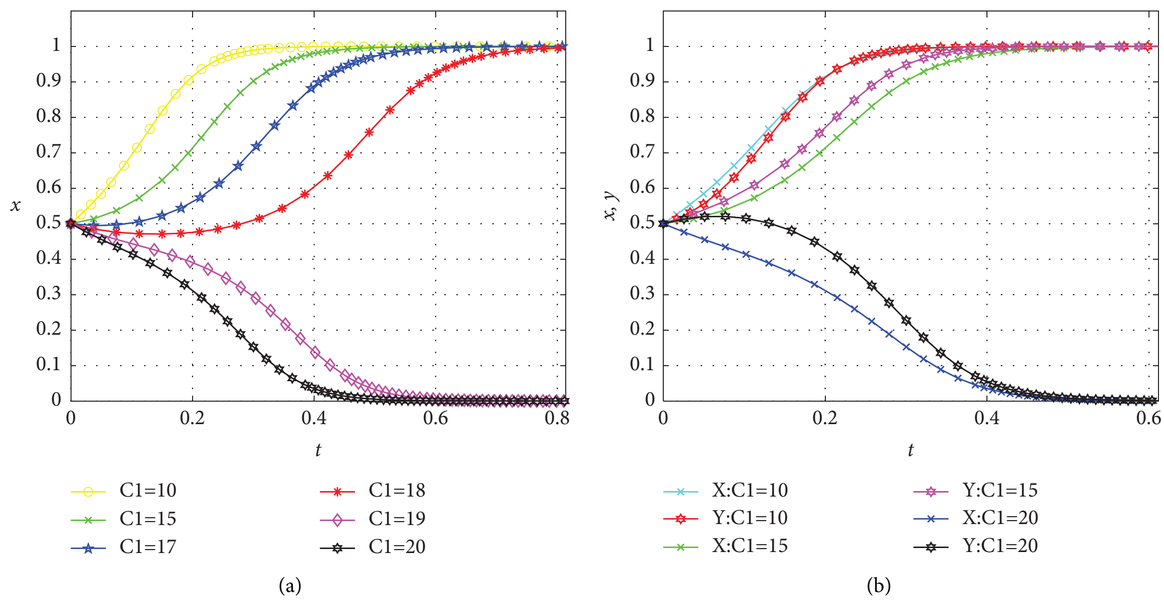

Figure 3: Impact of civilian input costs on evolution. (a) Impact on the civilian enterprise. (b) Impact on the civilian and military enterprises.

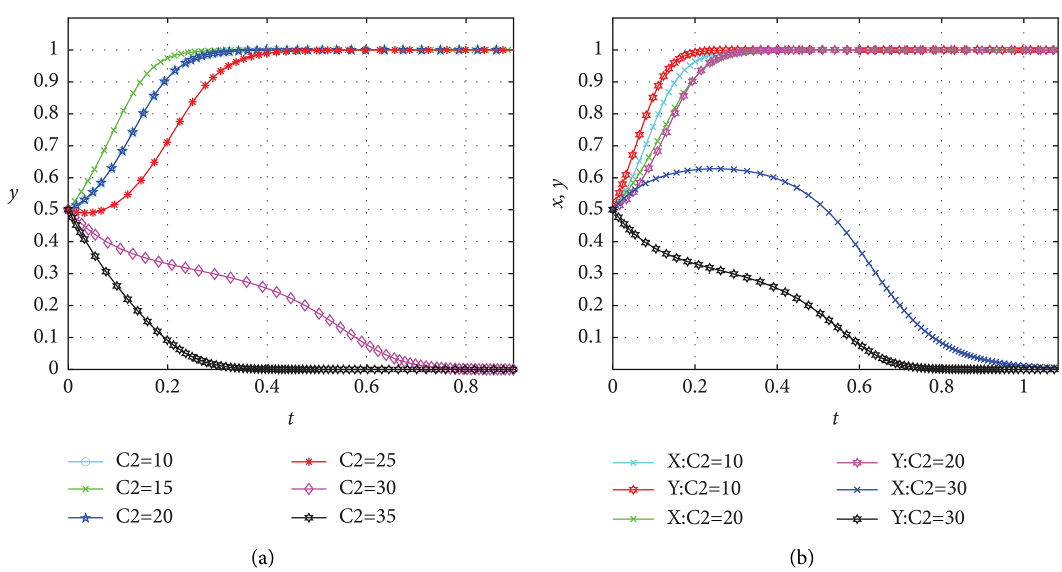

Figure 4: Impact of military enterprise input costs on evolution. (a) Impact on the military enterprise. (b) Impact on the civilian and military enterprises.

