Heliyon 10 (2024) e26450

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

# Study on the evolution of collaborative innovation in marine economy considering the participation of financial institutions and two types of cooperation

Hongwei Ma *, Guisheng Hou

*College of Economics and Management, Shandong University of Science and Technology, Qingdao, 266590, Shandong, China*

ARTICLE INFO

*Keywords:*
Major marine engineering
Implicit guarantee
Evolutionary game
Collaborative innovation

ABSTRACT

In the realm of significant technological research and innovation within the marine economy, enterprises and academic research institutions often grapple with a lack of innovation motivation due to financial constraints. This paper introduces the factor of "capital constraints" into the marine innovation chain, establishing a technological innovation chain within the marine economy. Utilizing a three-party evolutionary game model, the study delves into the strategy selection and evolution of financial institutions, marine enterprises, and academic research institutions. In contrast to previous studies, this paper categorizes technological innovation cooperation into two types: "cooperative tackling type" and "market-oriented promotion type." Additionally, it posits that collaboration between academic research institutions and marine enterprises establishes an implicit guarantee relationship, facilitating access to higher loan amounts for both parties. The research reveals that the behavior of governments and marine enterprises is influenced by the initial willingness of participants. Higher basic benefits of cooperation and innovation between academic research institutions and marine enterprises lead to a quicker attainment of an evolutionary stable state. Moreover, in collaborations between marine enterprises and research institutions, an excessively high proportion of funds occupied by marine enterprises proves disadvantageous. The paper suggests that pure market-oriented promotion innovation cooperation could serve as a supplementary approach to traditional cooperation and innovation. Finally, numerical examples are presented to elucidate the outcomes of the theoretical model, accompanied by policy suggestions.

## 1. Introduction

Since the reform and opening up policy in 1978, China's economy has experienced explosive growth, and the strategic role of the marine economy has attracted more and more attention. "Developing the marine economy" was first designated as a crucial national development strategy in China's 12th Five-Year Plan for National and Social Development (FYP) (2011–2015). In 2013, China launched the "21st Century Maritime Silk Road", which aims to accelerate the development of the Shanghai Pilot Free Trade Zone, and take advantage of its high degree of openness and advantages to support Fujian Province in building the core areas of the Silk Road, the Yangtze River Delta and other coastal areas. The huge influence of the economic zone. According to the 2019 China Marine Economic

* Corresponding author.
*E-mail address:* mhwtgzy@163.com (H. Ma).

https://doi.org/10.1016/j.heliyon.2024.e26450
Received 11 August 2023; Received in revised form 30 January 2024; Accepted 13 February 2024
Available online 17 February 2024

Development Report, the gross marine product (GOP) in 2018 was 8341.5 billion yuan, an increase of 6.7%, accounting for 9.3% of China's GDP. The overflow value of the marine primary, secondary and tertiary industries accounted for 4.4%, 37.0% and 58.6% of the total marine yield value respectively, and the tertiary industry also had the fastest growth rate (National Development and Reform Commission and MENR, 2019). The marine economic growth rate in the southern coastal areas is higher than that in the central and northern coastal areas, demonstrating greater future development potential (NDRC and MENR, 2019). With the further acceleration of the economic process, the high-quality development strategy of the marine economy is proposed in 2021, the adjustment of the marine economy and the transformation and upgrading of industrial structure should attract sufficient attention and recognition. The development of the marine economy through technological innovation is the only way to develop the marine economy in the future.

However, it is worth noting that China's marine economic growth has gone through tortuous development, and currently has entered a new stage of "qualitative breakthrough" in local areas from the stage of "quantitative accumulation". Although great achievements have been made in the development of marine science and technology across the country, the level of which is approaching that of developed countries or economies such as the United States, the European Union, and Japan, there is still a gap in the awareness and ability of scientific and technological innovation. Marine-independent innovation, especially primitive innovation needs to be strengthened.

Because marine economy encompasses various ecological elements that are influenced by economic and environmental factors, considering related issues involves a multitude of interactions and impacts among entities. Therefore, it aligns more closely with a dynamic-seeking stability process [1,2]. The framework of evolutionary game theory provides us with a tool that allows us to simultaneously consider the strategic choices of multiple entities and evolutionary stability. This is also why this model was chosen for this paper. On the other hand, incorporating Simon's concept of bounded rationality into the framework of evolutionary game theory is more in line with real-world situations. Furthermore, in the consideration of the development and planning process of the marine economy, a small number of studies have already recognized the importance of collaborative innovation [3–5]. However, practical strategies for alleviating funding constraints in the innovation process have not been proposed. Additionally, a plethora of empirical evidence [6–9] has indicated that the ownership nature of enterprises affects the difficulty of obtaining funds in the financing process, with state-owned enterprises being more likely to receive financial support from banks. This aspect has not received sufficient attention in theoretical model research. In reality, decision-makers in state-owned enterprises and state-owned banks often hold similar administrative-level roles, and this consistency in roles is one of the reasons they find it easier to establish "relationships" [10,11].

For the marine economy, its spatial components are relatively complex, so the process of exploring the sustainable development of the marine economy requires dynamics and process orientation [12]. Based on this background, this paper explores the technological innovation cooperation mechanism of financial institutions, marine enterprises and academic and research institutions, and explores the path of high-quality technological innovation mechanism of great significance and practical value.

Although research on industry-university-research collaboration is not a new topic, The importance of innovation has been widely acknowledged in existing literature [13,14]. Previous studies have primarily focused on discussing the outcomes of collaboration, often neglecting the consideration of collaboration types. This paper creatively categorizes collaboration into two types: the first being traditional collaborative innovation in research and development, with a focus on the outcomes and distribution of benefits; the second being innovation and research collaboration solely for market-oriented promotion, which centers around the process of pushing research results into the market. In real-world scenarios, there is often information asymmetry between enterprises and research institutions. As a result, many research outcomes from institutions are not brought to the market. Research institutions may be unaware of the needs of enterprises, and enterprises may not know that certain research outcomes from institutions could assist in their business management and technological efficiency. Given the latter scenario, collaboration focused on market-oriented promotion becomes particularly important.

Different from previous studies, the innovation of this paper lies in: (1) Based on China's cultural and customary factors, this paper believes that an "implicit guarantee relationship" can be formed when academic institutions and marine enterprises carry out innovation cooperation. This paper incorporates this typical fact into the model. (2)The industry-university-research institution cooperation in the economy is creatively divided into "traditional innovation in R&D cooperation" and "pure market-oriented promotion cooperation", and the research has confirmed the rationality and feasibility of the latter method. This discovery provides new insights into the innovation path and mechanism reform of marine economic cooperation. The rest of this paper was arranged as follows: Section 2 was the literature review, Section 3 was the construction of the evolutionary game model, Section 4 was the simulation of numerical examples, and Section 5 was the conclusion and enlightenment.

