An Intelligent Analysis and Decision-Making System for Innovative Entrepreneurial Ecosystem Based on Evolutionary Game Modeling

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ABSTRACT

The entrepreneurial ecosystem concept pertains to the environment shaping business activities among a region's entrepreneurial enterprises, providing support elements such as market dynamics, talent pool, policies, infrastructure, and cultural factors. Despite its importance, comprehensive research on its internal structure and evolutionary dynamics remains scarce. Similarly, the strategies regarding governmental management of innovation and entrepreneurship ecosystems in planning, operation, and administration lack in-depth study. This paper addresses these gaps by applying the evolutionary game model for analysis and modeling of entrepreneurial ecosystems. The research constructs an entrepreneurial platform analysis and management decision-making system for governmental use. This system, based on the evolutionary game model, undergoes simulation experiments with the selected entrepreneurial ecosystem sample. Through empirical and comparative experiments, key findings on the development and evolution of entrepreneurial ecosystems are obtained. Policy recommendations for government-led entrepreneurial ecosystem management are also provided. The algorithm's efficacy is validated through verification, reinforcing the credibility of the research outcomes.

Keywords: Entrepreneurial ecosystem, Evolutionary game, Government management, Simulation experiment, Entrepreneurial platform, Policy analysis, Assisted decision-making

1. Introduction

The innovation and entrepreneurship ecosystem [1] refers to a dynamic network composed of various interconnected entities and elements, including entrepreneurs, investors, universities[2], research institutions[3], government agencies[4], and businesses. These entities collaboratively promote innovation activities and entrepreneurial spirit through resource sharing, knowledge transfer[5], and collaborative innovation[6]. The practical significance of this ecosystem lies in its ability to drive economic growth, facilitate technological advancement, and create employment opportunities[7]. By connecting diverse resources and opportunities, the innovation and entrepreneurship ecosystem can swiftly respond to market demands, fostering the development of new products and services, thereby enhancing overall societal competitiveness. Additionally, this ecosystem helps address global challenges, such as climate change[8] and social inequality[9], by promoting innovative solutions for sustainable development. From a research perspective, delving into the composition, operational mechanisms, and influencing factors of the innovation and entrepreneurship ecosystem is crucial for understanding the dynamics of modern economies. Research can reveal the interactions between different entities and how policy interventions can optimize the ecosystem environment to encourage more innovation and entrepreneurial activities[10]. Furthermore, through case studies and theoretical framework construction, it can provide important empirical evidence for the academic community and offer scientific decision support for policymakers [11], ultimately contributing to comprehensive social and economic development. Thus, the innovation and entrepreneurship ecosystem are not only a significant area of theoretical research but also a vital foundation for driving practical change[12]. A complete innovation and entrepreneurship ecosystem is shown in Figure 1.

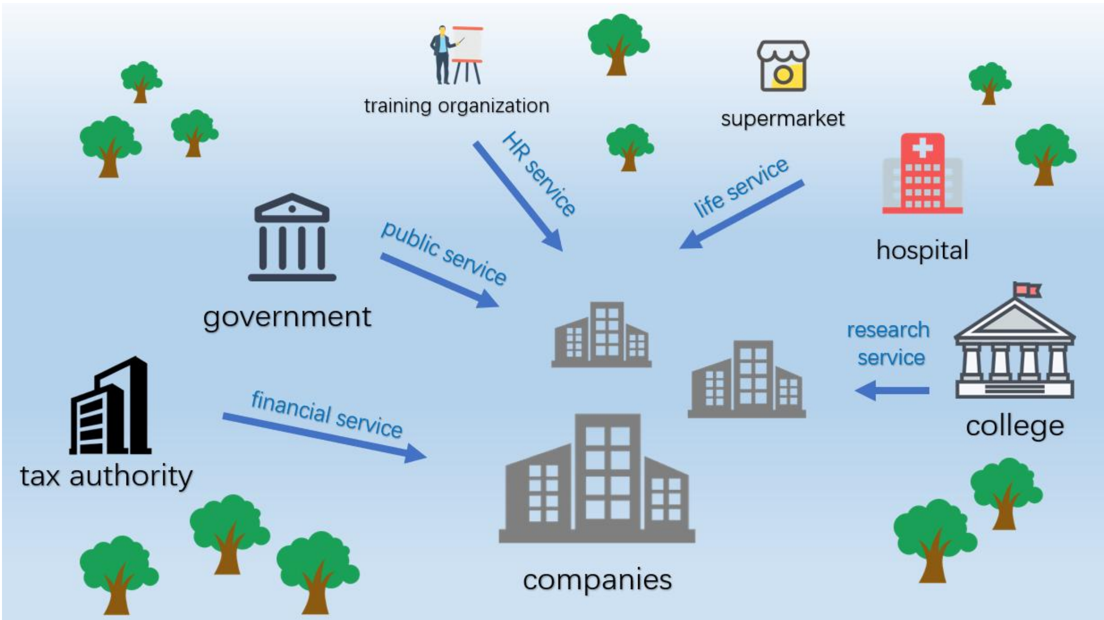

Figure 1. Schematic diagram of an innovation and entrepreneurship ecosystem.

The application of artificial intelligence (AI) technology in managing innovation and entrepreneurship ecosystems [13] holds significant research implications, primarily in enhancing decision-making efficiency [14], optimizing resource allocation [15], and facilitating information sharing [16]. By leveraging machine learning and data analytics, AI can identify market trends[17], analyze user needs [18], and predict the success probabilities of entrepreneurial projects [19], thereby providing entrepreneurs and investors with scientifically grounded decision support. This data-driven approach not only mitigates subjective biases but also improves the precision of management practices. Moreover, AI technologies, through intelligent recommendation systems [20], can connect entrepreneurs with suitable investors and partners, facilitating the efficient allocation of resources. Recent advancements in this field have seen researchers exploring the integration of AI with entrepreneurial ecosystem management [21]. For instance, deep learning algorithms are being employed to assess the market potential and technical feasibility of entrepreneurial initiatives[22], while natural language processing techniques [23] are used to analyze industry dynamics and provide real-time feedback to entrepreneurs. Additionally, AI-driven simulation tools are under development to assist managers in evaluating the impacts of various policies on the ecosystem [24]. The implementation of these technologies not only enhances the management efficiency of ecosystems but also fosters collaboration among different stakeholders. As AI technology continues to evolve, its potential in managing innovation and entrepreneurship ecosystems will expand, further driving economic growth and social progress. Therefore, in-depth research into AI applications in this domain is crucial for understanding and optimizing innovation and entrepreneurship ecosystems.

Currently, some of the deep learning algorithms commonly used in the startup ecosystem are as follows.

- Agent-Based Modeling (ABM) [25]: Agent-Based Modeling (ABM) entails simulating interactions among autonomous agents to comprehend their collective behavior. In entrepreneurial ecosystems, ABM can simulate diverse entities such as startups, investors, and support organizations. These agents mirror real-world entities, and their interactions emulate authentic scenarios. By integrating variables like funding, competition, and networking, ABM facilitates the analysis of successful venture emergence and policy impacts on the ecosystem's dynamics.
- System Dynamics (SD) [26]: System Dynamics (SD) focuses on comprehending feedback loops and interconnections within intricate systems. In entrepreneurship, SD models can depict factors like market demand, funding availability, and innovation diffusion. Through causal relationship analysis, SD discerns pivotal factors influencing ecosystem growth. It guides policymakers and entrepreneurs in making informed decisions to augment sustainability and innovation within the ecosystem.
- Innovation Diffusion Models [27]: Innovation Diffusion Models scrutinize the process of new idea or technology dissemination within a population. Within entrepreneurial ecosystems, these models dissect how innovations, such as novel business concepts or technologies, diffuse amid startups, investors, and consumers. By grasping adoption patterns, entrepreneurs can devise marketing strategies and outreach efforts, optimizing resource utilization and amplifying their innovations' impact.
- Game Theory Models [28]: Game Theory Models dissect strategic interactions among rational decision-makers. In entrepreneurship, they elucidate competitive scenarios among startups or negotiation processes between entrepreneurs and investors. Game theory equips entrepreneurs to anticipate competitors' moves and formulate strategic decisions for a competitive edge. Additionally, it aids investors in evaluating risks and rewards, refining investment strategies within the entrepreneurial ecosystem.

- Network Analysis Models [29]: Network Analysis Models delve into relationships and interactions among diverse entities within a system. In entrepreneurial ecosystems, network analysis delineates connections among startups, investors, accelerators, and other stakeholders. By mapping these relationships, entrepreneurs gain insights into potential collaborators, mentors, or investors. Analyzing the network structure identifies pivotal players and influential nodes, fostering strategic partnerships and resource mobilization for startups, thereby bolstering the entrepreneurial ecosystem's overall resilience.