When we contrast Figures 4(a) and 4(b), it becomes apparent that when input costs are designated as $C_2 = C_1 = 10$ for both the civilian and military enterprises, the civilian enterprise tends to progress towards 1 at a higher rate. In the case of input cost $C_2 = 15$, the military enterprise's convergence rate peaks, while the civilian enterprise's rate declines. Finally, when input cost $C_2 = C_1 = 20$ is examined, the civilian enterprise has already converged to evolution 0, while the military enterprise is still advancing towards 1. This analysis leads to the conclusion that the military enterprise is more willing to invest higher costs compared to the civilian enterprise when pursuing the "positive cooperation" strategy.

5.3. Impact of Conversion Rate. As illustrated in Figures 5(a) and 5(b), assuming all other parameters remain constant, changes in the conversion rate, denoted as $\alpha \geq 0.4$, drive the evolution curves of both civilian and military enterprises towards a convergence at point $(1, 1)$. This significant convergence underlines the shared adoption of the "positive cooperation" strategy by both enterprise types.

It is worth noting that a lower conversion rate for the civilian enterprise leads to a swifter convergence of the curve towards unity. In contrast, when the conversion rate is designated as $\alpha \leq 0.2$, the evolution curves for both civilian and military enterprises align at point $(0, 0)$, indicating a collective preference for the "negative cooperation" strategy.

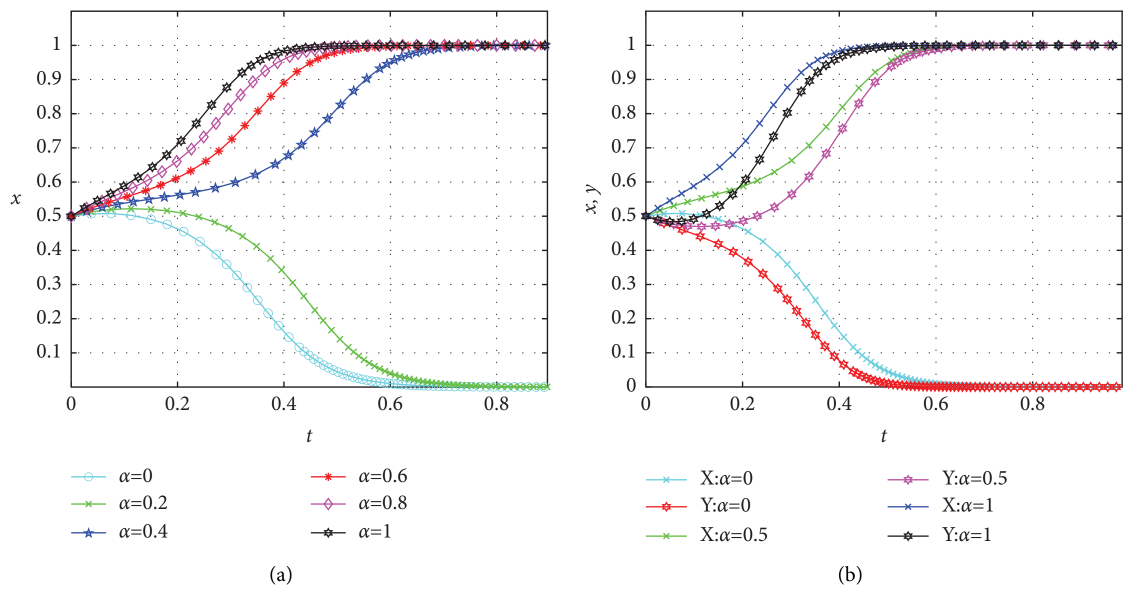

Figure 5: Impact of conversion rates on evolution. (a) Impact on the civilian enterprise. (b) Impact on the civilian and military enterprises.

Moreover, when we compare the conversion rates for the civilian enterprise, specifically $\alpha = 1$ and $\alpha = 0.5$, we observe that the civilian enterprise initially converges towards 1 more slowly with $\alpha = 0.5$, but then accelerates. This observation underscores the civilian enterprise's heightened sensitivity to an increase in the conversion rate associated with the "positive cooperation" strategy. This heightened sensitivity is attributed to the direct influence of the conversion rate on the feasibility of implementing innovative solutions in civilian products after selecting the "positive cooperation" strategy.