## 2. Literature review

### 2.1. Related research on marine economy and marine economic innovation

As far as the research on the marine economy is concerned, the existing research has involved: the Belt and Road, the transformation and upgrading of the marine industry, etc. Fang Ye et al. [15] studied the impact of government preferences in policies and regulations on the marine economy. The study pointed out that there is delayed effect in the promotion of environmental regulations to the green development of the marine economy. The influence of government preference varies. The industry preference has a negative impact on the green development of the marine economy, while environmental preference has a negative impact on the green development of the marine economy. The combined effect of industrial preference and environmental preference restrains the green development of the marine economy, while the combined effect of environmental preference and environmental regulations promotes it. Different government preferences indicate variable effects in diverse regions. Environmental preference promotes the green development of the marine economy in the Bohai Bay area, while industrial preference inhibits the development of the green economy. Both industrial preference and environmental preference in the Yangtze River Delta region have a positive effect, while only the environmental preference in the Pan-Pearl River Delta region has a facilitative effect. Qinglong Shao et al. [16] focused on marine industry upgrading as well as its relationship with marine economic growth and technological innovation. The study found that in the long run, marine economic growth has a positive impact on marine technological innovation, and vice versa. Furthermore, they neither has promoted industrial upgrading, nor has it promoted it. These findings indicate that marine economic growth and technological innovation promote each other in the long run, but the mutual driving mechanism between marine industrial upgrading and the other two variables has not yet manifested. The study also shows that the transition from secondary to tertiary industries is not conducive to improving marine technological innovation. Baiqiong Liu et al. [17] screened seven typical marine development activities in China to evaluate their comprehensive benefits, with the aim of selecting activities suitable for priority development. An evaluation index system including economic benefit index, social benefit index, resource depletion index and environmental cost index is established specifically. The weight of each index was calculated by Delphi method and Analytic Hierarchy Process (AHP), and a comprehensive benefit evaluation model was established for evaluation. The results show that the marine secondary industry has the highest comprehensive benefit, followed by the marine tertiary industry. The marine primary industry was the latest one. Xuan Chen et al. [18] studied the dual effects of different types of marine environmental regulations on the upgrading of the manufacturing industry structure and the transfer of polluting industries. Each marine environmental regulation has a positive U-shaped relationship with the transfermation of polluting industries and the upgrading of industrial structure. The threshold point of the transfer of polluting industries appears before the threshold point of industrial structure upgrading. Based on these two threshold points, the impact of each marine environmental regulation on the industrial restructuring of each province is divided into three stages: double inhibiting transfermation and upgrading, transfermation priority, and double promoting transfermation and upgrading. Under each marine environmental regulation, Hainan and Guangxi provinces are in the double suppression stage, while under the command-control and economic incentive marine environmental regulations, Shanghai and Shandong provinces have entered the double promotion stage. Hanna Dijkstra et al. [19] examined how blockchain technology can be used to improve global marine conservation and fisheries supply chain management, considering the technical and political challenges of building trust and equity for various stakeholders. Shuo Wang et al. (2022) studied the strategic selection and evolution of stakeholders in marine spatial planning from the perspective of marine ecosystems. They analyzed the effect of incentive mechanisms. Their study pointed out that factors such as initial selection probability and transaction cost coefficient distribution can significantly affect the three parties. The agent's strategy selection and evolution [20]. Srinivasa et al. [21] studied enterprises facing funding shortages and concluded that supply chain financing would bring mutual benefits to all parties involved in the supply chain, including commercial banks. Yan et al. [22] established a stronger partnership between financially constrained partners and banks, providing guarantees for sales to avoid defaults due to insufficient demand. Tunca et al. [23] found that financially constrained suppliers could invite retailers as guarantee intermediaries to secure loan financing from banks, benefiting supply chain members and enhancing channel performance. Based on these studies, it can be observed that current research on the marine economy primarily operates at the macro and meso levels, focusing on topics such as marine economic growth and industrial structural transformation. However, there is limited research and consideration from the perspective of collaborative innovation among entities. Additionally, existing studies have covered aspects of the industry and supply chain related to the marine economy, but there is insufficient attention and consideration given to the financial and innovation chains. Therefore, this paper specifically addresses these latter two aspects.

### 2.2. Research on evolutionary games

Evolutionary game adopts Simon's opinion of bounded rationality [24], and at the same time integrates dynamic evolution and game theory analysis into a intact framework. Evolutionary game theory is a research framework that can clearly demonstrate the selection pressure that affects the conflict of relevant stakeholders' strategies [25]. It is widely used to study the long-term evolution and stability of social habits, customs, norms, and institutions [26–30]. As far as the related research on evolutionary games is concerned, there are many literatures, including not only PPP project evolution but also carbon emission reduction, new energy vehicles, etc. Huiqun Yuan et al. [31] studied random policy selection in supply chain and proposed a random attack and defense algorithm based on evolutionary results. Yu Tu et al. [32] studied the strategy selection and evolution of stakeholders in the context of the extended production responsibility (EPR) system, which analyzed in detail the applicability and limitations of different environmental policy systems. Haiyan Shan et al. studied the strategy selection and evolution of stakeholder companies, poor households and governments in the context of photovoltaic poverty reduction, and found the thresholds for different strategy evolution. Yujuan Fang et al. [33] studied the use of solar energy in electric vehicles and proposed a public-private partnership to advance the implementation of the program, confirming that appropriate subsidies and pricing strategy can guide stakeholders evolves towards any ideal goal. Fang Y et al. [34] incorporated the idea of supply chain into the evolutionary game model. They found that the green investment input-output ratio of suppliers and manufacturers, or changes in government subsidies would lead to the development of the system to different development stability state strategy. The initial proportion of green investment can significantly affect the final evolution outcome. Yujuan Fang et al. [35] studied the fuel selection of urban heating systems. Taxes and subsidies can guide strategies to convert coal to electricity, so as to achieve the goal of energy clean-up. Moreover, the study also pointed out that through dynamic tax and subsidy instruments can shorten the time to strategic convergence. Tian Zhao et al. [36] studied the strategy selection and evolution of stakeholders in the context of carbon capture and carbon sequestration. Besides, he also analyzed the impact of the initial willingness of the subject on the evolution of equilibrium strategies. Mengjie You et al. [37] studied the strategy selection and evolution of stakeholders in the inside safety supervision of coal enterprises. The study pointed out that in the case of static rewards and punishments, the proportion of unsafe behaviors can be reduced by increasing the rewards and punishments, but at the same time it increases the instability of the equilibrium. In contrast to the context of dynamic rewards and punishments, it is difficult to achieve a satisfactory equilibrium state. The article further points out that it is necessary to introduce external supervision, and simultaneously, differentiated punishment measures should be taken for regulators and miners. Hong Shen et al. [38] combined prospect theory and evolutionary games to study the recycling and disposal of dismantling waste in the construction industry. Additionally, the study pointed out factors such as initial strategy, production cost, technology, subsidies, and recycling benefits as well as the perception level of stakeholders, has a certain impact on the steady state. For cooperation between different subjects, it can be divided into horizontal vs. vertical, formal vs. informal, temporary vs. permanent; institutionalized vs. non-institutionalized and other different types [39]. Its new context with Chinese characteristics is an issue worthy of attention. Regarding research using evolutionary game methods, there have been numerous topics such as clean energy production, mining safety regulation, supply chains, and more. This phenomenon, from another perspective, confirms the power of evolutionary game model tools. However, it is worth noting that while some studies focus on the evolution of the initial choice intentions of agents (e.g., literature 34, 38), there are also some that do not consider the impact of initial choice intentions. This paper considers the influence of initial choice intentions within the framework of evolutionary game theory, aiming to discover how the initial attitudes of financial institutions, enterprises, and research institutions affect the overall evolution of the system.

### *2.3. Research review*

From the analysis above, it can be seen that the existing marine economy related research has involved marine transformation and upgrading, marine solid waste recycling, marine supply chain, and marine economic development under the background of environmental regulation. Regrettably, however, few literature has paid enough attention to this important issue of marine technological innovation. As far as the current reality is concerned, China has proposed a stage of high-quality development, but the quality of the current technological innovation achievements is still relatively poor. In the process of technological innovation, it is difficult for each subject to effectively coordinate, and the phenomenon of acting independently is relatively serious. Diversified technological research and development Collaborative models need to be established urgently. On the other hand, marine technological innovation is faced with serious financial shortfall problem and many other uncertain risks. In order to better understand the paths and new ways of marine technological innovation, this study intends to use a three-parties evolutionary game model to analyze the strategic choices and evolution of stakeholders to discover the decisive factors. Existing tripartite evolutionary game research has covered many topics, such as carbon capture and carbon sequestration, safety behavior of coal enterprises, fuel selection in heating systems, and new energy vehicles. These studies provide a good foundation and reference for the development of this paper.

