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ANALYSIS OF COLLABORATIVE INNOVATION BEHAVIOR OF MEGAPROJECT PARTICIPANTS UNDER THE REWARD AND PUNISHMENT MECHANISM

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Abstract. Megaprojects are characterized by significant environmental uncertainty and technical complexity, which bring great challenges to engineering construction. Cross-organizational collaborative innovation is an important way to solve these problems. As the main body that understands the difficulties of the construction site and uses innovative products, the participation of megaproject participants is not only conducive to increasing innovation efficiency but also conducive to the application and promotion of innovative achievements. The collaborative innovation behavior of the participants in megaprojects under the reward and punishment incentive mechanism was studied. A game model between different participants was built by combining evolutionary game theory with prospect theory. Then, the dynamic evolution process of the collaborative innovation strategy of participants was analyzed, and the main factors affecting the evolutionary stability strategy of collaborative innovation through numerical simulation were examined. The research results indicate that reward and punishment incentives of collaborative innovation can encourage participants to choose the evolutionary stability strategy of participating in collaborative innovation from both objective and subjective aspects. Factors, such as the cost of participating, the synergy coefficient, the proportion of collaborative revenue distribution, and risk preference, can influence participants' willingness to engage in collaborative innovation to different degrees.

Keywords: collaborative innovation, megaprojects, participants, reward and punishment mechanism, prospect theory, evolutionary game.

Introduction

In recent years, with the rapid development of the economy and the increase in urbanization, the scale of infrastructure investment around the world has been expanding (Owolabi et al., 2020), and some megaprojects have been gradually completed and are now being put into use, such as the Hong Kong-Zhuhai-Macao Bridge in China (Chen et al., 2020a) and the Crossrail, Europe's largest civil engineering project (Worsnop et al., 2016). Because the technical complexity and environmental uncertainty of megaprojects bring about great challenges with regard to a smooth construction (Bahadorestani et al., 2020; Romestant, 2020), which increases the demand for technological innovation (Liu & Ma, 2020), an increasing number of scholars are paying attention to topics related to megaproject innovation. Innovation in megaprojects can be defined as "the successful commercial exploitation of new ideas, and it includes the scientific, technological, organizational, financial, and business activities leading to the introduction of a new (or improved) product or service" (Cantarelli, 2022). Moreover, megaproject innovation needs to cross organizational boundaries and relies on the close cooperation of a large number of participants (Brockmann et al., 2016). For instance, the Sichuan–Tibet Railway megaproject, which was under construction in China, has been in an extremely complex geological environment. It's bridges and tunnels account for more than 80% of the whole railway line, which is a world-class problem in railway engineering design and construction (Zhu, 2017). To ensure the implementation of the megaproject, the Chinese government has established the Sichuan Tibet Railway Technology Innovation Center, to gather advantageous innovation resources and provide technical support for the construction of the Sichuan–Tibet Railway megaproject.

Due to the uncertainty of the megaproject construction environment, technological innovation is often separated from the actual engineering needs. The question is

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how to integrate technological innovation with engineering construction so that innovation can serve megaprojects? The participation of units joining into the construction in collaborative innovation is considered to be an effective solution (Ozorhon, 2013). On the one hand, due to the uncertainty of the construction site environment, the innovation demand has dynamic characteristics. Since the participating units have a better understanding of the actual situation of the construction site, their participation in collaborative innovation will increase innovation efficiency. The participation of the units joining into the construction, who are generally users of innovation achievements, in collaborative innovation cooperation will not only contribute to the application and promotion of innovation achievements and also improve the implementation efficiency of megaprojects. For example, in the Hong Kong-Zhuhai-Macao Bridge project, the general contractor participated in collaborative innovation through deep embedding, and successfully developed the prediction and guarantee system of the immersed pipe docking window and real-time monitoring system of motion attitude, ensuring the smooth installation of immersed pipes in deep grooves (Chen et al., 2020b). Therefore, the participation of the units joining into the construction (the following is expressed as participants) in collaborative innovation plays an important role in the construction of megaprojects and the development of scientific and technological innovation. It is of great practical significance to study the innovative cooperation behavior of participating units in the collaborative innovation of megaprojects.