Summarizing the current research on the application of the evolutionary game model, we believe that the advantages of applying the evolutionary game model to the analysis of entrepreneurial ecosystems and assisted decision-making include:

- The model's assumption about the limited rationality of human beings is more in line with the reality of human beings in entrepreneurial environments, and the passion brought about by entrepreneurship will limit the degree of rationality of entrepreneurial personnel to a certain extent;
- The evolutionary game model emphasizes a kind of systemic dynamic, equilibrium, this view is very close to the view held by the government in social governance, so it is very suitable for supporting the research on the government's management strategy for the entrepreneurial ecosystem;
- The evolutionary game model has strong predictive ability and explains the state change of the entrepreneurial ecosystem, so it is very suitable for helping the government to analyze and predict the trend of the entrepreneurial ecosystem's evolution.

This study applies the evolutionary game model for in-depth analysis and modeling of entrepreneurial ecosystems. Beginning with a thorough exploration of the fundamental principles and application studies of the evolutionary game model, the research proceeds to construct an entrepreneurial platform analysis and auxiliary management decision-making system tailored for governmental use. This system, rooted in the evolutionary game-based entrepreneurial ecosystem model, undergoes exhaustive simulation experiments. Through empirical examination and comparative experiments, pivotal research findings on the developmental patterns and evolution of entrepreneurial ecosystems are obtained. Additionally, policy recommendations for government-led entrepreneurial ecosystem management are formulated.

Based on the literature research and the three considerations about evolutionary games, the main three contributions of this study are:

- Based on the investigation of the fundamentals and applied research of evolutionary game models, we try to apply evolutionary game models to the analysis and modeling of entrepreneurial ecosystems.
- Using the entrepreneurial ecosystem model based on evolutionary game, an entrepreneurial platform analysis and auxiliary management and decision-making system serving the government was constructed.
- Exhaustive simulation experiments were conducted to analyze and compare in detail the

performance of algorithms for modeling entrepreneurial ecosystems using the evolutionary game model.

The structure of this paper is described below. First, the paper details the current academic work on entrepreneurial ecosystems and evolutionary game models and categorizes and summarizes these works. Second, this paper details the methodology of entrepreneurial ecosystem evolution prediction based on the evolutionary game approach. Third, this paper designs a comparative experiment to compare the analytical prediction performance of the evolutionary game algorithm proposed in this paper with 10 baseline models selected from the literature. Finally, based on the results of the experimental analysis, this paper gives some suggestions for the government to manage the entrepreneurial ecosystem. The structure of this paper is shown in Figure 2.

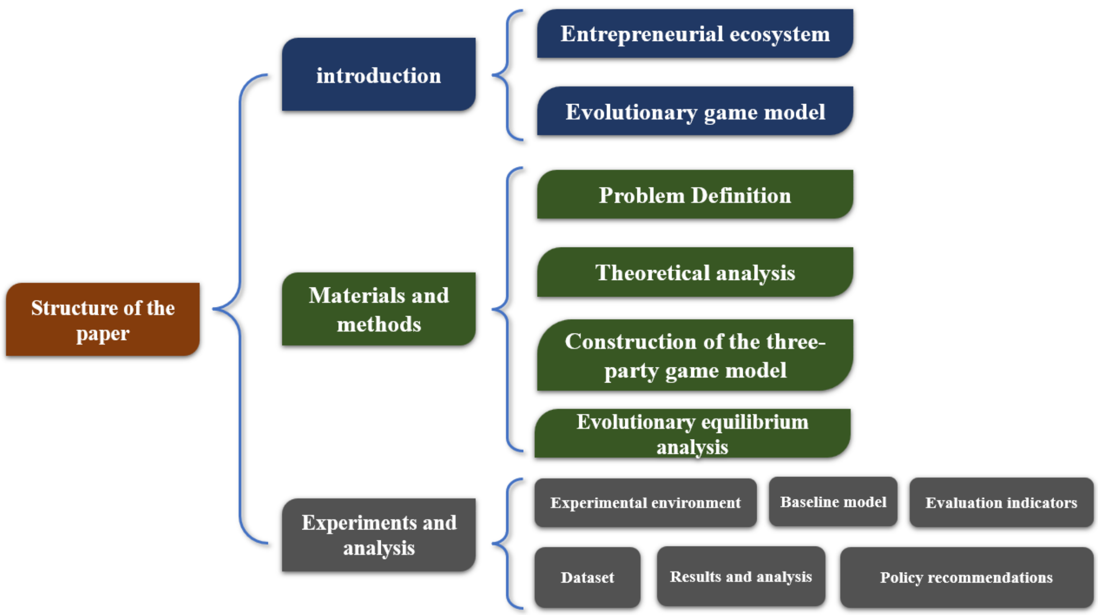

Figure 2. Structure of the paper.

2. Related Work

2.1 Entrepreneurial Ecosystem

At present, the research related to entrepreneurial ecosystem involves many aspects, and the types of research include theoretical research, policy research, model construction, case study and so on. In terms of theoretical analysis, Wei Jiang et al. firstly clarified the concept and connotation, typical characteristics and basic configuration of platform enterprise-led entrepreneurial ecosystems based on content analysis and practical insights, and secondly sorted out three major schools of platform enterprise-led entrepreneurial ecosystems based on the bibliometric analysis: entrepreneurship, strategic management and business model schools, and sorted out the research problems, contents and core viewpoints of each school. The research problems, contents and core viewpoints of each school are sorted out. Finally, the future research direction of platform enterprise-led entrepreneurial ecosystems is proposed from four aspects: power system, enabling mechanism, synergy and evolution, and governance mechanism. In terms of policy research, Sha Dechun et al. [30] extract the theoretical concept of policy-driven entrepreneurial ecosystem based on the thinking of policy-driven entrepreneurial practice. Tian Jing [31] who constructs an ecosystem model of innovation and entrepreneurship education in colleges and universities based on vocational education based on the ecological niche theory. Zhang Yanping et al [32] who used longitudinal case study method to study the whole process of building entrepreneurial ecosystem of Guangzhou Daan Chuanggu Incubator under the professional support of the parent company and explored the process of realizing the entrepreneurial ecosystem led by the professional incubator and the realization mechanism of the problem. Tabas et al [33] designed a qualitative case study of the regional ecosystem built around health technology is researched to get an in-depth understanding of the orchestration roles taken by actors in the ecosystem. Table 1 lists some of the current research work on entrepreneurial ecosystems from various aspects.

Table 1. Classification of current research on entrepreneurial ecosystems

Research theme	Literature	
Ecosystems	Theodoraki etc. [34]	Abootorabi etc. [35]
Innovation and Entrepreneurship	Marinelli etc.[36]	Barbulescu etc. [37]
Entrepreneurship Education and Training	Motoyama etc. [38]	Zhang etc. [39]
Model Building	Tao etc. [40]	Ajah etc. [41]
Incubator	Roundy etc. [42]	Boulmakoul etc. [43]
Case Studies	Zhao etc. [44]	Muhammad etc. [45]
Theory Research	Roundy etc. [46]	Duan etc. [47]
Government Policy	Roundy etc. [42]	Muhammad etc. [45]

Table 1 presents the progress of research on various aspects of the entrepreneurial ecosystem from the perspectives of Ecosystems, Innovation and Entrepreneurship, Entrepreneurship Education and Training, Model Building, Incubator, Case Studies, Theory Research, and Government Policy, 8 perspectives, each citing two pieces of literature on the current progress of research on various aspects of entrepreneurial ecosystems.

Recent research on entrepreneurial ecosystems has highlighted the importance of social networks[48] and community engagement in driving innovation and business success. Scholars are increasingly examining the impact of digital technologies[49], which facilitate collaboration and market access. Sustainability is also emerging as a focal point [48], with studies exploring how eco-entrepreneurship can be integrated into these ecosystems. Furthermore, the role of government policies in fostering supportive environments is gaining attention[50]. Lastly, the use of data analytics and artificial intelligence is providing new insights into ecosystem dynamics, enhancing decision-making for effective ecosystem management and development.[51]

An overview of domestic and international research on entrepreneurial ecosystems reveals three shortcomings: firstly, domestic research on the internal structure and evolution of innovation and entrepreneurship ecosystems is insufficient; secondly, there is limited research on government management strategies for these ecosystems in planning, functioning, and management; and thirdly, most current research focuses on empirical analysis and lacks the use of advanced technologies, such as information systems, for practical results.