## 3. Theoretical models

### *3.1. Problem description and research hypothesis*

Consider an evolutionary game model of financial cooperation in major marine technology research. Here, we mainly consider the strategy selection and evolution of three types of subjects: financial institutions, marine enterprises and academic research institutions. For financial institutions, they can choose whether to provide them with innovative loans based on the actual situation as well as the performance of marine enterprises and academic research institutions. At the same time, financial institutions need to monitor the use of these funds. For marine enterprises, whether to choose innovation needs to be comprehensively considered in combination with cost-benefit and their own actual operating conditions. For academic and research institutions, they can choose whether or not to cooperate with marine enterprises in innovation, but it is worth noting that when marine enterprises do not innovate, academic and research institutions can still use marine enterprises to help themselves realize the large-scale production and put the innovative patents or products to the market, such situation can exist. The former situation can be regarded as a kind of innovation cooperation in the category of technical research, and the latter can be regarded as a kind of innovation cooperation in the category of pure technology marketing promotion.

**Assumption 1**. There are three main types of subjects in this game, financial institutions, marine enterprises and academic research institutions.Furthermore, all three are bounded rationality, which means they will make the most beneficial and self-determined decisions based on the information obtained.

**Assumption 2**. The source of innovative funds for marine enterprises and academic research institutions can only be completed through financial institutions, regardless of the use of private capital or other sources of funds. In the process of major marine technological innovation, financial institutions obtain special loan funds for exclusive use and do not use them for other purposes.

**Assumption 3**. Financial institutions will choose whether to disburse loans according to the cost of financial supervision and the credit level (such as repayment probability of marine enterprises and academic research institutions), as well as their operational status. Marine enterprises and academic research institutions will choose whether to accept loans according to the impact of other factors such as cost and benefit. The strategic combination of financial institutions is {provide loans, do not provide loans}, the strategic combination of marine enterprises is {innovate, not innovate}, and the strategic combination of academic research institutions is {cooperation, no cooperation}. Therefore, this paper contains 8 pure strategy combinations. It is assumed that the decisions of each subjects are independent of each other.

**Assumption 4**. In reality, when banks decide whether to provide financial loan support, they will consider and judge the qualifications plus past experiences of enterprises and research institutions comprehensively. Partnership can to some extent convey the "power" signal of enterprises and research institutions, which is due to the status of cultural factors with Chinese characteristics such as "guanxi" in commercial cooperation that cannot be ignored [40,41], and this effect usually manifests as a "synergistic" property [42,43]. Given this viewpoint, this article believes that the "cooperative relationship" between enterprises and research institutions can increase the probability of both parties obtaining financial support, which is actually an "implicit guarantee" relationship from the perspective of Chinese cultural background.The regulatory cost of banks is positively related to the amount of loans provided.That is, in the case of a larger amount loan, a larger regulatory cost is required. At the same time, when marine enterprises and academic research institutions cooperate, they form an "implicit guarantee relationship".Simultanously, the probability of obtaining a loan is much higher. When marine enterprises and academic research institutions carry out innovative cooperation, they will allocate loans according to a certain proportion. When only one party chooses to cooperate, they will each obtain loans from financial institutions from independent channels.

**Assumption 5**. This paper defines the innovation cooperation between marine enterprises and academic research institutions into two categories, one is innovation cooperation in the type of technological breakthrough, and the other is cooperation in innovation-items marketing promotion. The former situation occurs in the strategic combination {Marine Enterprise innovate, academic research institutions cooperate}, the latter situation occurs in the case of strategic combination {marine enterprises do not innovate, academic research institutions cooperate}, when marine enterprises and academic research institutions carry out technological innovation cooperation, the academic research institutions do not need to provide marine enterprise pays the promotion fee. When the marine enterprise and the academic research institution carry out technology promotion cooperation, the academic research institution needs to pay a certain market promotion fee to the marine enterprise.

### 3.2. Parameter setting

The probabilities of financial institutions choosing “providing loans” and “not providing loans” are $\{x, 1-x\}$ respectively; the probabilities of marine enterprises choosing “innovate” and “not innovate” are $\{y, 1-y\}$ respectively; the probabilities of academic research institutions choosing “cooperate” and “not cooperate” are $\{z, 1-z\}$ respectively in turn, these three parameters are satisfied： $0 \le x \le 1, 0 \le y \le 1, 0 \le z \le 1$, and these three parameters are time parameters. At the same time, the initial loan provision willingness of financial institutions is recorded as $x_0$ , the initial cooperation willingness of marine enterprises is marked as $y_0$, and the initial cooperation willingness of academic and research institutions is marked as $z_0$ , and the parameters are also satisfied： $x_0, y_0, z_0 \in [0,1]$.

Based on the above analysis and assumptions, the parameter settings and definitions are summarized in Table 1 below. When the

**Table 1**
Main parameter settings and meanings.

| parameters | meaning |
|---|---|
| $T_0$ | When academic research institutions and marine enterprises do not cooperate, and marine enterprises do not innovate, the loans marine enterprises obtain |
| $T_1$ | When the academic and research institutions do not cooperate and the marine enterprise chooses to innovate, the bank loan obtained by the marine enterprise |
| $T_2$ | Loan amounts when academic research institutions and marine enterprises cooperate and marine enterprises choose to innovate |
| $T_3$ | When academic research institutions choose to cooperate, but marine enterprises choose not to innovate, the share of loans that academic and research institutions can obtain |
| $T_4$ | Bank loans obtained by academic research institutions when they do not cooperate and marine enterprises choose to innovate |
| $T_5$ | When the academic research institution and the marine enterprise do not cooperate, and the marine enterprise does not innovate, the academic research institution obtains the loan |
| $T_6$ | When the academic research institutions choose to cooperate, and the marine enterprise chooses not to innovate, the loan marine enterprise obtains |
| $K_0$ | When academic research institutions choose to cooperate and marine enterprises choose not to innovate, the benefits obtained by academic research institutions |
| $K_1$ | When marine enterprises and academic research institutions cooperate, the synergistic benefits obtained by marine enterprises |
| $K_2$ | When marine enterprises and academic research institutions cooperate, the synergistic benefits obtained by marine enterprises |
| $C_1$ | The cost of marine companies choosing innovation |
| $C_2$ | The cost of marine companies choosing not to innovate |
| $E_1$ | The basic benefits of marine enterprises when they choose innovation |
| $E_2$ | Basic income when marine enterprises choose not to innovate |
| $H_1$ | Basic income when marine enterprises choose not to innovate |
| $H_2$ | Basic benefits obtained when academic institutions choose not to cooperate |
| $L_1$ | Costs when institutions choose to cooperate |
| $L_2$ | Costs when academic institutions choose not to cooperate |
| $\gamma$ | The cost factor of the loan supervision of financial institutions to the loan amount |
| $F$ | When academic research institutions choose to cooperate and marine enterprises choose not to innovate, the fees that academic research institutions need to pay to marine enterprises |
| $\beta$ | Proportion of marine enterprise loans when academic research institutions cooperate with marine enterprises and marine enterprises innovate |

marine enterprise chooses to innovate, the cost is $C_1$ [44,45], and the basic benefit is $E_1$. When the marine enterprise chooses not to innovate, the cost is $C_2$, and the basic benefit is $E_2$. When the institution chooses to cooperate, the cost is $L_1$ , and the basic benefit obtained at this time is $H_1$. When the institution chooses not to cooperate, the cost is $L_2$, and the basic benefit that can be obtained at this time is $H_2$. Taking into account the government's policy support orientation for innovation, when the academic research institution does not cooperate, the bank loan obtained by the marine enterprise when it chooses to innovate is $T_1$.When the academic research institutions choose to cooperate with marine enterprise，the latter can obtain $T_2$, and there is $T_2 > T_1$.Some of the loans are allocated among marine enterprises and academic research institutions, of which marine enterprises account for $\beta$. When the academic research institutions choose to cooperate, but the marine enterprise chooses not to innovate, the share of the loans that the academic research institutions can obtain is $T_3$ and there is $T_1 > T_3$. Financial institution's supervision costs are $\gamma$ multiples of the loan amount, and there is $\gamma \in (0, 1)$. When marine enterprises and academic research institutions carry out cooperation, they will bring certain synergistic benefits to themselves, like $K_1, K_2$ respectively. When academic research institutes choose to cooperate and marine enterprises choose not to innovate, academic and research institutes can use marine enterprises to promote the market share their R&D results/products, which can also be regarded as a kind of cooperation [46,47]. At this time, the income obtained $K_0$ by the academic esearch institutions is that the fees that need to be paid to the marine enterprises are $F$, the former cooperation can be regarded as a kind of "technological innovation" innovation cooperation, and the latter form is "Market-oriented Promotion of Technology R&D″ cooperation.