However, the risks and uncertainties of megaprojects lead to the avoidance of innovation (van Marrewijk et al., 2008). Participants, such as designers and contractors, are very reluctant to introduce novel ideas and innovative approaches. They often seek to minimize risks by relying on tested-and-tested techniques, established practices, and proven technologies (Dodgson et al., 2015; Flyvbjerg et al., 2009). Our team investigated the designers and contractors of megaprojects. Findings confirm that these participating units do not have high enthusiasm for collaborative innovation, even if they know that their participation can enhance the innovation efficiency because of some concerns: 1. Project risk and accountability (Bruzelius et al., 2002); 2. Innovation resource spillovers in the process of collaborative innovation; 3. Innovation investment; 4. Achievement sharing among peers with competitive relationships; 5. Insufficient innovation personnel. Another reason for low enthusiasm among the designers and contractors is that they are resistant to change (Ozorhon, 2013). However, the participating units can feel the benefits of innovation after trying, including in both the short term and long term. However, everything is difficult at the beginning. As the leader of collaborative innovation in megaprojects, the client plays an important role in the collaborative relationship of each stage of engineering and technological innovation (Manley, 2006). They can promote innovation by putting pressure on the participants in the project construction (Ozorhon, 2013), because of the principal-agent relationship (Jensen & Meckling, 1976). In this manuscript, the innovation led by the client is considered; for example, the client asks the contractor to apply the digital twin platform in the Sichuan Tibet Railway project. The collaborative innovation behavior of participants in megaprojects under the most common reward and punishment mechanism in the incentive mechanism is the focus.

Due to its sheer scale, the megaproject is generally constructed by multiple contractors. The behavior of participants whether to participate in collaborative innovation is a dynamic evolution process due to the long construction period, and it will be affected by the strategies of other construction participants. To analyse the behavior dynamic process of megaproject participants participating in collaborative innovation under the reward and punishment mechanism, we quantitatively describe the cooperative behavior of collaborative innovation is quantitatively described by using evolutionary game theory (Smith, 1974) based on the limited rationality of participants and the complexity of megaproject collaborative innovation. Moreover, considering the risk attitude of the actor when facing losses and benefits, prospect theory (Kahneman & Tversky, 1979) was integrated into the evolutionary game model. The study primarily focuses on the following questions: (1) the evolution of collaborative innovation behavior of construction participants under reward and punishment mechanisms; (2) the effect of objective factors such as reward and punishment factors and innovation income distribution factors on participants' collaborative innovation behavior; and (3) the effect of behavioral factors such as risk preference factors and loss sensitivity factors on participants' collaborative innovation behavior. The findings contribute to new insights on the incentive mechanism for collaborative innovation, and effectively improve the governance and smooth implementation of megaprojects.

This study is organized as follows. First, a logical review of the literature was undertaken, including innovation in construction megaprojects, collaborative innovation in construction megaprojects, evolutionary game theory and its applications, and prospect theory and its applications. Then, a payoff matrix for the game process between participants was constructed after the model assumptions, followed by our calculations and discussion of the results. Next, we simulated and analysed the factors affecting the collaborative innovation behavior of participants in megaprojects to examine the theoretical applications of this model. Finally, the research concludes with a discussion of the findings and some management suggestions.

1. Literature review

1.1. Innovation in construction megaprojects

Early innovation in the construction industry was mainly defined from the perspective of the mass production of products based on the particularity of construction products. Slaughter (1998) defined innovation in construction as the significant improvement of process, product, or system, in particular, the first time that enterprises have implemented such improvement. Later, Winch (2013) believed that innovation in construction is the first successful application of new technology in construction enterprises and that this technology can significantly improve the design and construction conditions of buildings, reduce construction costs and improve construction performance. Sergeeva and Zanello (2018) define innovation in the context of megaprojects as a new product, process, or service that has a step change and creates value, e.g., financial value, environmental value, societal value, job creation, etc. It may be new to a megaproject but not necessarily new to the world.