5.4. Impact of Profit and Loss Barrier Factors. As depicted in Figures 6(a) and 6(b), while keeping other parameters constant, when the investment profit and loss obstacle factor denoted as $\varepsilon \leq 0.4$ is altered, the evolution curves for both the civilian and military enterprises across the four datasets converge at point $(1, 1)$. This convergence signifies the joint adoption of the "positive cooperation" strategy by the two enterprises. Notably, a lower profit and loss obstacle factor corresponds to a swifter convergence of the curves towards 1. In essence, a smaller barrier to profit and loss leads to a quicker convergence to unity. Conversely, with the factor set as $\varepsilon \geq 0.5$, the evolution curves for both the civilian and military enterprises converge at point $(1, 1)$. This convergence indicates the shared selection of the "negative cooperation" strategy by both types of enterprises. Importantly, a higher profit and loss obstacle factor accelerates the curve's convergence towards 0.

Examining Figure 6(b), when the profit and loss obstacle factor is defined as $(0, 0)$, the speed at which the civilian enterprise approaches convergence to 1 outpaces that of the military enterprise. Conversely, with the factor $\varepsilon \leq 0.4$, the civilian enterprise converges to $\varepsilon \geq 0.5$ at a slower pace compared to the military enterprise. This observation illustrates that when the civilian and military enterprises tend towards the "positive cooperation" strategy, the civilian enterprise exhibits greater sensitivity and more swiftly embraces the "positive cooperation" strategy. Likewise, when both types of enterprises opt for the "negative cooperation" strategy, the military enterprise reacts more sensitively and embraces the "negative cooperation" strategy more rapidly. This scenario demonstrates that the military enterprise is particularly sensitive and quicker to adopt the "negative cooperation" strategy when both the civilian and military enterprises opt for it.

5.5. Impact of Discounts Given by Civilian Enterprises to Military Enterprises. In Figures 7(a) and 7(b), while keeping all other parameters constant, changes in the discount rate offered by the civilian enterprise, denoted as $\gamma \geq 0.5$, lead to a noticeable trend in the evolution curves of both civilian and military enterprises across the four datasets. These trends show the curves gravitating towards point $(1, 1)$, signifying the concurrent adoption of the "positive cooperation" strategy by both enterprises. Specifically, when the civilian enterprise offers a larger discount ($\gamma \geq 0.5$), the convergence towards 1 occurs more rapidly.

Conversely, when the discount is represented as $\gamma \leq 0.4$, the evolution curves for both types of enterprises converge towards point $(0, 0)$, indicating their joint selection of the "positive cooperation" strategy. Notably, the civilian enterprise's discount curve, when converging faster towards 1, plays a pivotal role in driving this overarching trend. Examining the scenario where $\gamma \leq 0.4$, both the civilian and military enterprises exhibit an evolution curve converging at point $(0, 0)$, indicating their choice of the "negative cooperation" strategy. It is particularly remarkable that a smaller discount offered by the civilian enterprise leads to a quicker convergence of the curve towards 0.

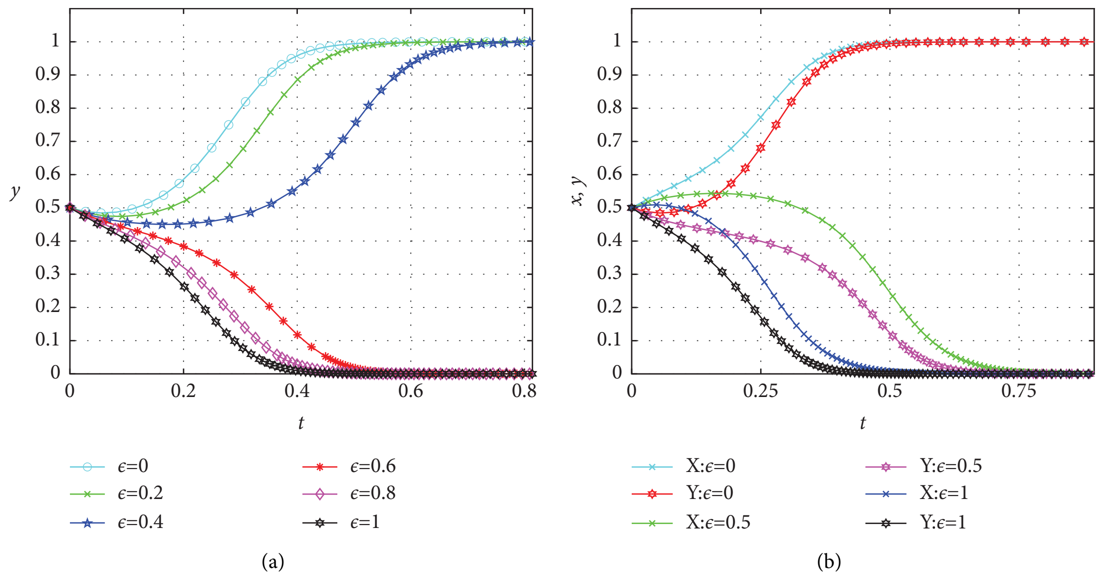

Figure 6: Impact of investment profit and loss factors on evolution. (a) Impact on the military enterprise. (b) Impact on the civilian and military enterprises.