The return matrix for the three entities is summarized in Table 2 below.

### 3.3. Replicator dynamics equation

According to the analysis above, we can get the expected return function of the financial institution choosing "to provide loans" and "not to provide loans", which can be recorded $R_{11}, R_{12}$ as follows:

$$\begin{aligned} R_{11} &= yz[(1-\gamma)T_2] + y(1-z)[(1-\gamma)(T_1+T_4)] + (1-y)z[(1-\gamma)(T_3+T_6)] + (1-y)(1-z)[(1-\gamma)(T_0+T_5)] \\ &= (1-\gamma)[yzT_2 + y(1-z)(T_1+T_4) + (1-y)z(T_3+T_6) + (1-y)(1-z)(T_0+T_5)] \end{aligned} \tag{1}$$

$$R_{12} = 0 \tag{2}$$

Then the average expected return of financial institutions is $R_x$:

$$R_x = xR_{11} + (1-x)R_{12} \tag{3}$$

The expected benefits of marine enterprises choosing "innovation" and "non-innovation" are recorded $R_{21}, R_{22}$ as follows:

$$\begin{aligned} R_{21} &= xz(\beta T_2 + E_1 - C_1 + K_1) + x(1-z)(T_1 + E_1 - C_1) + (1-x)z(E_1 - C_1 + K_1) + (1-x)(1-z)(E_1 - C_1) \\ &= E_1 - C_1 + zK_1 + xz(\beta T_2 - T_1) + xT_1 \end{aligned} \tag{4}$$

$$\begin{aligned} R_{22} &= xz(E_2 - C_2 + T_6 + F) + x(1-z)(E_2 - C_2 + T_0) + (1-x)z(E_2 - C_2 + F) + (1-x)(1-z)(E_2 - C_2) \\ &= E_2 - C_2 + zF + xT_0 + xz(T_6 - T_0) \end{aligned} \tag{5}$$

Then the average expected income of marine enterprises is $R_y$:

$$R_y = yR_{21} + (1-y)R_{22} \tag{6}$$

The expected benefits of "cooperation" and "non-cooperation" selected by academic and research institutions are recorded $R_{31}, R_{32}$ as follows:

$$\begin{aligned} R_{31} &= xy[(1-\beta)T_2 + H_1 - L_1 + K_2] + x(1-y)(H_1 - L_1 + T_3 + K_0 - F) + (1-x)y(H_1 - L_1 + K_2) + (1-x)(1-y)(H_1 - L_1 + K_0 - F) \\ &= H_1 - L_1 + yK_2 + (1-y)(K_0 - F) + xy[(1-\beta)T_2 - T_3] + xT_3 \end{aligned} \tag{7}$$

$$\begin{aligned} R_{32} &= xy(H_2 - L_2 + T_4) + x(1-y)(H_2 - L_2 + T_5) + (1-x)y(H_2 - L_2) + (1-x)(1-y)(H_2 - L_2) \\ &= H_2 - L_2 + xT_5 + xy(T_4 - T_5) \end{aligned} \tag{8}$$

**Table 2**
Tripartite evolutionary game benefits of marine economic collaborative innovation.

| Strategy mix | Financial institution | Marine enterprise | Academic research institutions |
|---|---|---|---|
| (offer, innovate, cooperate) | $(1-\gamma)T_2$ | $\beta T_2 + E_1 - C_1 + K_1$ | $(1-\beta)T_2 + H_1 - L_1 + K_2$ |
| (provide, innovate, not cooperate) | $(1-\gamma)(T_1 + T_4)$ | $T_1 + E_1 - C_1$ | $H_2 - L_2 + T_4$ |
| (provide, not innovate, cooperate) | $(1-\gamma)(T_3 + T_6)$ | $E_2 - C_2 + T_6 + F$ | $H_1 - L_1 + T_3 + K_0 - F$ |
| (provide, not innovate, not cooperate) | $(1-\gamma)(T_0 + T_5)$ | $E_2 - C_2 + T_0$ | $H_2 - L_2 + T_5$ |
| (not provide, innovate, cooperate) | 0 | $E_1 - C_1 + K_1$ | $H_1 - L_1 + K_2$ |
| (not provide, innovate, not cooperate) | 0 | $E_1 - C_1$ | $H_2 - L_2$ |
| (not provide, not innovate, cooperate) | 0 | $E_2 - C_2 + F$ | $H_1 - L_1 + K_0 - F$ |
| (not provide, not innovate, not cooperate) | 0 | $E_2 - C_2$ | $H_2 - L_2$ |

Then the average expected return of academic institutions is $R_z$:

$$R_z = zR_{31} + (1-z)R_{32} \tag{9}$$

According to the idea of replicating dynamic equations in evolutionary game models, if the expected payoff of strategy is higher than the average, then the strategy will be retained and developed. Based on equations (1)–(9), we can obtain the replication dynamic equation of financial institutions, marine enterprises and academic research institutions is:

$$G(x) = \frac{dx}{dt} = x(1-x)(R_{11}-R_{12}) = x(1-x)\left\{(1-\gamma)\left[yzT_2 + y(1-z)(T_1+T_4) + (1-y)z(T_3+T_6) + (1-y)(1-z)(T_0+T_5)\right]\right\} \tag{10}$$

$$G(y) = \frac{dy}{dt} = y(1-y)(R_{21}-R_{22}) = y(1-y)\left\{\left[E_1 - C_1 - E_2 + C_2 + z(K_1 - F) + xz(\beta T_2 - T_1 - T_6 + T_0) + x(T_1 - T_0)\right]\right\} \tag{11}$$

$$\begin{aligned} G(z) &= \frac{dz}{dt} = z(1-z)(R_{31}-R_{32}) \\ &= z(1-z)\left\{H_1 - L_1 - H_2 + L_2 + yK_2 + (1-y)(K_0 - F) + xy[(1-\beta)T_2 - T_3 - T_4 + T_5] + x(T_3 - T_5)\right\} \end{aligned} \tag{12}$$

### 3.4. Evolutionary stability strategy solution and equilibrium point stability discrimination

Let the above three replication dynamic equations (10)–(12) be 0, that is $\frac{dx}{dt} = \frac{dy}{dt} = \frac{dz}{dt} = 0$, there are 8 pure strategy equilibrium points: $R_1(1,1,1), R_2(1,1,0), R_3(1,0,0), R_4(1,0,1), R_5(0,1,0), R_6(0,1,1), R_7(0,0,1), R_8(0,0,0)$ . Solve the Jacobian matrix (The expression of the elements in the matrix is shown in formulas (13) - (21).)for the above replicated dynamic equation, we can obtain:

$$J = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix} = \begin{bmatrix} \frac{\partial G(x)}{x} & \frac{\partial G(x)}{y} & \frac{\partial G(x)}{z} \\ \frac{\partial G(y)}{x} & \frac{\partial G(y)}{y} & \frac{\partial G(y)}{z} \\ \frac{\partial G(z)}{x} & \frac{\partial G(z)}{y} & \frac{\partial G(z)}{z} \end{bmatrix} \text{ among them:}$$

$$J_{11} = (1-2x)\{(1-\gamma)[yzT_2 + y(1-z)(T_1+T_4) + (1-y)z(T_3+T_6) + (1-y)(1-z)(T_0+T_5)]\} \tag{13}$$

$$J_{12} = x(1-x)\{(1-\gamma)[zT_2 + (1-z)(T_1+T_4) - z(T_3+T_6) - (1-z)(T_0+T_5)]\} \tag{14}$$

$$J_{13} = x(1-x)\{(1-\gamma)[yT_2 - y(T_1+T_4) + (1-y)(T_3+T_6) - (1-y)(T_0+T_5)]\} \tag{15}$$

$$J_{21} = y(1-y)\{[z(\beta T_2 - T_1 - T_6 + T_0) + T_1 - T_0]\} \tag{16}$$

$$J_{22} = (1-2y)\{[E_1 - C_1 - E_2 + C_2 + z(K_1 - F) + xz(\beta T_2 - T_1 - T_6 + T_0) + x(T_1 - T_0)]\} \tag{17}$$