Innovation has a context-sensitive nature; thus, innovation in construction differs from those in other industries. Hemström et al. (2017) pointed out that the discrete and temporary nature (Turner & Müller, 2003) of project organization and the resultant high risks are the core obstacles restricting the innovation of construction projects. The project organization mode is the root cause of the temporary and decentralized nature, which hinders knowledge innovation and exchange (Tatum, 2018). Because the construction project is not reversible, the application of innovation experience in other projects is limited, which will reduce innovation income, weaken the enterprise's innovation willingness, and lead to repeated innovation (Dodgson et al., 2014). Given the temporary dispersion of project organization, Winch (2013) believes that the performance of technology innovation in construction megaprojects can be improved through integrated management, including multi-project integrated management, design and construction integrated management, etc. Cantarelli (2022) examined how the technical complexity of megaprojects specifically affects the innovation dimension. Davies et al. (2014) pointed out that there are two kinds of technological innovation activities: "top-down innovation" and "bottom-up innovation" in the construction megaproject according to how the innovation starts and develops. The split and short-sighted management mode caused by the separation of design and construction of system integrators is one of the reasons for the obstacles of "top-down innovation", and the decentralized cooperation mode among clients, contractors, and system integrators restricts "bottom-up innovation" (Sergeeva & Zanello, 2018). When the client has the ability to lead the project, bear risks, and coordinate design and construction activities, it can also play the role of a system integrator. As a system integrator, the client can better integrate the whole innovation process in a megaproject (Winch, 2013). Ozorhon (2013) found that building regulations and client requirements are the major drivers of innovative solutions in the construction sector based on four cases. He believed that the barriers that participants were hesitant to face as a result of the additional costs and resistance to change were primarily overcome by the integration of the project teams, such as the early involvement of contractors. Regarding the innovation of construction megaprojects, previous research has demonstrated many successful experiences. However, these studies rarely consider the principal-agent relationship of construction and analyse the innovation behavior of participants with limited rationality on the microscopic view. How to analyse the behavior of participants who make innovation decisions according to their gains and losses, and build an adaptive innovation incentive mechanism is an urgent research field from the perspective of innovation in the construction of megaprojects.

1.2. Collaborative innovation in construction megaprojects

Practical problems faced during the construction of megaprojects generally require innovative solutions. Therefore, innovation may occur out of a necessity as well (Ozorhon & Ora, 2016). On the one hand, the innovation demand of megaprojects is characterized by significant uncertainty. The innovation of megaprojects highly depends on the cooperation and interaction among stakeholders, which requires cross-organization, cross-department, cross-industry, and cross-regional collaborative innovation (Brockmann et al., 2016; Ercan, 2019). On the other hand, collaborative innovation in megaprojects has the characteristics of multistage interactive evolution, and there are many modes, such as symbiosis, competition, and cooperation, among innovation subjects (Sergeeva & Zanello, 2018). Gil et al. (2012) emphasized the importance of collaborative cooperation in megaproject innovation and suggested integrating internal and external resources and strengthening cooperation and exchange among multiple subjects to meet the innovation needs of megaprojects. In addition, some influencing factors of collaborative innovation of megaprojects were pointed out, such as project complexity, client requirements, innovation policy, leadership, innovative culture, organizational capacity, etc., (Ozorhon & Ora, 2016; Sergeeva & Zanello, 2018).

Because the collaborative innovation of megaprojects presents the characteristics of highly complex technology, many innovation subjects and dynamic replacement of innovation subjects lead to problems such as low enthusiasm of innovation subjects, low innovation efficiency, and the unclear ownership of achievements (Chen et al., 2020b; Xue et al., 2021). Therefore, it is necessary to build a series of innovative coordination mechanisms in construction megaprojects, including engineering supply chain management and incentive measures. Liu and Ma (2020) stated that appropriate incentive and supervision mechanism is an effective means to improve innovation performance in megaproject technology innovation, and they proposed a novel supervision method based on risk assessment. Xue et al. (2021) designed bilateral collaborative innovation incentive contracts for major projects under moral hazard, focused on the problem of low innovation efficiency caused by the unreasonable design of the collaborative innovation contract of major projects. Ma and Liu (2020) explored the incentive mechanism of collaborative innovation of megaprojects and analysed the impact of fairness on the design of the incentive mechanism. Davies et al. (2014) analysed the realization path of collaborative innovation in megaprojects from four levels and indicated that the project manager can promote the innovation efficiency of megaprojects by formulating targeted innovation incentive measures. Previous research on the driving factors and incentive mechanism of the collaborative innovation of megaprojects has laid a solid foundation for our study and improved our understanding of the collaborative innovation of megaprojects. At present, the innovation cooperation behavior of construction participants in megaprojects is still "under-researched". However, because scholars have different research perspectives and focuses, few studies have analysed the cooperative innovation behavior of megaproject participants under the client's reward and punishment mechanism from the perspective of the game, and they have not considered the risk attitude of people in the face of income and loss.