2.2 Evolutionary Game Model

Evolutionary game theory (EGT) [45] is a theory based on biological evolution theory and genetic theory [52], and traditional game theory [53] as a carrier, to seek for the optimal equilibrium strategy of each game party in the dynamic development process. Different from traditional game theory, evolutionary game theory studies the strategy selection behavior of limited rational individuals under the state of incomplete information. The parties to the game are not able to choose the optimal strategy to satisfy their interests at the beginning but are in a dynamic process that needs to be constantly adjusted. Figure 3 shows the schematic diagram of the evolutionary game model.

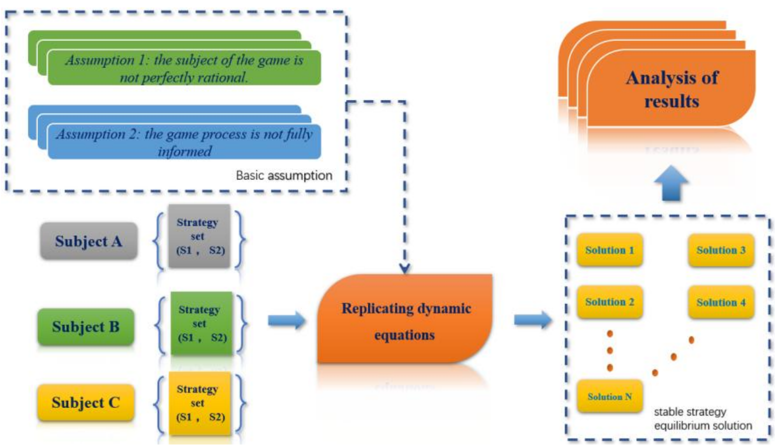

Figure 3. Schematic diagram of evolutionary game mode

Currently, the applied research of evolutionary game includes Li Jichen et al [54] by constructing an evolutionary game model of the entrepreneurial investment strategy behavior of the government, VC, and entrepreneurial enterprises of the three subjects. Zheng Chuanbin et al. [55] explored the behavioral strategies of public and private sector performance improvement and their influencing factors. Peng Zhengyin et al. [56] based on the dual embeddedness of the resident merchants and consumers, the interaction of participants' behaviors and the assumption of finite rationality, constructed an embedded risk evolution game model including "online platform-resident merchants-consumers", and analyzed the asymptotic stability of the equilibrium and the system's evolutionary stability by using the evolutionary game theory and the Lyapunov’s discriminant method. Table 2 lists some current studies on the application of evolutionary game models.

Table 2. Summary of studies on the application of evolutionary game models

Areas of application	literatures
Government	EGT is widely used in government administration, such as literatures [57], [58]
Business	EGT is widely applied in business, such as literatures [59], [58]
Environment	EGT is widely used in environmental protection, such as literatures [60], [61]
Healthcare	EGT is widely used in healthcare, such as literatures [62], [63]
Management	EGT is widely used in management, such as literatures [64], [65]

Recent advancements in evolutionary game models have expanded their application across various fields, including economics[66], biology[67], and social sciences[68]. Researchers are increasingly using these models to analyze complex interactions among agents, particularly in contexts like cooperation, competition[66], and resource sharing. Innovations in computational methods, such as agent-based modeling[69], have enabled more detailed simulations of dynamic environments. Additionally, interdisciplinary approaches are being explored, integrating insights from network theory and behavioral economics[70]. Recent studies are also investigating how external factors, such as policy changes [71] and environmental shifts[72], influence strategy evolution, providing deeper insights into adaptive behaviors in diverse systems.

This study employs evolutionary game theory as the core algorithm for managing innovation and entrepreneurship ecosystems because it effectively simulates interactions and competition among individuals. This framework helps understand cooperative and competitive behaviors within complex systems, making it suitable for multi-agent environments. In innovation ecosystems, decisions are influenced not only by self-interests but also by other stakeholders' actions. Evolutionary game theory reveals how individuals can optimize their strategies through adaptation in a changing environment, enhancing the system's overall innovation capacity. It also aids in designing cooperation mechanisms, such as incentive structures for resource and knowledge sharing, crucial for establishing collaborative networks and increasing ecosystem resilience. By simulating evolutionary processes, managers can predict system responses to policies and environmental changes, enabling targeted management strategies. Thus, evolutionary game theory serves as a powerful tool for understanding and optimizing innovation ecosystems.

2.3 Smart Entrepreneurial Ecosystem Management Based on EGM

Currently, research of smart entrepreneurial ecosystem management by using EGM includes Zhou Yuhong et al. [73] constructed a tripartite evolutionary game model of startups, venture capital institutions and the government, and used Matlab numerical simulation to study how the government's bootstrap fund can achieve the policy objectives by setting up different operation modes and utilizing market-oriented operation. Based on the perspective of evolutionary game, Lin Linna et al [74] establish a game model between project organization and government accident investigation team, compare the optimization strategies of accident investigation mechanism under the role of each constraint mechanism, and further analyze the constraint strategies through Matlab simulation.

Evolutionary game models offer several advantages in the realm of entrepreneurial ecosystem management. Firstly, these models adeptly simulate the intricate interrelationships within entrepreneurial ecosystems, encompassing diverse behaviors such as competition, collaboration, and resource allocation among enterprises. Secondly, they incorporate the adaptive nature of participants, mirroring their strategies' evolution amidst dynamic environmental shifts, aligning closely with the real-time dynamics of entrepreneurial ecosystems. Thirdly, evolutionary game models enable a comprehensive evaluation of various strategies, providing invaluable assistance to both enterprises and governmental decision-makers in optimizing entrepreneurial policies and strategies, thereby enhancing the overall system efficiency. Lastly, these models facilitate an insightful exploration of the developmental trends within entrepreneurial ecosystems through simulation and analysis, serving as a valuable reference for future decision-making processes.

However, despite their merits, evolutionary game models in entrepreneurial ecosystem management encounter several limitations. Firstly, these models heavily rely on substantial data for accurate simulation and analysis. Insufficient or inaccurate data could compromise the accuracy of the models. Secondly, the complexity of entrepreneurial ecosystems, with numerous participants and uncertain factors, poses a challenge. Simplifying the model to match real-world situations might lead to the loss of crucial details, impacting precision. Thirdly, the computational demands of intricate models, including time and memory resources, could be substantial, posing limitations in practical applications. Lastly, the predetermined selection of strategies by participants within the model might not fully mirror real decision-making, where multiple factors influence choices, presenting a gap between model representation and real-world scenarios.

3. Research Design

3.1. Overview of Our Work

In the entrepreneurial ecosystem within the entrepreneurial platform, the relevant governmental supervisory department, as the main supervisory body of the operation of the entrepreneurial platform, needs to carry out real-time supervision of the operation status of the platform. The entrepreneurs have the responsibility to effectively supervise whether the operation and management of the entrepreneurial platform fulfills the relevant management and service duties and provide timely feedback to the government. The operation and management of the entrepreneurial platform bears the responsibility of ensuring the innovation level of entrepreneurs and the working environment of enterprises. The relationship between the government, the operation and management organization and the entrepreneurs are shown in Figure 4.

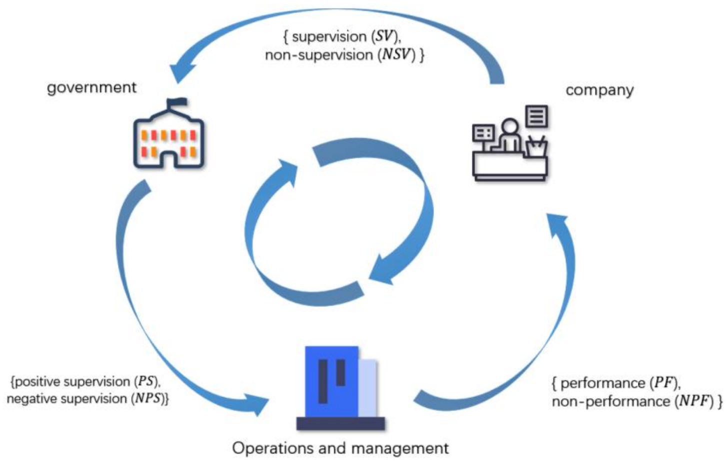

Figure 4. elationship between government, operation and management organization, and enterprises

This chapter focuses on the role of government policies in the entrepreneurial ecosystem, and on the basis of theoretical analysis, constructs a three-party game model between the government, the operation and management of the entrepreneurial ecosystem and entrepreneurs, and analyzes the interactions among the three in the process of the entrepreneurial ecosystem and its operation mechanism, so as to better play the roles and functions of the main bodies, and to help the government to change the operation and management of the entrepreneurial ecosystem and the entrepreneurs' passivity to stay in work.