**Table 3**
Characteristic roots corresponding to equilibrium points and discrimination of stability.

| Equilibrium | Characteristic root | Stability judgment |
|---|---|---|
| $R_1(1,1,1)$ | $\lambda_{11} = -(1-\gamma)T_2, \lambda_{12} = -(E_1 - C_1 - E_2 + C_2 + K_1 - F + \beta T_2 - T_6)$,<br>$\lambda_{13} = -[H_1 - L_1 - H_2 + L_2 + K_2 + (1-\beta)T_2 + T_4]$ | when $\lambda_{12} < 0, \lambda_{13} < 0$ , ESS |
| $R_2(1,1,0)$ | $\lambda_{21} = -(1-\gamma)(T_1+T_4), \lambda_{22} = -(E_1 - C_1 - E_2 + C_2 + T_1 - T_0)$<br>$\lambda_{23} = H_1 - L_1 - H_2 + L_2 + K_2 + (1-\beta)T_2 + T_4$ | when $\lambda_{22} < 0, \lambda_{23} < 0$ , ESS |
| $R_3(1,0,0)$ | $\lambda_{31} = -(1-\gamma)(T_0+T_5), \lambda_{32} = E_1 - C_1 - E_2 + C_2 + T_1 - T_0$<br>$\lambda_{33} = H_1 - L_1 - H_2 + L_2 + K_0 - F + T_3 - T_5$ | when $\lambda_{32} < 0, \lambda_{33} < 0$ , ESS |
| $R_4(1,0,1)$ | $\lambda_{41} = -(1-\gamma)(T_3+T_6), \lambda_{42} = E_1 - C_1 - E_2 + C_2 + K_1 - F + \beta T_2 - T_6$<br>$\lambda_{43} = -(H_1 - L_1 - H_2 + L_2 + K_0 - F + T_3 - T_5)$ | when $\lambda_{42} < 0, \lambda_{43} < 0$ , 为ESS |
| $R_5(0,1,0)$ | $\lambda_{51} = (1-\gamma)(T_1+T_4), \lambda_{52} = -(E_1 - C_1 - E_2 + C_2)$<br>$\lambda_{53} = H_1 - L_1 - H_2 + L_2 + K_2$ | $\lambda_{51} > 0$ , unstable |
| $R_6(0,1,1)$ | $\lambda_{61} = (1-\gamma)T_2, \lambda_{62} = -(E_1 - C_1 - E_2 + C_2 + K_1 - F)$,<br>$\lambda_{63} = -(H_1 - L_1 - H_2 + L_2 + K_2)$ | $\lambda_{61} > 0$ , unstable |
| $R_7(0,0,1)$ | $\lambda_{71} = (1-\gamma)(T_3+T_6), \lambda_{72} = E_1 - C_1 - E_2 + C_2 + K_1 - F$<br>$\lambda_{73} = -(H_1 - L_1 - H_2 + L_2 + K_0 - F)$ | $\lambda_{71} > 0$ , unstable |
| $R_8(0,0,0)$ | $\lambda_{81} = (1-\gamma)(T_0+T_5), \lambda_{82} = E_1 - C_1 - E_2 + C_2$<br>$\lambda_{83} = H_1 - L_1 - H_2 + L_2 + K_0 - F$ | $\lambda_{81} > 0$ , unstable |

$$J_{23} = y(1-y)\{[K_1 - F + x(\beta T_2 - T_1 - T_6 + T_0)]\} \tag{18}$$

$$J_{31} = z(1-z)\{y[(1-\beta)T_2 - T_3 - T_4 + T_5] + T_3 - T_5\} \tag{19}$$

$$J_{32} = z(1-z)\{K_2 - (K_0 - F) + x[(1-\beta)T_2 - T_3 - T_4 + T_5]\} \tag{20}$$

$$J_{33} = (1-2z)\{H_1 - L_1 - H_2 + L_2 + yK_2 + (1-y)(K_0 - F) + xy[(1-\beta)T_2 - T_3 - T_4 + T_5] + x(T_3 - T_5)\} \tag{21}$$

The eigenvalue corresponding to the equilibrium point can be obtained from the above matrix, and the corresponding results are summarized as shown in Table 3 below.

#### 3.4.1. *Situation $R_1$(1,1,1)*

If $R_1$ is an evolutionary stable point, the inequality conditions that need to be satisfied are: $E_1 - C_1 - E_2 + C_2 + K_1 - F + \beta T_2 - T_6 > 0$ , and $H_1 - L_1 - H_2 + L_2 + K_2 + (1-\beta)T_2 + T_4 > 0$, at this time, there are expected benefits of marine enterprises choosing cooperative innovation (the first part of the former formula is the basic net income, and the second half is the net income of cooperative innovation.) is greater than the cost of choosing not to innovate. For academic research institutions, the expected benefit of choosing cooperative innovation is greater than the cost of choosing not to innovate. At this time, the system reaches the ideal state of win-win-win, and evolves towards the strategy combination (provide, cooperate, cooperae).

#### 3.4.2. *Situation $R_2$(1,1,0)*

If $R_2$ is an evolutionary stable point, the inequality conditions that need to be satisfied are: $E_1 - C_1 - E_2 + C_2 + T_1 - T_0 > 0$ and $H_1 - L_1 - H_2 + L_2 + K_2 + (1-\beta)T_2 + T_4 < 0$, at this time, the expected benefit of marine enterprises choosing cooperative innovation is greater than the cost of non-cooperative innovation, while the expected benefit of academic research institutions choosing cooperative innovation is less than that of non-cooperative innovation cost. At this point the system will evolve towards a strategy combination (provide, cooperate, not cooperate). At this time, marine enterprises choose to carry out technological innovation research and development activities through cooperation between enterprises or cooperation with other supply chain members.

#### 3.4.3. *Situation $R_3$(1,0,0)*

If $R_3$ is an evolutionary stable point, the inequality conditions that need to be satisfied are: $E_1 - C_1 - E_2 + C_2 + T_1 - T_0 < 0$, and $H_1 - L_1 - H_2 + L_2 + K_0 - F + T_3 - T_5 < 0$. At this time, the net income of marine enterprises and academic research institutions choosing cooperative innovation is less than 0. At this time, the system will evolve towards a strategic combination (provide, not cooperate, not cooperate). At this time, although financial institutions provided loans, marine enterprises and academic research institutions chose to "follow their own agendas" and conduct R&D activities independently, which is consistent with the current innovation status of marine enterprises.

#### 3.4.4. *Situation $R_4$(1,0,1)*

If $R_4$ is an evolutionary stable point, the inequality conditions that need to be satisfied are: $E_1 - C_1 - E_2 + C_2 + K_1 - F + \beta T_2 - T_6 < 0$ , and $H_1 - L_1 - H_2 + L_2 + K_0 - F + T_3 - T_5 > 0$. At this time, the net income of marine enterprises choosing cooperative research and development is less than 0, while the net income of academic research institutions choosing cooperative research and development is greater than 0. At this time, the system will evolve towards (provide, not cooperate, cooperate). At this time, marine enterprises and academic research institutions carry out technological innovation respectively, but the process of marketization of technological achievements by academic research institutions realized and completed with the help of marine enterprises.