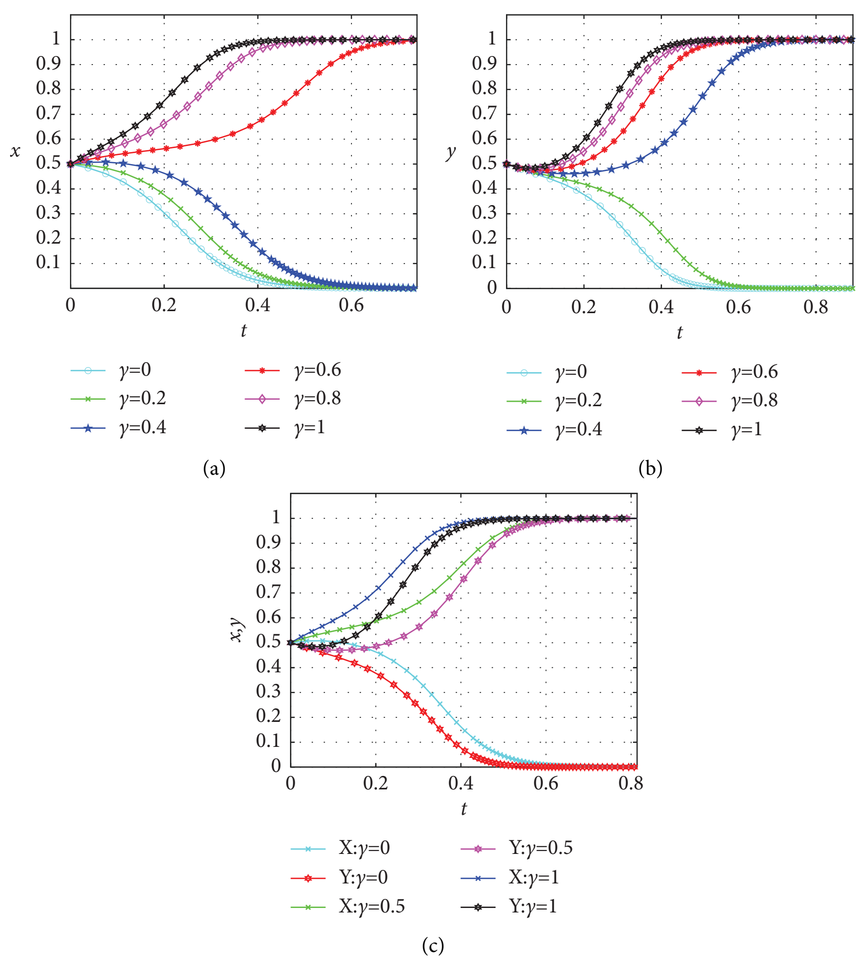

Figure 7: Impact of price discounts on evolution. (a) Impact on the civilian enterprise. (b) Impact on the military enterprise. (c) Impact on the civilian and military enterprises.

As emphasised in Figure 7(c), when the civilian enterprise's discount rate is set at $\gamma \geq 0.5$, it is evident that the civilian enterprise achieves convergence towards 1 at a faster rate compared to the military enterprise. Conversely, when both enterprises share a discount rate of $(1, 1)$, the civilian enterprise exhibits a slower approach towards 0 in contrast to the military enterprise.

This observation underscores the fact that when both civilian and military enterprises incline towards the "positive cooperation" strategy, the civilian enterprise demonstrates a heightened sensitivity and a more rapid embrace of the strategy. Conversely, when both enterprise types opt for the "negative cooperation" strategy, the military enterprise displays greater responsiveness, moving towards this strategy more quickly. This sensitivity arises from the interplay between preferences and their implications, where a higher preference results in lower costs for the military enterprise and greater benefits for the civilian enterprise.

5.6. Impact of Technological Capabilities of Collaborative Innovation R&D. As seen in Figures 8(a) and 8(b), assuming all other parameters remain constant, modifications to the technological capability associated with the "positive cooperation" strategy's innovation outcomes, referred to as $L_3 \geq 5$, result in the convergence of the evolution curves for both civilian and military enterprises across the four datasets at point $(1, 1)$. This convergence signifies the mutual adoption of the "positive cooperation" strategy by both enterprises. Notably, a higher technological capability for the innovation outcomes of the "positive cooperation" strategy leads to a quicker convergence towards the point $(1, 1)$.