3.2. Problem Definition

Problem definition: Considering that the main players of the game are the local government G, the operation and management of the entrepreneurial ecosystem A, and the entrepreneurial group B, the three parties of the game have different abilities in terms of rationality consciousness, identification judgment, analytical reasoning, etc., and they are not completely rational. In the process of the game, the three parties need to continuously learn and adjust their strategy choices until they reach the equilibrium state. Among them, the set of strategic choices of operation and management party A is {performance (PF), non-performance (NPF)}, the set of strategic choices of entrepreneurial personnel group B is {supervision (SV), non-supervision (NSV)}, and the set of strategic choices of the government G is {positive supervision (PS), negative supervision (NPS)}, and the three parties constantly acquire external information in the process of the game to change their own strategic choices and the main body of the game is a risk-averse type when facing the benefits, and a risk-preferring type when facing the losses. In the face of loss is the type of risk preference. The system is constantly changing in the process of dynamic evolution in order to maximize its own interests and will eventually be in a stable state. The following hypothesizes are made about the decision-making process:

Hypothesis 1: The probability that the government department G chooses the strategy of PS is i, which satisfies $0 \leq i \leq 1$, and the probability that it chooses the strategy of NPS is $1-i$; the probability that the operation management G chooses the strategy of PF is j, which satisfies $0 \leq j \leq 1$, and the probability that it chooses the strategy of NPF is $1-j$; the probability that the entrepreneurship and innovation group B chooses the strategy of SV is k, which satisfies $0 \leq k \leq 1$, and the probability that it chooses the strategy of NSV is $1-k$, and i, j, k are all functions of time t.

Hypothesis 2: For government departments G, the cost of choosing the strategy of PS is C_g, and the benefit of positive regulation is R_g, while the cost of choosing the strategy of NPS is $C_g{}'$, and the benefit is $R_g{}'$. At this time, if the entrepreneurial community B discovers that the entrepreneurial platform is not performing its duties, the loss of the government's credibility and the punishment of the relevant departments will be F_g. If the government actively regulates, such incidents can be avoided.

Hypothesis 3: For the operations manager A, the expected return of the entrepreneurial ecosystem when operating normally is denoted as R_m, the cost to the operations manager A when choosing a strategy of PF is C_m, and the cost to the operations manager A when choosing a strategy of NPF is $C_m{}'$, at which point the expected value of being penalized by the government G is F_m.

Hypothesis 4: For the entrepreneurial and innovative group B, the cost when choose the strategy of SV is denoted as C_p, at which time the expectation of the incentives given by the government G is R_p. When the entrepreneurial group B chooses the strategy of NSV, the social loss caused by the non-performance of the operation management A is denoted as F_p.

3.3. Construction of Three-Party Game Model

According to the four assumptions, the parameter symbol table of algorithm derivation (Table 3) and the benefit perception matrix of the three parties of the game (Table 4) are given. The construction principle of three-party game model is shown in figure 5.

Table 3. Parameter symbol table

symbolic	symbolic meaning
C_g	Costs when the government G choose the

	strategy of PS
R_g	Benefits received when the government G choose the strategy of PS
C_g'	Costs when the government G choose the strategy of NPS
R_g'	Benefits received when the government G choose the strategy of NPS
F_g	Penalties for government G when entrepreneurial groups B report on the strategy chosen of the operation and management A.
R_m	Expected benefits when the ecosystem is operating normally
C_m	Costs of operation and management A's strategy chosen of PF
C_m'	Costs of operation and management A's strategy chosen of NPF
F_m	Expected value of penalties from the government G when the operation and management A chose the strategy of NPF
C_p	Costs to the entrepreneurial community B for chose the strategy of SV
R_p	Expectation of government G rewards when the entrepreneurial community B choose the strategy of SV
F_p	Social damage caused by operation management A's strategy of NPF when the entrepreneurial community B chose the strategy of NSV

Table 4. Perceived benefit matrix of the three parties of the game

		Government G	
Operations and management A	Entrepreneurial community B	PS	NPS
PF	SV	$R_g - C_g - \nu(R_p)$ $\nu(R_m) - C_m$ $\nu(R_p) - C_p$	$R_g' - C_g'$ $\nu(R_m) - C_m$ $-C_p$
	NSV	$R_g - C_g$ $\nu(R_m) - C_m$ 0	$R_g' - C_g'$ $\nu(R_m) - C_m$ 0

NPF	SV	$R_g - C_g - \nu(R_p) + \nu(F_m)$ $\nu(R_m) - C'_m + \nu(-F_m)$ $\nu(R_p) - C_p - F_p$	$R'_g - C'_g - F_g$ $\nu(R_m) - C'_m - \nu(-F_m)$ $-C_p - F_p$
	NSV	$R_g - C_g + \nu(F_m)$ $\nu(R_m) - C'_m - \nu(-F_m)$ $-F_p$	$R'_g - C'_g$ $\nu(R_m) - C'_m$ $-F_p$

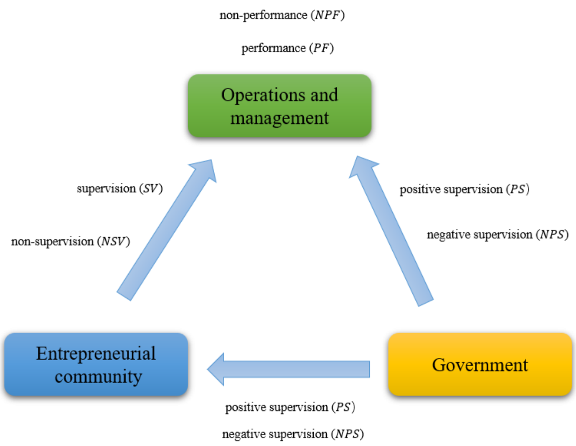

Figure 5. The construction principle of three-party game model

3.4. Analysis of the Evolutionary Equilibrium of Each Game Subject

According to the benefit perception matrix of the three parties of the game among the G, A and B, it can be concluded that the expected benefit for the government G to choose the PS strategy as in (1).

$$E_i = jk[R_g - C_g - \nu(R_p)] + j(1-k)(R_g - C_g) + (1-j)k[R_g - C_g - \nu(R_p) + \nu(F_m)] + (1-j)(1-k)[R_g - C_g + \nu(F_m)] \quad \cdots\cdots\cdots\cdots \text{[Formular 1]}$$

The expected return to the government G's choice of a NPS strategy as in (2).

$$E_{1-i} = jk(R'_g - C'_g) + j(1-k)(R'_g - C'_g) + (1-j)k(R'_g - C'_g - F_g) + (1-j)(1-k)(R'_g - C'_g) \quad \cdots\cdots\cdots\cdots \text{[Formular 2]}$$

The average expected return to the government G is $\overline{E_g} = iE_i + (1-i)E_{1-i}$.

The equation for the government G's replication dynamics can be derived as in (3).

$$F(i)\& = \frac{di}{dt} = i(E_i - \overline{E_g}) = i(i-1)\{j \cdot [k \cdot F_g + \nu(F_m)] + k \cdot [\nu(R_p) - F_g] + C_g - C'_g - \nu(F_m) - R_g + R'_g\} \quad \cdots\cdots\cdots\cdots \text{[Formular 3]}$$

The expected benefits of the operations and manager A's strategy choice of PF in a dynamic evolutionary process as in (4).

$$E_j = ki[\nu(R_m) - C_m] + k(1-i)[\nu(R_m) - C_m] + (1-k)i[\nu(R_m) - C_m] + (1-k)(1-i)[\nu(R_m) - C_m] \quad \cdots\cdots\cdots\cdots \text{[Formular 4]}$$

The expected benefit of the strategy choice by the operation and manager A as in (5).

$$E_{1-j} = ki[v(R_m) - C'_m + v(-F_m)] + k(1-i)[v(R_m) - C'_m + v(-F_m)] + (1-k)i[v(R_m) - C'_m + v(-F_m)] + (1-k)(1-i)[v(R_m) - C'_m] \text{[Formular 5]}$$

The average expected return for the operations manager A is $\overline{E_m} = jE_j + (1-j)E_{1-j}$.