## 4. Numerical analysis and discussion

In September 2022, BlueSurvey (Qingdao) Ocean Technology Co., Ltd.'s "Exploration Sea Needle Project" emerged as an outstanding example of technological innovation contributing to the construction of a maritime powerhouse. The "Exploration Sea Needle" series is a set of high-end marine equipment developed by the company's team ( Some team members are from universities and other research institutions ) with completely independent intellectual property rights. Its appearance resembles a round acupuncture needle, but the similarities go beyond just the external shape. In terms of functionality, while the round acupuncture needle acts on the skin and muscles during acupuncture, the "Exploration Sea Needle" functions in the process of entering the sea, specifically targeting the mechanism of sediment layers. In marine geotechnical surveys, this "round acupuncture needle" is inserted into the seabed to explore surface sediment layers. Great achievements start with attention to detail. In 2015, the team initiated market research for marine engineering surveys. Serving technology to meet demands, the project team continuously refined technical solutions through ongoing market research. Simultaneously, they emphasized the practical application of technological achievements, creating a closed-loop development for the entire project. In September 2022, the "Exploration Sea Needle" project landed in the Qingdao National University Science and Technology Park, giving rise to the establishment of "BlueSurvey (Qingdao) Ocean Technology Co., Ltd." Over the past year, the project has received considerable attention and support from the government departments in the high-tech zone and the park where it is located. This support includes providing facilities and policies for project development. Initiatives like "Tide Star" (Qingdao High-tech Zone) have organized multiple business networking events and industry achievement docking meetings, assisting companies in expanding their cooperation channels. Throughout the research and development innovation process of the entire project, there has been significant public relations for the technology. Simultaneously, attention has been given to the practical application and commercialization of technological achievements. BlueSurvey (Qingdao) Ocean Technology Co., Ltd. has provided real-world evidence supporting our theoretical model. In order to more intuitively find the influence of different parameters on the evolution system, this section uses numerical simulations to furtherly analize the above model. Referring to the real-world context. and previous research [48–54], this paper makes: $C_1 = 3, C_2 = 2, T_0 = 2, T_1 = 2, T_2 = 10, T_3 = 4, T_4 = 4, T_5 = 5, T_6 = 6, K_0 = 1, K_1 = 2, K_2 = 3, E_1 = 2, E_2 = 1, H_1 = 1, H_2 = 0.5, L_1 = 2, L_2 = 1, \gamma = 0.02, F = 1.5, \beta = 0.6$. Brief explanation for parameter selection is as follows: Considering the various uncertainties that can impact the collaboration process in reality, a value slightly greater than the basic benefit parameter is chosen for the cost parameter. This allows focusing the system evolution on the perspective of our main interest, which is the financing collaboration and guarantee relationships. Additionally, in general, in industry-academia-research collaborations, the share of profits for enterprises is often higher than the other two parties. In cases where the enterprise takes on the role of marketing in market-oriented promotion scenarios, the costs for research institutions are typically smaller. Unfortunately, due to different industry conventions and the strong confidentiality of many commercial data in reality, it is challenging to obtain reference to real data in the simulation part. This paper mainly analyzes the evolution from two perspectives: (1) the strategy selection and evolution of the three subjects in the case of different initial willingness to choose different strategies; (2) the impact of changes in the benefit and cost parameters on the evolution of equilibrium results.

### *4.1. The impact of changes in financial institution regulatory cost coefficients on equilibrium evolution*

As can be seen from the above Fig. 1, with the increase of the regulatory cost coefficient of financial institutions, both academic research institutions and marine enterprises tend to choose cooperative innovation, while financial institutions tend to choose to provide loans when the regulatory cost coefficient is low. In most cases (meaning that all the provided loans have become sunk costs), the initial willingness will remain unchanged, which is consistent with the current actual situation. Many good innovative projects cannot be financed. Due to information asymmetry, there is a "wait-and-see situation" for projects on the market.

### *4.2. The impact of changes in the loan allocation ratio of marine enterprises on the equilibrium evolution*

It can be seen from the above Fig. 2 that when the proportion of loans occupied by marine enterprises is relatively low, the strategic choices of the three subjects are not affected by the initial willingness, but when the proportion of loans occupied by marine enterprises increases to a medium level, the strategic choices of financial institutions are not affected. But in the case of low initial choice willingness, neither academic institutions nor marine enterprises converged to strategy 1. When marine enterprises occupy a relatively high proportion of loans, the strategies of marine enterprises and academic research institutions quickly converge to 0 regardless of the initial selection willingness. Simultanously, marine enterprises choose not to innovate, and academic research institutions choose not to cooperate. The reasons for this are worth thinking about. With the increase in the proportion of loans occupied by marine enterprises, the willingness of academic and research institutions to carry out innovation cooperation gradually decreases. At this time, it is a better choice to carry out pure technology promotion cooperation or "Let me alone". Synergy benefits are not very attractive. When the proportion of loans occupied by marine enterprises gradually increases to a high level, eventually academic research institutions and marine enterprises will gradually abandon the "cooperative R&D strategy".

### *4.3. The impact of changes in the income of academic research institutions and marine enterprises on the equilibrium of purely market-oriented promotion cooperation*

As can be seen from the above Fig. 3, when the income of market promotion is relatively low, the strategies of the three main parties tend to evolve towards the ideal state (provide, innovate, cooperate). When the willingness of marine enterprises and academic research institutions to cooperate is relatively low, academic research institutions tend to choose not to cooperate, which only carry

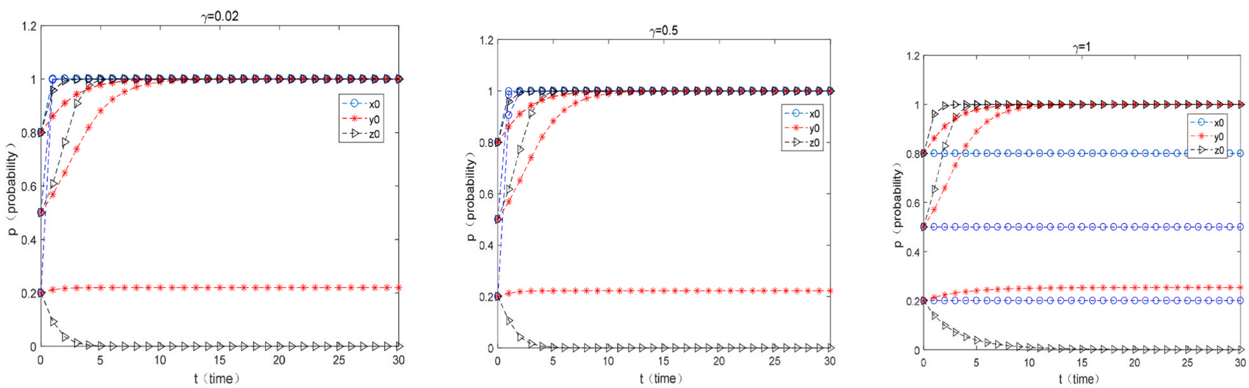


**Fig. 1.** The impact of changes in the regulatory cost coefficient of financial institutions on the evolution of equilibrium.