Conversely, when the capability is represented as $L_3 \leq 4$, the evolution curves for both civilian and military enterprises converge to the origin $(0, 0)$, indicating that neither enterprise will opt for the cooperative innovation strategy. It is important to highlight that a lower technological capability in cooperative innovation research and development leads to a faster convergence of the curve towards 0.

Moving to Figure 8(c), with the technological capability denoted as $L_3 \geq 5$ for "positive cooperation" innovation outcomes, the civilian enterprise converges towards 1 faster compared to the military enterprise. Conversely, with capability $L_3 \leq 4$, the civilian enterprise takes longer to approach 0 compared to the military enterprise. In scenarios where both entities select the "positive cooperation" strategy, the civilian enterprise exhibits greater sensitivity and tends to embrace the strategy more swiftly.

However, at technological capabilities $L_3 = 4$ for the military enterprise and $L_3 = 3$ for the civilian enterprise, the speeds at which both enterprise types choose the "negative cooperation" strategy are closely aligned. This indicates that the military enterprise is more inclined to opt for the "negative cooperation" strategy when their innovation results are lower.

5.7. Impact of the Amount of Supply Scale of Civilian Enterprises. As depicted in Figures 9(a) and 9(b), while maintaining all other parameters constant, adjustments to the supply side of the civilian enterprise, denoted as $m_1 \geq 3$, lead to the convergence of the evolution curves for both the civilian and military enterprises across the four datasets, ultimately reaching the point $(1, 1)$. This convergence underlines the shared adoption of the "positive cooperation" strategy by both enterprises. Significantly, the larger the supply size of the civilian enterprise, the quicker the convergence of the curve towards 1.

When the supply size is represented as $m_1 \leq 2$ and is smaller than or equal to the demand size of the military enterprise, the evolution curves for both the civilian and military enterprises converge faster compared to scenarios where only the military enterprise is involved. Within the context of $m_1 \leq 2$, where the supply scale of the civilian enterprise remains smaller than or equal to the demand scale of the military enterprise, the evolution curves for both enterprise types tend towards point $(0, 0)$. This trend reflects the joint selection of the "negative cooperation" strategy by both enterprise types. Remarkably, the smaller the demand scale, the faster the convergence of the curve towards 0.

In Figure 9(b), when the demand quantity side is denoted as $m_1 \geq 3$, the civilian enterprise approaches 1 faster than the military enterprise. Conversely, with a quantity of $m_1 \leq 2$, the civilian enterprise converges towards 0 more slowly compared to the military enterprise. In situations where both parties opt for the "positive cooperation" strategy, the civilian enterprise demonstrates greater sensitivity, embracing the strategy more promptly. Additionally, when the supply of the civilian enterprise is smaller than the demand of the military enterprise, the military enterprise displays heightened sensitivity. Conversely, when the civilian enterprise's supply surpasses the demand of the military-industrial enterprise, the civilian enterprise exhibits greater responsiveness.

5.8. Impact of Government Regulatory Efforts. As illustrated in Figures 10(a) and 10(b), under constant conditions for all other parameters, adjustments to the strength of government supervision, labelled as $\theta \geq 0.4$, result in the convergence of the evolution curves for both civilian and military enterprises across the four datasets, ultimately converging at point $(1, 1)$. This convergence signifies the joint adoption of the "positive cooperation" strategy by both enterprises. Notably, a higher degree of government supervision leads to a faster convergence of the curves towards unity. Conversely, when the strength is marked as $\theta \leq 0.2$, the evolution curves for both civilian and military enterprises tend towards $(0, 0)$. This convergence indicates the mutual selection of the "negative cooperation" strategy by both types of enterprises. Importantly, a lower strength of government supervision expedites the convergence of the curves towards 0.