The replication dynamic equation for the operations manager A can be derived as in (6).

$$F(j)\& = \frac{dj}{dt} = j(E_j - \overline{E_m}) = j(1-j)\{i \cdot [k \cdot v(-F_m) - v(-F_m)] - k \cdot v(-F_m) + C'_m - C_m\} \cdots\cdots \text{[Formular 6]}$$

The expected benefit of the entrepreneurial group B when choosing the strategy of SV as in (7).

$$E_k\& = ij[v(R_p) - C_p] + (1-i)j(-C_p) + i(1-j)\left[v\left(R_p\right) - C_p - F_p\right] + (1-i)(1-j)(-C_p - F_p) \cdots\cdots \text{[Formular 7]}$$

The average expected return for the entrepreneurial group B is $\overline{E_p} = kE_k + (1-k)E_{1-k}$.

The equation for the replication dynamics of the entrepreneurial group B can be derived as in (8).

$$F(k) = \frac{dk}{dt} = k\left(E_k - \overline{E_p}\right) = k(1-k)[i \cdot v(R_p) - C_p] \cdot\cdot \text{[Formular 8]}$$

Then the replication dynamic equations of each game subject of the government G, operation management A, and entrepreneurship groups B are analyzed as follows.

The derivation of equation for the government G's replication dynamics as in (9).

$$F'(i) = (2i-1)\{j \cdot [k \cdot F_g + v(F_m)] + k \cdot \left[v\left(R_p\right) - F_g\right] + C_g - C'_g - v(F_m) - R_g + R'\} \cdots\cdots \text{[Formular 9]}$$

When $j = \frac{C'_g - C_g + v(F_m) + R_g - k \cdot [v(R_p) - F'_g] - R'_g}{k \cdot F_g + v(F_m)}$, $F(i) \equiv 0$, at this point all i are in a steady state.

When $j \neq \frac{C'_g - C_g + v(F_m) + R_g - k \cdot [v(R_p) - F_g]}{k \cdot F_g + v(F_m)}$, let $F(i) = 0$, it is known that $i = 0, i = 1$ are two stabilization points.

When $j > \frac{C'_g - C_g + v(F_m) + R_g - k \cdot [v(R_p) - F_g] + R'_g}{k \cdot F_g + v(F_m)}$, $F(i) > 0, F'(i)|_{i=1} < 0, F'(i)|_{i=0} > 0$, At this point $i = 1$ is a stabilization strategy, where the government G chooses the strategy of PS to the operations manager A.

When $j < \frac{C'_g - C_g + v(F_m) + R_g - k \cdot [v(R_p) - F_g] + R'_g}{k \cdot F_g + v(F_m)}$, $F(i) < 0, F'(i)|_{i=1} > 0, F'(i)|_{i=0} < 0$, At this point, $i = 0$ is the stabilization strategy, where the government G chooses the strategy of NPS to the operations manager A.

For the operation and management A, the derivation of its replication dynamic equation as in (10).

$$F'(j) = (1-2j)j(1-j)\{i \cdot [k \cdot v(-F_m) - v(-F_m)] - k \cdot v(-F_m) + C'_m -$$

$C_m\}$ ·· [Formular 10]

When $i = \frac{C_m - C'_m + k\cdot\nu(-F_m)}{\nu(-F_m) - k\cdot\nu(-F_m)}$, $F(j) \equiv 0$, at this point all j's are in a stable state.

When $i \neq \frac{C_m - C'_m + k\cdot\nu(-F_m)}{\nu(-F_m) - k\cdot\nu(-F_m)}$, let $F(j) = 0$, it is known that $j = 0$, $j = 1$ are two stabilization points.

When $i > \frac{C_m - C'_m + k\cdot\nu(F_m)}{\nu(F_m) - k\cdot\nu(F_m)}$, $F(j) > 0, F'(j)|_{j=1} < 0, F'(j)|_{j=0} > 0$, at this point $j = 1$ is the stabilization strategy, the operations manager A will choose the strategy of PF.

When $i < \frac{C_m - C'_m + k\cdot\nu(-F_m)}{\nu(-F_m) - k\cdot\nu(-F_m)}$, $F(j) < 0, F'(j)|_{j=1} > 0, F'(j)|_{j=0} < 0$, at this point $j = 0$ is the stabilization strategy, the operations manager A will choose the NPF strategy.

For the entrepreneurial group B, the derivation of its equation for the replication dynamics as in (11).

$$F'(k) = (1 - 2k)[i \cdot \nu(R_p) - C_p] \quad \text{[Formular 11]}$$

When $i = \frac{C_p}{\nu(R_p)}$, $F(k) = 0$, at this point, all k is in a steady state.

When $i \neq \frac{C_p}{\nu(R_p)}$, let $F(k) \equiv 0$, it is known that $k = 0, k = 1$ are two stabilization points.

When $i > \frac{C_p}{\nu(R_p)}$, $F(k) > 0, F'(k)|_{k=1} < 0, F'(k)|_{k=0} > 0$, at this point $k = 1$ is the stabilization strategy, where the entrepreneurial group B chooses the strategy of SV.

When $i < \frac{C_p}{\nu(R_p)}$, $F(k) < 0, F'(k)|_{k=1} > 0, F'(k)|_{k=0} < 0$, at this point $k = 0$ is the stabilization strategy and the entrepreneurial group B chooses the strategy of NSV.

3.5 Evolutionary Equilibrium Analysis of Entrepreneurial Ecosystems

The three subjects constitute a three-dimensional dynamical system of an entrepreneurial ecosystem with the following replicated dynamic equations as in (12).

$$\begin{cases} F(i) = i(i-1)\{j \cdot [k \cdot F_g + \nu(F_m)] + k \cdot [\nu(R_p) - F_g] + C_g - C'_g - \nu(F_m) - R'_g + R'_g\} \\ F(j) = j(1-j)i \cdot [k \cdot \nu(-F_m) - \nu(-F_m)] - k \cdot \nu(-F_m) + C'_m - C_m\} \\ F(k) = k(1-k)[i \cdot \nu(R_p) - C_p] \end{cases} \quad \text{[Formular 12]}$$

Let $\frac{di}{dt} = 0, \frac{dj}{dt} = 0, \frac{dk}{dt} = 0$, The Nash equilibrium solution can be obtained for the 8 pure strategies of the system(0,0,0), (0,0,1), (0,1,0), (1,0,0), (1,0,1), (1,1,0), (0,1,1), (1,1,1).

The subject of the game is in a state of choosing a particular strategy, and if there is no mutating factor that can change its strategy, the subject of the game will remain in the state of that strategy.

There is also a Nash equilibrium with mixed strategies as in (13).

$$\begin{cases} j \cdot [k \cdot F_g + \nu(F_m)] + k \cdot [\nu(R_p) - F_g] + C_g - C'_g - \nu(F_m) - R_g + R'_g = 0 \\ i \cdot [k \cdot \nu(-F_m) - \nu(-F_m)] - k \cdot \nu(-F_m) + C'_m - C_m = 0 \\ i \cdot \nu(R_p) - C_p = 0 \end{cases} \cdots \text{[Formular 13]}$$

When not all of the parameters affecting the choice of strategies of the three parties to the game are zero, there exists a unique solution to the equation (i^*, j^*, k^*), and $0 \le i^* \le 1, 0 \le j^* \le 1, 0 \le k^* \le 1$, at this point $F(i) \equiv 0, F(j) \equiv 0, F(k) \equiv 0$.

Next, determine the stability of the system. The corresponding Jacobi matrix of the system is shown in equation as in (14).

$$J = \begin{bmatrix} \frac{\partial F(i)}{i} & \frac{\partial F(i)}{j} & \frac{\partial F(i)}{k} \\ \frac{\partial F(j)}{i} & \frac{\partial F(j)}{j} & \frac{\partial F(j)}{k} \\ \frac{\partial F(k)}{i} & \frac{\partial F(k)}{j} & \frac{\partial F(k)}{k} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \cdots \text{[Formular 14]}$$

Among them,

$$a_{11} = (2i - 1)\{j \cdot [k \cdot F_g + \nu(F_m)] + k \cdot [\nu(R_p) - F_g] + C_g - C'_g - \nu(F_m) - R_g + R'_g\} \cdots \text{[Formular 15]}$$

$$a_{12} = i(i-1)[k \cdot F_g + \nu(F_m)] \cdots \text{[Formular 16]}$$

$$a_{13} = i(i-1)[j \cdot F_g + \nu(R_p) - F_g] \cdots \text{[Formular 17]}$$

$$a_{21} = j(1-j)[\nu(-F_m) \cdot k - \nu(-F_m)] \cdots \text{[Formular 18]}$$

$$a_{22} = (1-2j)\{i \cdot [k \cdot \nu(-F_m) - \nu(-F_m)] - k \cdot \nu(-F_m) + C'_m - C_m\} \cdots \text{[Formular 19]}$$

$$a_{23} = j \cdot (1-j)(i-1) \cdot \nu(-F_m) \cdots \text{[Formular 20]}$$

$$a_{31} = k(1-k) \cdot \nu(R_P) \cdots \text{[Formular 21]}$$

$$a_{32} = 0 \cdots \text{[Formular 22]}$$

$$a_{33} = (1-2k)[i \cdot \nu(R_p) - C_p \cdots \text{[Formular 23]}$$

Table 5. Equilibrium points of the system and their eigenvalue.