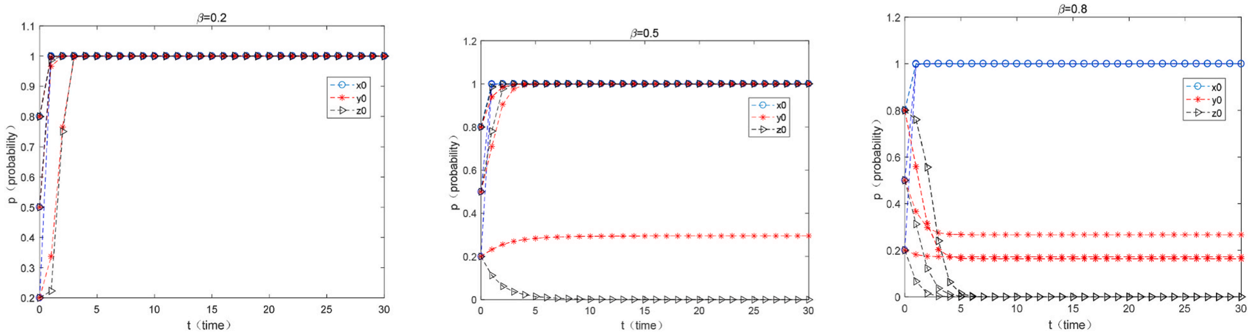


**Fig. 2.** The impact of changes in the loan allocation ratio of marine enterprises on the evolution of equilibrium.

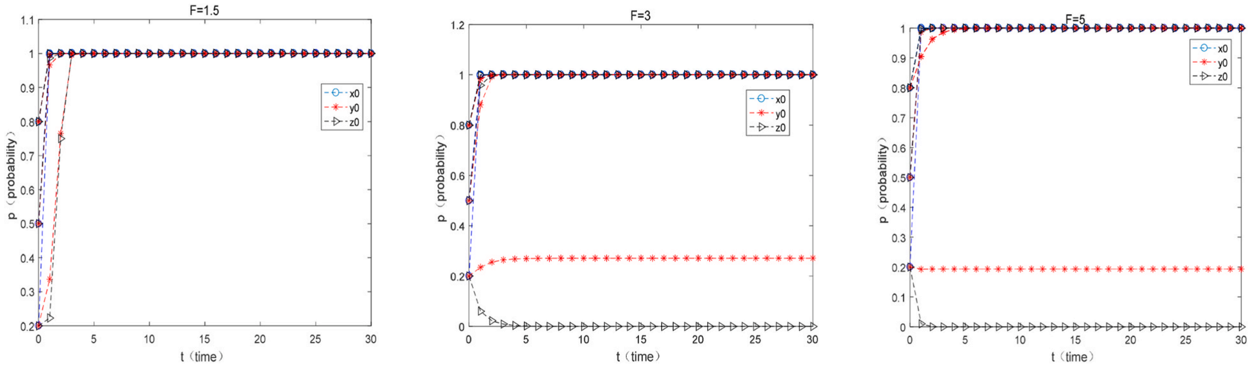


**Fig. 3.** The impact of changes in the benefits of purely market-oriented promotion cooperation between academic research institutions and marine enterprises on the equilibrium.

out marketization/invovation promotion of achievements through marine enterprises. However, when the willingness of the two to collaborative innovation is relatively high, the three still evolve towards the ideal state of tripartite cooperation. The management implication here is that when the willingness of each parties to cooperate is low, only market-oriented cooperation can become an effective supplement to traditional cooperation, which is helpful for realizing the ultimate goal of marine technology innovation.

### *4.4. The impact of changes in synergistic benefits on equilibrium evolution*

As can be seen from the above Fig. 4, with the increase of synergistic benefits, the strategy choices of the three do not change, and this result is not affected by the initial willingness.

### *4.5. The impact of changes in the underlying income of the main body on the equilibrium evolution*

As can be seen from Fig. 5 below, with the increase of the basic income of marine enterprises innovate, when the basic income of

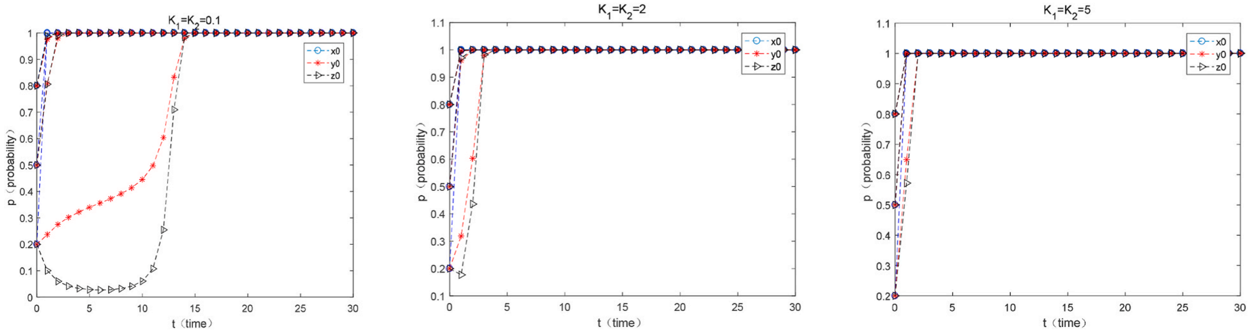


**Fig. 4.** The impact of changes in the synergistic benefits of cooperative innovation between marine enterprises and academic-research institutions on equilibrium evolution.

innovation is low, marine enterprises and academic research institutions will choose to converge to (not innovate, not cooperate), The conditions that need to be satisfied simultaneously are the low initial willingness. However, with the increase of the basic income of innovation, the three will eventually converge to a win-win synergy state (provide, innovate, cooperate), and the results will not be affected by the initial selection willingness. In this scenario, the equilibrium state will transfer from (1, 0,0) to (1,1,1). With the increase of the basic income of choosing not to innovate, when the basic income of non-innovation is low, marine enterprises will choose to gradually converge to the vicinity of the initial value with a relatively low initial willingness. Moreover, as the basic income of non-innovation increases, the initial willingness of marine enterprises will converge to 0, and only in the case of a very high initial willingness will it converge to a state of win-win-win (1, 1, 1). In other words, the basic benefits of no innovation when it is relatively high, it is difficult for the system to achieve a state of multi-parties' win-win-win cooperation. Without innovation and independent governance, it will become a "locked state", which is consistent with the current situation in China.

As the basic benefits of the cooperation chosen by the academic research institutions increase, the strategy of the academic research institutions will gradually change from non-cooperation at the beginning to cooperation. At this time, the system evolves from (1,0,0) to (1,1,1).

### *4.6. Discussion*

From the above analysis, it can be seen that the increase of the regulatory cost coefficient of financial institutions can promote academic research institutions and marine enterprises to choose cooperative innovation strategies. Furthermore, the willingness of financial institutions to provide loans is higher when the cost is relatively low. Cost has always been one of the crucial factors in the related studies of evolutionary games. For example, literature [55–57] clearly points out that cost can significantly affect the strategic choice and evolution of relevant stakeholders. In reality, financial institutions are more reluctant to lend because of asymmetric information. Although the model in this paper does not strictly subdivide the ownership types of marine enterprises, some empirical