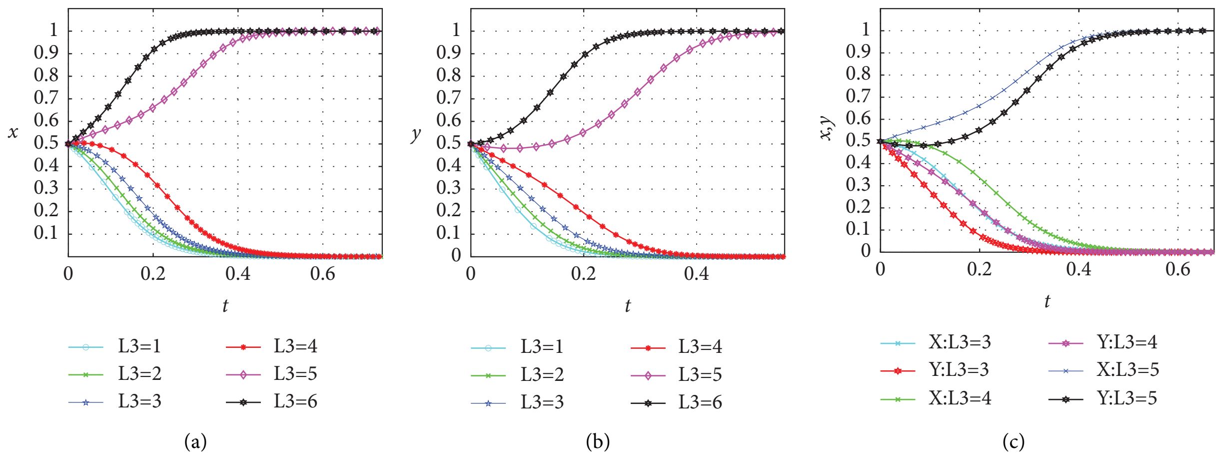

FIGURE 8: Impact of innovations on evolution. (a) Impact on the civilian enterprise. (b) Impact on the military enterprise. (c) Impact on the civilian and military enterprises.

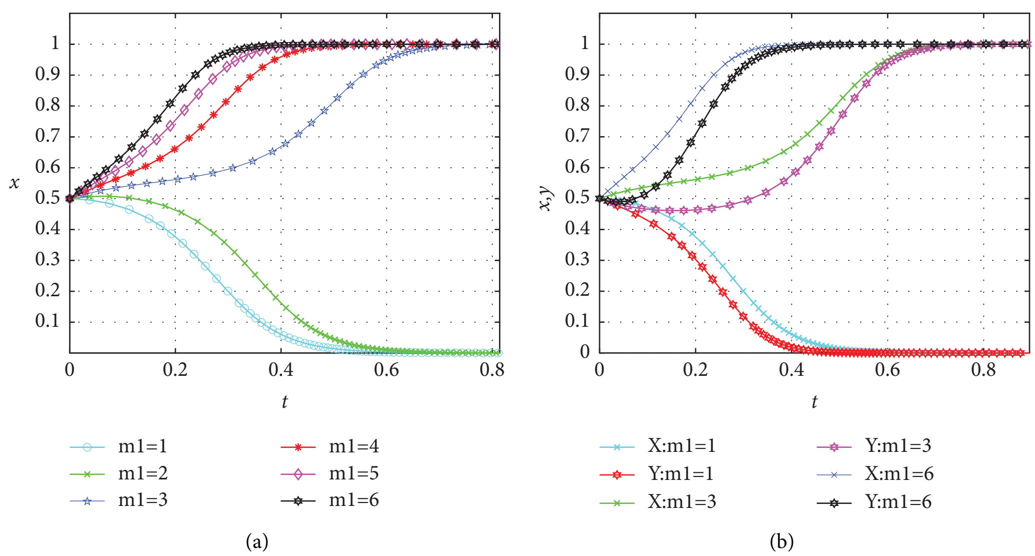

FIGURE 9: Impact of supply scale volume on evolution. (a) Impact on the civilian enterprise. (b) Impact on the civilian and military enterprises.

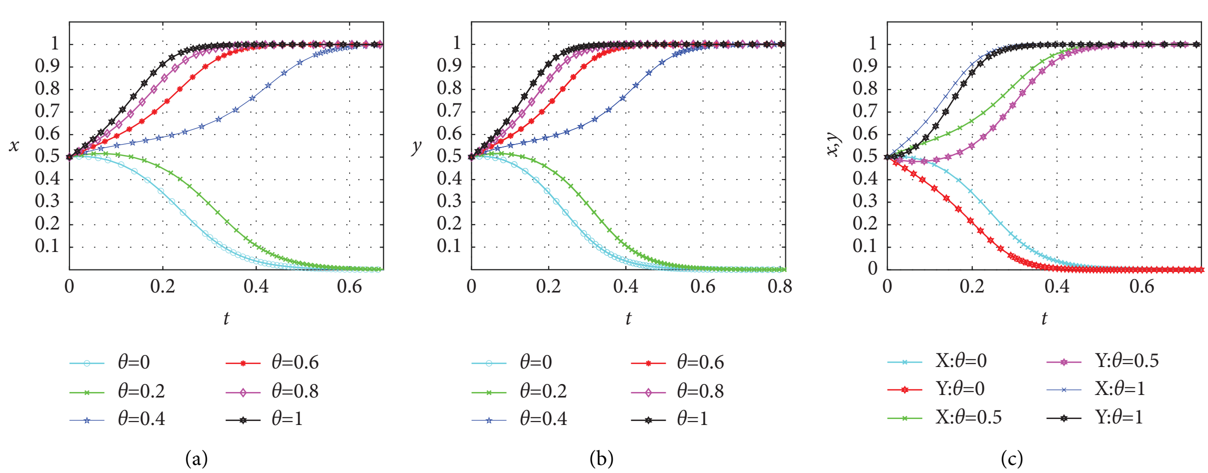

FIGURE 10: Impact of government regulatory effort on evolution. (a) Impact on the civilian enterprise. (b) Impact on the military enterprise. (c) Impact on the civilian and military enterprises.