balance point	λ_1	λ_2	λ_3
(0,0,0)	$-C_g + C'_g + \nu(F_m) + R'_g - R'_g$	$C'_m - C_m$	$-C_p$
(0,0,1)	$F_g - \nu(R_p) - C_g + C'_g + \nu(F_m) + -C_g + C'_g + R_g - R'_g$	$C'_m - C_m - \nu(-F_m)$	C_p
(0,1,0)	$-C_g + C'_g + R'_g - R'_g$	$C_m - C'_m$	$-C_p$
(1,0,0)	$C_g - C'_g - \nu(F_m) - R_g + R'_g$	$C'_m - C_m - \nu(-F_m)$	$\nu(R_p) - C_p$
(1,0,1)	$\nu(R_p) - F_g + C_g - C'_g - \nu(F_m) - R_g + R'_g$	$C'_m - C_m - \nu(-F_m)$	$C_p - \nu(R_p)$
(0,1,1)	$-\nu(R_p) - C_g + C'_g + R_g - R'_g$	$\nu(-F_m) - C'_m + C_m$	C_p

(1,1,0)	$C_g - C'_g - R_g + R'_g$	$\nu(-F_m) - C'_m + C_m$	$\nu(R_p) - C_p$
(1,1,1)	$\nu(R_p) + C_g - C'_g - R_g + R'_g$	$\nu(-F_m) - C'_m + C_m$	$C_p - \nu(R_p)$
(i^*, j^*, k^*)	0	0	0

The stability conditions of each equilibrium are further analyzed, and the results are shown in Table 6.

Table 6. Local Stability Conditions for Equilibrium Points

balance point	Stability conditions	local stability
(0,0,0)	$\nu(F_m) + R_g - C_g < R'_g - C'_g, C'_m < C_m, C_p > 0$	ESS
(0,0,1)	$\nu(F_m) + R_g - C_g - \nu(R_p) < R'_g - C'_g - F_g, C'_m - \nu(-F_m) < C_m, C_p < 0$	Unstable point
(0,1,0)	$R_g - C_g < R'_g - C'_g, C_m < C'_m, C_p > 0$	ESS
(1,0,0)	$R'_g - C'_g < \nu(F_m) + R_g - C_g, C'_m - \nu(-F_m) < C_m, \nu(R_p) < C_p$	ESS
(1,0,1)	$R'_g - C'_g < \nu(F_m) + R_g - C_g - \nu(R_p), C'_m - \nu(-F_m) < C_m, C_p < \nu(R_p)$	ESS
(0,1,1)	$R_g - C_g - \nu(R_p) < R'_g - C'_g, C_m < C'_m - \nu(-F_m), C_p < 0$	Unstable point
(1,1,0)	$R'_g - C'_g < R'_g - C'_g, C_m < C'_m - \nu(-F_m), \nu(R_p) < C_p$	ESS
(1,1,1)	$R'_g - C'_g < R_g - \nu(R_p) - C_g, C_m < C'_m - \nu(-F_m), C_p < \nu(R_p)$	ESS

4. Results and Discussion

4.1 Experimental Environment and Details

The simulation experiment in this paper is mainly realized by using Python language and Matlab software. The hardware and software in the experimental environment are shown in Table 7.

Table 7. Experimental environment.

hardware		software	
Computer	Lenovo	development language	Python
CPU	intel core i5-13400	operating system	window 11
RAM	32G	data analysis	Matlab
hard disk	1T	plot	Excel

The sample for this experiment is a large-scale entrepreneurial platform in Chaoyang District, Beijing. Established in 2008, by the end of 2023, this platform has developed several office-sharing ecosystems in Beijing, including one large-scale platform, three medium-sized platforms, five small platforms, and one micro platform. One of the selected large-scale platforms spans over 10,000 square meters, housing more than 300 innovative startups, with over 5,500 active entrepreneurs currently engaged in the ecosystem. This entrepreneurial ecosystem follows the SOHO model, offering a range of diversified services to the entrepreneurial community, including comprehensive counseling, operational support, investment opportunities, collaboration matchmaking, and optional value-added services.

And according to the actual situation of the sample entrepreneurial platform, the setting of relevant parameters is shown in Table 8.

Table 8. Parameter settings.

Parameter	Parameter Value					
Name	Setting 1	Setting 2	Setting 3	Setting 4	Setting 5	Setting 6
C_g	25	22	8	8	8	8
C_g'	9	9	9	9	13	13
C_m	15	12	20	20	7	5
C_m'	5	19	11	11	17	12
C_p	10	8	19	7	12	2
F_g	9	9	9	9	9	9
F_m	10	15	15	15	15	15
R_g	12	12	12	12	16	21
R_g'	18	18	10	15	18	18
R_p	12	15	15	15	9	9

4.2 Comparative Experimental with Different Parameter Settings

Running the simulation program with parameter setting 1~6 in Table 8, you can get the running results as in Figure. 6~11.

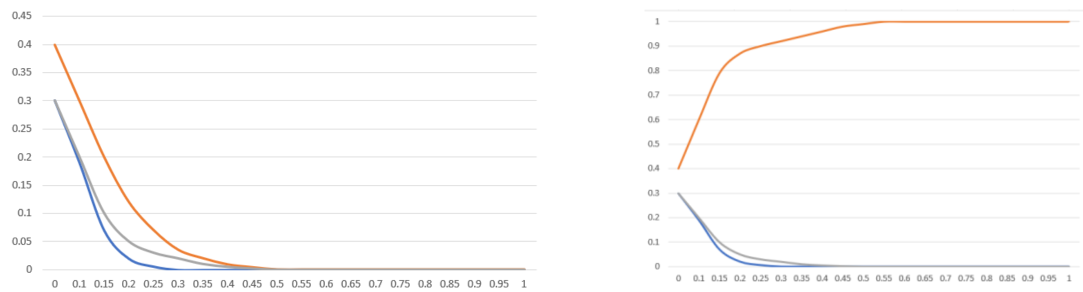

Figure 6-7. Schematic diagram of the evolution process No.1-2

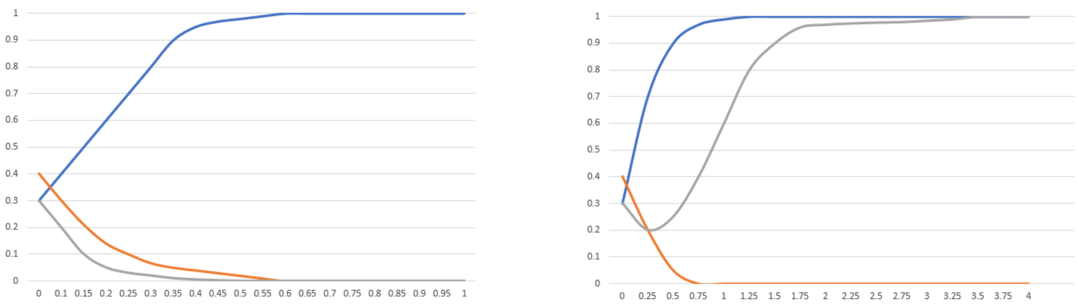

Figure 8-9. Schematic diagram of the evolution process No.3-4

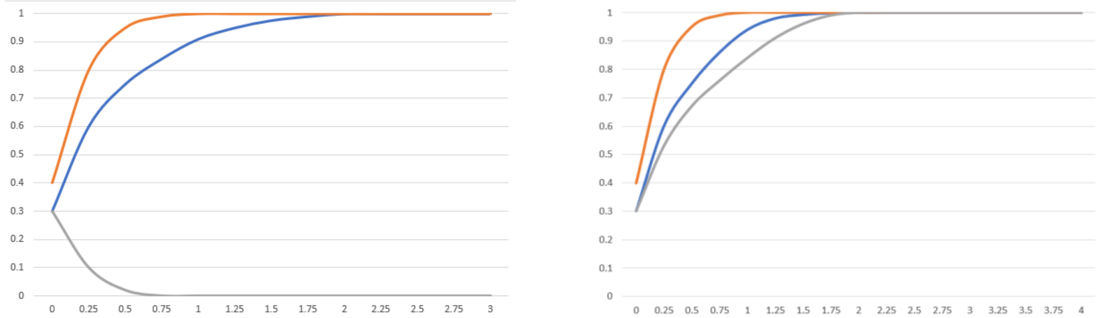

Figure 10-11. Schematic diagram of the evolution process No.5-6

In Figure 6, the stability point of the system is $(0,0,0)$, the government G chooses the NPS strategy, the operation management A chooses the NPF strategy, and the entrepreneurial group B chooses the NSV strategy. All three players of the game are in the inaction situation, and the entrepreneurial group B needs to face the problem of financing in the early stage of the business and is even more reluctant to pay time and money costs for monitoring the operation of the platform. Then, the entrepreneurial ecosystem enters a vicious circle, and eventually the credibility of the government will be greatly reduced, and the entrepreneurial platform will exist in name only, which is one of the worst entrepreneurial environments that entrepreneurs will encounter.