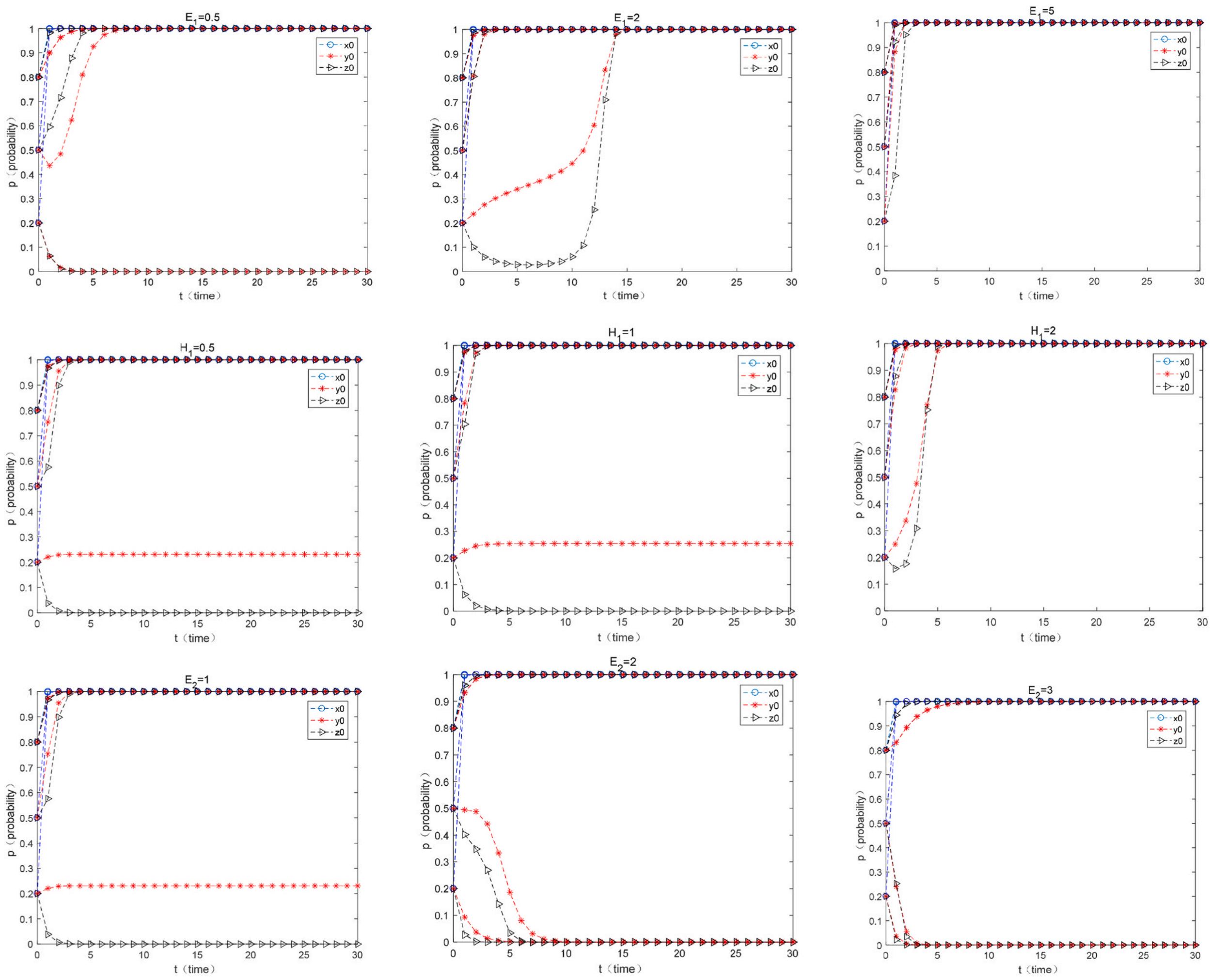


**Fig. 5.** The impact of changes in underlying returns on equilibrium evolution.

studies point out [58] that for state-owned enterprises and private enterprises, it is easier for the subject to obtain loans from financial institutions. Benefits and costs are like two sides of the same coin. There are certain costs that can significantly affect the strategic choice and evolution of the subject, and it is self-evident that certain revenue factors can achieve the same effect. It is found in this paper that the changes of the basic returns of the three parties can significantly affect the strategy selection and evolution. When financial institutions provide financial support, the lower the basic returns of innovation, the more likely marine enterprises and research institutions choose not to cooperate. As we all know, there is a high risk of failure in innovation, which leads to a high risk of failure in debt, so policy makers are usually cautious when it comes to innovation cooperation. Hence, it's not unexpected that the fundamental income from innovation plays a substantial role in influencing the strategic decisions and evolution of pertinent stakeholders. Unfortunately, predicting the income from cooperative innovation in advance is challenging. Moreover, the initial choice intentions of the three parties significantly impact the ultimate evolutionary outcome. When the initial willingness for cooperation strategy is relatively low, the likelihood of the three parties opting for cooperation diminishes. Consequently, they are more prone to end up in an undesirable "locked state." This aligns with the present scenario of insufficient innovation collaboration between Chinese domestic marine enterprises and research institutes.

In addition, the allocation ratio after applying for loans is also an Indispensable factor worth paying attention. When carrying out innovation cooperation, if the proportion of marine enterprises is relatively high, the cooperation willingness of academic research institutions will be reduced. At this time, compared with the benefits of cooperation, determined benefits such as loans or "capital control rights" seem to become more attractive. Some literatures also point out that the "myopic" behavior of relevant stakeholders will affect the willingness to cooperate [59]. At this time, pure technology marketization promotion cooperation is more likely to be adopted. When the loan amount occupied by marine enterprises increases to a certain extent, both academic research institutions and marine enterprises will abandon the cooperation strategy and return to the state of "let me alone". When Marine enterprises and research institutions only carry out market-oriented promotion cooperation without R&D cooperation, the strategy evolution of the three parties will be significantly affected by the benefits of market-oriented promotion cooperation, and with the increase of such benefits, the cooperation willingness of Marine enterprises and research institutions will be enhanced. Finding from a comparing previous studies with the discovery of this paper is novel, the past study only from the angle of "dichotomy" to discuss the main body of cooperation or not, this study will open the "black box" of cooperation, to explore the middle of the cooperation fields and not cooperation in previous views-a step backwards in the form of cooperation. The above example has found that the parameter conditions of the cooperation are weaker than that of the complete cooperation, which is a pleasant finding. At the same time, the management implication of the explanation lies in that the market-oriented cooperation only can be used as a supplement to the traditional cooperation form, and it is easier to realize in practice.

## 5. Conclusions and implications

With the further acceleration of the economic process, the central government proposed a high-quality development strategy for the marine economy in 2021, which puts forward new requirements for the adjustment of the marine economy and the upgrading of the industrial structure. The development of the marine economy with technological innovation is the only way to develop the marine economy in the future. After tortuous and difficult exploration and development, China's marine science and technology work has entered a new stage of "qualitative breakthrough" from the stage of "quantitative accumulation". Although great achievements have been made in the development of marine science and technology across the country, there is still a gap in the awareness and ability of scientific and technological innovation. Marine independent innovation, especially primitive innovation needs to be strengthened.

To explore the pathways and mechanisms of technological innovation in the marine sector, this study innovatively categorizes industry-university-research collaboration in the marine economy into traditional innovative R&D cooperation and pure market-driven promotion. Employing a tripartite evolutionary game model, we investigate the strategic decisions of financial institutions, marine enterprises, and academic-research institutions. Our findings reveal that the actions of financial institutions and marine enterprises are influenced by the initial willingness of participants. When the basic benefits of cooperation and innovation between academic research institutions and marine enterprises are higher, the system reaches an evolutionary stable state more rapidly. Moreover, pure market-oriented innovation promotion is anticipated to serve as a complementary approach to traditional cooperative innovation. As the basic income of marine enterprises opting for innovation increases, and especially when the basic income of innovation is low, marine enterprises and academic research institutions tend to converge towards a state of not innovating and not cooperating when the initial willingness is low. Eventually, they converge to a win-win-win synergy state (provide, innovate, and cooperate), unaffected by the initial willingness to choose. During this phase, the equilibrium state shifts from (1,0,0) to (1,1,1). Conversely, with an increase in the basic income of choosing not to innovate, marine enterprises gradually converge towards the vicinity of the initial value when the initial choice willingness is relatively low. However, as the basic income of non-innovation rises, the initial willingness of marine enterprises converges to 0, reaching a win-win-win state (1, 1, 1) only in cases of very high initial willingness. This illustrates that when the basic benefits of not innovating are relatively high, achieving multi-party cooperation and a win-win-win state becomes challenging for the system. The state of no innovation and independent governance consequently becomes a "locked state."

From the above results, the following policy implications can be drawn: ①First, when the basic benefits of innovation increase, it is conducive to achieving a win-win-win situation of collaborative innovation among the three parties. Major technological breakthroughs can bring about a great increase in basic benefits. This puts forward higher requirements on the innovation quality of marine enterprises and academic research institutions. For major technological breakthroughs and achievements in other fields, we must dare to break the blank and not stuck in a rut; ②Secondly, when marine enterprises and academic research institutions carry out technological innovation when the initial willingness to cooperate is relatively low, it is possible to simply carry out cooperative innovations such as technology promotion. At the beginning, both parties may not be familiar enough with each other. At this time, this process can be used as a foreshadowing and transition process, laying the foundation for further in-depth cooperation. ③Thirdly, financial institutions can flexibly conduct risk review in the lending process. In the process of cooperative innovation and R&D, if there are many participants, risk sharing can be carried out among multiple entities, and these entities guarantee each other. The success rate of obtaining the loan can be increased.

Of course, there are still some shortcomings in this paper. First, the selection of simulation parameters in this paper lacks the support of real data. In the future, different means can be used to provide more empirical evidence for the research results of this paper. Secondly, in addition to pure technical promotion cooperation additionally, there may be other flexible cooperation means, which need to be further explored and studied. Finally, the development of digital technology will play an increasingly crucial role in the future of the marine economy. Exploring related research in the field of digital economics will be an intriguing direction. Last but not least, We have not developed the latest software that applies new methods. Future research could delve deeper into this aspect and potentially lead to market implementation.

## Data availability

Data will be made available on request.

## CRediT authorship contribution statement

**Hongwei Ma:** Writing – original draft, Conceptualization. **Guisheng Hou:** Investigation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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