Shifting our focus to Figure 10(c), when the regulatory efforts are denoted as $\theta \geq 0.4$, the civilian enterprise converges towards 1 more rapidly than the military enterprise. Conversely, with effort marked as $\theta \leq 0.2$, the civilian enterprise takes longer to approach 0 compared to the military enterprise. Whether both entities choose the “positive cooperation” strategy or lean towards the “positive cooperation” strategy or the “negative cooperation” strategy, the civilian enterprise consistently demonstrates greater sensitivity and a swifter embrace of the chosen strategy. In cases where the military-industrial enterprise and the civilian enterprise opt for the “negative cooperation” strategy, the military enterprise exhibits heightened sensitivity and a faster tendency towards the “negative cooperation” strategy.

6. Conclusion and Practical Implications

6.1. Conclusion. Taking the evolutionary game model as the theoretical basis, this study explores the impacts of input costs, conversion rates, price discounts, technological capabilities, government regulations, and supply and demand scales on the returns of civilian and military enterprises in the process of vertical cooperation and innovation in the supply chain of civil-military integration, primarily focusing on four dimensions: exploration and absorption capacity, network synergy, transformation and integration capacity, and change and innovation capacity. The conclusions are as follows:

(1) The potential for civilian enterprises and military-industrial enterprises to establish a cooperative innovation agreement is significantly influenced by the input costs of these enterprises. The disparity in input costs between civilian and military-industrial enterprises during the process of cooperation and innovation is a crucial consideration. Civilian enterprises, given their nature of specialization and innovation, typically have relatively lower input capital costs, while military-industrial enterprises must contend with higher capital costs. To facilitate effective cooperation while maintaining quality, both types of enterprises should work towards minimizing input costs. By doing so, they can expedite the convergence of the evolutionary system towards the ideal state, thereby enhancing the likelihood of civilian and military enterprises forming cooperative innovation agreements. This approach not only reduces the expenses associated with independent R&D but also augments the overall collaborative benefits within the supply chain.

(2) In the context of vertical cooperation and innovation within the military-civilian integration supply chain, the issues of confidentiality and the unique characteristics of military technology, as well as the mutual adaptation of military-civilian technology, hold pivotal significance. The restrictive nature of innovation outcomes emerges as a critical factor influencing the successful transition of technologies into civilian applications, and it has the potential to significantly impact the willingness of civilian enterprises to engage in cooperative innovation efforts. Civilian enterprises play a crucial role in assimilating and adapting technologies from military-industrial enterprises for civilian purposes. However, it is essential to recognize that some military technologies are inherently confidential and non-standard. Therefore, their integration into civilian use must be carried out with a focus on technical safety and compliance with state regulations. The level of innovation results achieved through collaborative research and development by both parties, as well as the proportion of these results that can be successfully converted into civilian technology, plays a vital role in bolstering the likelihood of active cooperation and innovation between civilian enterprises and military-industrial enterprises.

(3) In the landscape of vertical cooperation and innovation within the civil-military integration supply chain, a notable disparity emerges concerning the supply and demand scales between civilian enterprises and military-industrial enterprises. This discrepancy plays a pivotal role in shaping the competitive dynamics of upstream civilian enterprises in the larger market competition within the supply chain. In addition to supply and demand scales, the pricing strategy in terms of offering discounts is another critical factor influencing the dynamics of cooperation and innovation between civilian and military-industrial enterprises. An appropriately structured discount mechanism can serve as a catalyst, stimulating the engagement of military-industrial enterprises in cooperative research and development efforts. However, it is important to strike a balance in setting the discount rates since overly generous discounts can have adverse consequences, potentially affecting the profitability and long-term sustainability of civilian enterprises. It is common practice for civilian enterprises to leverage competitive pricing strategies, including offering discounts, to secure more orders, enhance their market share, and bolster their influence in the marketplace. This approach can help establish a stronger foothold in the supply chain's competitive arena.