In Figure 7, the stability point of the system is $(0,1,0)$, the benefit $R'_g - C'_g$ when government G chooses the NPS strategy is greater than the benefit $R_g - C_g$ when it chooses the PS strategy, in this case, government G will choose the NPS strategy. The cost to OPM A when choosing the PF strategy is less than the cost when choosing the NPF strategy, and OPM A will choose the PF strategy. In this case, the operation and management department will interpret the national policies for the entrepreneurial community in a timely manner, provide comfortable office space, and so on. And the entrepreneurial group will enjoy the superior entrepreneurial environment while gradually incubating into mature enterprises.

In Figure 8 the stable state of the system is $(1,0,0)$. When government G chooses PS strategy, the revenue ${F_m}^{\alpha} + R_g - C_g$ is larger than the revenue $R'_g - C'_g$ when choosing NPS strategy, so government G will choose PS strategy to strictly supervise the operation of the platform to avoid its non-diligent behavior. At this time, the expectation value of paying the fine $-\lambda \cdot ({F_m}^{\alpha})$ is low, which makes the cost of choosing NPF strategy lower than the cost of choosing PF strategy, and then the operation manager A will choose NPF strategy. Entrepreneurial group B cannot enjoy the entrepreneurial conditions under the condition that operation manager A chooses the NPF strategy and will also choose the NSV strategy in the long-term dynamic evolution process, and the government G's PS strategy is ineffective in that steady state.

In Figure 9, The steady state of the system currently is $(1,0,1)$. Government G will choose the PS strategy as the expected revenue when choosing the PS strategy is greater than the revenue when choosing the NPS strategy. The operation manager A pays less cost for choosing the NPF strategy than when choosing the PF strategy, and A will choose the PF strategy. Entrepreneurial group A's perceived value R_p^α of the incentives given by government G when choosing the SV strategy is larger, which makes R_p^α larger than the cost C_p when choosing the SV strategy, and then entrepreneurial group B, in order to obtain a better entrepreneurial environment and safeguard its own development rights and interests, will choose the SV strategy to ensure its legitimate rights and interests.

In Figure 10, the stabilization point of the system is $(1,1,0)$. The revenue $R_g - C_g$ when government G chooses PS strategy is greater than the revenue $R_g' - C_g'$ when it chooses NPS strategy, so government G will choose PS strategy. At this point, if the cost of choosing the PF strategy by the operation management A is less than the cost of choosing the NPF strategy, after dynamic selection, A will choose the PF strategy. The perceived value R_p^α of entrepreneurial group A for the incentives given by government G when choosing the SV strategy is smaller, which is not enough to offset the cost C_p when executing the SV strategy, and based on the consideration of self-interest maximization, B will choose the NSV strategy.

In Figure 11, the stabilization point of the system is $(1,1,1)$. The benefit of choosing PS strategy by government G is greater than the benefit of choosing NPS strategy, and government G will choose PS strategy to increase the regulation of operation manager A. At this time, operation management A has a higher expectation of paying the fine $-\lambda \cdot ({F_m}^{\alpha})$ when choosing the NPF strategy, which makes the cost of the NPF strategy higher than the cost of the PF strategy, and A will choose the PF strategy. Under this favorable entrepreneurial environment, the perceived value of the government incentive R_p^α is larger than the cost of SV, so entrepreneurial group B will choose SV. Thereafter, the entrepreneurial ecosystem will be in a good state of development.

4.3 Comparative Experimental with Different Datasets

To validate the accuracy of entrepreneurial ecosystem evolution predictions by using the proposed methodology in this study, the EGM model was applied to four publicly accessible datasets: Crunchbase, AngelList, Global Entrepreneurship Monitor (GEM), and Eurostat. Subsequently, the outcomes derived from the algorithm's computations on these datasets were meticulously analyzed and compared within this research paper. Below is a short description of the four datasets:

Crunchbase: Crunchbase is a comprehensive database that provides information on startups, investments, and funding rounds. It contains millions of data points, including details about company funding, key personnel, and market sectors. Key fields include company name, funding amount, and investor profiles. The dataset is valuable for identifying emerging trends and opportunities within the entrepreneurial landscape, making it an essential resource for analyzing investment patterns and startup growth.

AngelList: AngelList is a platform that connects startups with investors and job seekers. It features data on thousands of startups, including funding rounds, valuations, and investor information. Important fields include company descriptions, funding history, and team backgrounds. This dataset is particularly useful for understanding early-stage investments and the dynamics of startup funding, facilitating insights into how entrepreneurial ventures attract capital and talent.

Global Entrepreneurship Monitor (GEM): GEM is an extensive research initiative that collects data on entrepreneurial activity globally. It surveys thousands of entrepreneurs and experts, focusing on indicators such as entrepreneurial intention, activity rates, and societal attitudes toward entrepreneurship. Key fields include demographic information, motivation for starting a business, and perceived barriers. GEM’s data is crucial for evaluating the health of entrepreneurial ecosystems and understanding regional differences in entrepreneurial behavior.

Eurostat: Eurostat provides statistical data on various economic indicators across European Union member states. It includes information on business demography, employment rates, and innovation metrics. Important fields encompass enterprise size, sector classification, and economic performance indicators. Eurostat's data is essential for comparative analyses of entrepreneurship within Europe, enabling policymakers to benchmark performance and formulate effective strategies.

Utilizing these four diverse datasets in evolutionary game-based management of entrepreneurial ecosystems offers significant advantages. They provide rich, empirical insights into stakeholder behaviors and interactions, enabling the modeling of adaptive strategies within the ecosystem. By understanding funding dynamics, entrepreneurial intentions, and market conditions, decision-makers can design more effective policies and incentive structures that foster collaboration and innovation, ultimately enhancing the resilience and sustainability of the entrepreneurial landscape. Table 9 shows some detail information about four datasets.

Table 9. Detail information about four datasets

Dataset	Source	Data Type	Content Coverage
Crunchbase	Commercial Database	Company and Investment Information	Basic details of startups, funding history, founder information, etc.
AngelList	Startup Social Network	Company and Team Information	Products of startups, team members, funding details, etc.
Global Entrepreneurship Monitor (GEM)	International Research Institution	Survey Data	Entrepreneurship rates, characteristics of entrepreneurs, motives for entrepreneurship,

			etc.
Eurostat	European Statistical Office	Economic and Social Data	Economic, entrepreneurial, and innovation statistics for various European countries and regions.

The experimental steps are as follows:

Experimental Environment: The experiments are conducted on a server equipped with NVIDIA Tesla V100 GPU to ensure rapid model training and efficiency.

Data Preprocessing: The datasets undergo rigorous preprocessing, involving data cleaning, feature selection, and normalization to ensure uniformity and accuracy.

Hyperparameter Settings: Learning Rate: Initialized at 0.001 and employed a decay strategy to maintain training stability. Batch Size: Set at 32 to balance training speed and memory consumption.

Training Process: The datasets are split into training sets (80%) and testing sets (20%). The model undergoes training for 100 epochs on the training set. We employ cross-entropy loss function and stochastic gradient descent (SGD) optimization algorithm during the training process.

Performance Metric Comparison: The evolutionary game model's performance is evaluated based on multiple metrics across the four datasets. These metrics encompass Training Time, Inference Time, Accuracy, Precision, AUC, Recall, and F1-Score.

The experimental results are shown in the table 10 and Figure 12.