(4) Government supervision and the level of mutual trust between military and civilian enterprises represent critical factors that significantly impact vertical cooperation and innovation within the military-civilian integration supply chain. To ensure the success of these cooperative ventures, it is essential for the government to play a proactive role by bolstering its regulatory efforts and fostering a fair and competitive environment. The strength of government oversight directly influences the financial outcomes and risks for both civilian and military enterprises involved in the supply chain. In cases where robust regulatory measures are in place, both

parties stand to benefit, provided they engage in transparent and sincere cooperation, underpinned by comprehensive contractual agreements. This approach serves to encourage active cooperation and innovation between these enterprises. However, it is crucial for businesses, especially those within the supply chain, to exercise due diligence when considering collaborative relationships with their counterparts. Blindly entering into partnerships without conducting thorough background checks and assessing the reputation of prospective partners can lead to unfavourable outcomes. Such ill-informed decisions might stem from the pursuit of speculative gains but could ultimately cause a loss of willingness to actively participate in cooperative and innovative endeavours.

6.2. Theoretical Contributions. Building upon a comprehensive review and synthesis of prior research on civil-military integration supply chains, we have formulated a vertical cooperation and innovation model tailored to civil-military integration supply chains. This model is a departure from existing studies, which have primarily focused on areas such as technology spillover, government subsidies, and benefit distribution. By taking an industrial supply chain perspective, this paper delves into the impact of supply and demand dynamics, trust, and government regulatory measures on cooperation and innovation between upstream and downstream enterprises engaged in civil-military integration. Our research effectively bridges a critical gap in the realm of vertical cooperation and innovation within civil-military integration supply chains. Additionally, it lays a robust theoretical foundation for future in-depth investigations into the development of civil-military integration industrial supply chain clusters and the dynamics of digitalized civil-military integration supply chains.

6.3. Practical Implications

(1) The Chinese government should take proactive steps to advance the future integration of digital technology into the military-civilian supply chain. Leveraging digital technology and fostering green innovation hold the potential to significantly boost enterprise innovation performance [39], all while reducing the costs associated with military-civilian integration. This can be achieved through judicious resource allocation, the establishment of an efficient synergy mechanism, and the implementation of information-sharing platforms. The overarching objective here is to enhance the overall efficiency of the supply chain.

(2) Military enterprises, in particular, can play a pivotal role in driving down input costs. This can be accomplished through the promotion of technical standardization and normalization, elevating the entry requirements for civilian enterprise participation, and streamlining production costs for civilian entities, among other strategies. To further incentivize civilian enterprises to actively engage in the military-civilian fusion strategy, the Chinese government may consider introducing financial subsidies and tax incentives. This will not only enhance research and development efficiency but also reinforce the security of the national defence supply chain.

(3) Given that some technologies held by military-industrial enterprises are characterised by confidentiality and a lack of standardization, it is imperative for vertical cooperation and innovation within the civil-military integration supply chain to focus on their conversion into civilian technologies. This strategic shift facilitates technology transfer and application, resulting in increased economic benefits. The key to enhancing the conversion rate lies in technological innovation and collaborative approaches. To facilitate this transformation, the government can play a vital role. By establishing a dedicated technology conversion agency, it can support military-industrial enterprises in the process of converting military technologies into civilian applications, thereby boosting the technology conversion rate between the military and civilian sectors. Additionally, the government can provide incentives and supportive policies to encourage military technology enterprises to convert their innovations into civilian technologies.

(4) To foster collaboration between civilian enterprises and military-industrial enterprises in the realm of scientific and technological research and innovation, the Chinese government can take proactive measures. These measures may include the establishment of scientific research projects and training programs focused on major frontier technological fields. Furthermore, the government can extend support for the creation of a platform aimed at facilitating the exchange of military and civilian technological innovations, fostering the seamless flow of technology and cooperation among enterprises. In the process of cooperation and innovation, military-industrial enterprises and civilian counterparts can engage in technology sharing. This not only strengthens their technological research and development efforts but also amplifies the output rate of research and development initiatives. This approach promotes the transformation of technological achievements into practical productivity, elevates their technological capabilities and market competitiveness, and bolsters the overall efficiency and effectiveness of the entire supply chain.

(5) The Chinese government should intensify its support for civilian enterprises regarding their supply scale and work on enhancing their production capacity and supply capabilities to meet the requirements of the defence and military industries effectively.

Simultaneously, military-industrial enterprises should concentrate on strengthening their management and control within the supply chain to ensure that the scale of supply consistently aligns with the demands of the military-industrial supply chain. This approach reduces the risk of disruptions across the entirety of the military-industry supply chain. To maintain adaptability and efficiency, civilian enterprises should remain responsive to market demand, prepared to adjust their supply scales as necessary, establish flexible production plans, and deploy robust supply chain management systems. Achieving harmony between demand and supply not only helps to reduce inventory costs but also fortifies the resilience of the supply chain, ensuring that the needs of military-industrial enterprises are consistently met.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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