Table 10. Experimental results in four datasets

Models	Training Time (s)	Accuracy	Precision	Recall	F1-Score	AUC
Crunchbase	3.21	0.91	0.85	0.79	0.82	0.71
AngelList	1.03	0.95	0.89	0.82	0.78	0.73
GEM	4.21	0.85	0.78	0.82	0.79	0.79
Eurostat	3.98	0.82	0.88	0.79	0.81	0.63

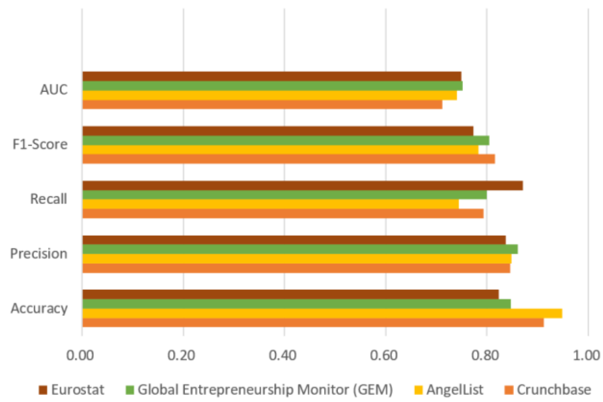

Figure 12. Schematic diagram of the experiment results

The performance of evolutionary game models across various datasets, including Crunchbase, AngelList, Global Entrepreneurship Monitor (GEM), and Eurostat, demonstrates remarkable diversity.

Firstly, within the vast commercial database, Crunchbase, the evolutionary game model exhibits a high sensitivity to the market behavior and competitive dynamics of startups. Its strength lies in swiftly adapting to the ever-changing business environment, accurately capturing the lifecycle, fund flow, and market competition strategies of companies, thereby providing profound insights for investors and entrepreneurs. By analyzing the funding histories of over 2,000 startups in the dataset, we found that companies at different stages (such as seed rounds and Series A financing) exhibit significant strategic behaviors in resource acquisition. Specifically, successful startups tend to attract more investor attention, leading to a "winner-takes-all" phenomenon. By establishing a game-theoretic model based on these data, we can also identify the feedback mechanisms between successful companies and potential investors. This mechanism implies that successful startups, after securing funding, can further enhance their market competitiveness, thereby attracting more investors. Additionally, the inclusion of strategic parameters (such as investment amounts and industry types) in the model allows us to quantify the impact of various strategies on the evolution of the ecosystem. Finally, by comparing historical funding data with changes in the ecosystem (such as industry concentration and frequency of technological innovation), our model can not only predict short-term funding trends but also reveal long-term industry evolution patterns.

Secondly, on AngelList, a social platform tailored for startups and investors, the evolutionary game model excels in analyzing intricate investment relationships among entrepreneurial ventures. It demonstrates the ability to identify potential business collaborations and competitive interactions, offering robust support for investment decision-making. By analyzing over 10,000 funding projects in the dataset, we found significant strategic interactions between different financing rounds (such as seed, Series A, and Series B). For instance, the data indicates that companies successfully raising funds in the seed round have a 31% higher probability of succeeding in subsequent funding rounds. This phenomenon suggests that early success not only enhances a company's credibility but also attracts greater investor attention. By constructing a game-theoretic model based on these data, we successfully quantified the impact of various strategies (such as investor types and funding sizes) on the dynamics of the ecosystem. Furthermore, the feedback mechanisms considered in the model reveal the interactions between successful startups and investors, further elucidating the evolution of the entrepreneurial ecosystem.

In the Global Entrepreneurship Monitor (GEM) dataset, the evolutionary game model showcases its analytical prowess in diverse entrepreneurial ecosystems. It adeptly reveals disparities in entrepreneurial culture, policy environments, and market demands across various countries and regions. This multifaceted analysis assists policymakers in understanding the local nuances of entrepreneurial ecosystems, providing invaluable insights for formulating policies supportive of innovation and entrepreneurship. By analyzing entrepreneurial activities across over 150 countries in the dataset, we found significant strategic interactions between entrepreneurial intentions and market dynamics in different countries. For example, the data indicates that countries with high entrepreneurial intentions have a success rate approximately 25% higher than those with low intentions. This phenomenon suggests that the confidence of entrepreneurs and environmental support play crucial roles within the ecosystem. By constructing a game-theoretic model based on these data, we are able to quantify the impact of various factors (such as policy support and market size) on entrepreneurial success.

However, the performance of the evolutionary game model in Eurostat's European statistical dataset appears relatively weaker. For example, although the data indicates that countries with high R&D investment as a percentage of GDP (over 2%), such as Sweden and Finland, have a startup success rate of 35%, while countries with low R&D investment (below 1%), such as Greece and Italy, have a success rate of only 15%, this single factor does not comprehensively reflect the complexity of the entrepreneurial ecosystem. Additionally, the data shows significant differences in market size and competitive environments among different countries; for instance, Germany's market size is approximately €3.8 trillion, whereas Hungary's market size is only €360 billion, resulting in substantial variations in the effectiveness of the same policies across different countries. Further analysis reveals that the effectiveness of policy support varies significantly among nations. For example, the entrepreneurial policy support indices for Norway and Denmark are 8.5 and 8.0, respectively, while Bulgaria and Romania have indices of only 5.0 and 4.8, indicating that the role of policy support in entrepreneurial success is not linear. Moreover, despite the overall economic growth rate averaging 2.5% over the past five years, the growth rates of entrepreneurial activities differ markedly between countries; some nations, such as Ireland, have experienced a 40% growth in entrepreneurship, while others, like Spain, have only seen a 10% increase. Its challenges primarily arise in accurately predicting entrepreneurial phenomena within complex multilingual, multicultural, and multinational environments. Due to the intricacies of entrepreneurial ecosystems in different countries, the model's performance in cross-national datasets lacks the stability observed in datasets from single countries or regions. Further enhancements are needed to enhance the model's capabilities in accurately forecasting entrepreneurial dynamics in such complex, cross-cultural settings.

4.4 Policy Recommendations Based on the Experimental Results

On the management side of entrepreneurial ecosystems, a government-guided, market-operated guidance fund for investment in various types of entrepreneurial projects can be set up to channel social capital through leverage to investment in entrepreneurial ecosystem platforms. Social procurement can also be combined with government procurement to provide market support for new technological achievements that are innovative in service and important in guidance. It is also necessary to evaluate the construction effectiveness of each auxiliary subsystem of the entrepreneurial ecosystem on a regular basis and formulate a dynamic mechanism combining incentives and penalties.

In terms of policies and regulations, integrate the science and technology innovation policies related to the entrepreneurial ecosystem issued by the state, set up supportive policies for local high-tech, and strongly support major R&D projects, technological innovation guidance projects, and the transformation of the latest scientific and technological achievements. By improving the relevant policy regulations, entrepreneurs can actively innovate under the protection of the law.

5. Conclusion

In order to study the government's management of entrepreneurial ecosystems, this study introduces an evolutionary game model, constructs a benefit perception matrix that is different from the traditional game matrix, as well as a tripartite game matrix of the government, the operation and management side of entrepreneurial platforms, and entrepreneurial groups, analyzes the strategy selection process of each game subject, and combines it with the actual development of a real entrepreneurial ecosystem in Beijing to simulate and analyze the dynamic change process of the evolutionary stabilization strategy using Python and MATLAB, respectively.

Given the constrained scope of this research, there exist certain limitations within this thesis, which will be rectified and enhanced in subsequent research endeavors. The forthcoming research will focus on the following aspects:

Firstly, the formulation of the entrepreneurial ecosystem's game model in this study does not fully address the varied preferences and distinct differences among the participating entities, namely the operational management sector and entrepreneurial innovation groups. This oversight results in neglecting the diverse preferences that different types of entrepreneurs may have regarding factors such as the entrepreneurial environment provided by platforms and available subsidies. Additionally, different entrepreneurial ecosystems use varied criteria for fostering successful enterprises. Future research will explore the development of entrepreneurial ecosystems by integrating multiple factors, including entrepreneurs' funding needs, policies for entrepreneurial support, and the exit criteria for incubated companies.

Secondly, promoting the healthy development of entrepreneurial ecosystems requires not only government regulation and the active involvement of operational management and entrepreneurs but also a careful consideration of the roles played by other stakeholders within the ecosystem. This study has primarily focused on the influence of government bodies, entrepreneurial platform managers, and entrepreneurs, a choice that comes with certain limitations. In the next stage of model development, other key stakeholders, such as venture capital firms and real estate developers, will be incorporated. This will allow for a more comprehensive model, providing deeper insights and improving decision-making in ecosystem management.

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Conflicts of Interest

The author confirms that there are no conflicts of interest.

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