1.3. Evolutionary game theory and its applications

With the development of experimental economics in recent years, the hypothesis of complete rationality in traditional games has been questioned. In reality, it is difficult for decision-makers to meet the high requirements of complete rationality, especially when the socioeconomic environment and decision-making problems are complex, and the bounded rationality (Simon, 1955) of decision-makers is more obvious. Moreover, the hypothesis of being completely rational not only makes the analysis of the game lack a dynamic process but also makes the game unable to completely solve the choice problem of multiple equilibria (Fan & Hui, 2020). Inspired by the idea of biological evolution, Maynard Smith and Price (1973) introduced into game theory the idea of evolution in biological theory. They put forward the idea of the evolutionary game and the concept of evolutionary stability strategy, or ESS. Since then, evolutionary game theory which has improved on complete rationality and static games, has become an important branch of game theory for investigating behavioral regularities (He et al., 2022).

Evolutionary game theory has been used extensively to study various social and economic phenomena. For instance, Zhao et al. (2021) employed evolutionary game theory to analyse the issue of how government subsidies promote the diffusion of new energy vehicles in a complex network environment. Based on evolutionary game theory, Liu and Zhou (2023) analysed the game behavior between resource demanders and resource providers in collaborative innovation of megaprojects from the perspective of resource sharing among collaborative innovation subjects. Song et al. (2020) constructed an evolutionary game model to explore the role and options of the public policy agent to support collaboration on innovation. Similarly, evolutionary game theory is thus an appropriate method to dissect the cooperative behavior of multiagents participating in collaborative innovation in megaprojects. In megaprojects, the client, as the investor of the whole construction project, is entrusted with the responsibility to encourage the participant's innovative behavior through some measures to ensure performance. Under the reward and punishment mechanism, the process of the strategy selection of multiple participants participating in collaborative innovation can be represented as a mutual game between the different agents. Given the long cycle of megaprojects, the uncertainty of the construction environment, and the dynamic change in innovation demand, participants are likely to change their strategy over time, and thus, other subjects will adjust the innovation strategy accordingly, which can be considered as dynamic and repeated game process (Gao & Liu, 2019). Ideally, the participants will choose the equilibrium strategy to maximize their interests in completely rational scenarios. However, affected by the complexity of collaborative innovation and information asymmetry between subjects, the participants are bounded to rational groups in decision-making, and it is difficult, initially, for them to adopt the optimal strategy. They are often constantly learning, imitating, adjusting and optimizing their strategies to seek the game equilibrium through trial and error (Gao & Liu, 2019; Li & Zeng, 2021).

1.4. Prospect theory and its applications

In the 1960s, some economists found that the theory based on the assumption of complete rationality could not explain some abnormal phenomena in the economy (Becker & Brownson, 1964). Kahneman and Tversky (1979) described several classes of choice problems in which preferences systematically violate the axioms of expected utility theory commonly interpreted and applied. Then, prospect theory was proposed and developed, which advanced the decision-making theory under uncertainty. They found that when making decisions under conditions of uncertainty, the individual's final utility is simply not to take the expected value of the possible future utility. People will avoid risk in choices involving sure gains and seek risk in choices involving sure losses. The value function and weight function are the most important research results of prospect theory. The value function is normally concave for gains, commonly convex for losses, and is generally steeper for losses than gains. The value function and weight function are the most important research results of prospect theory. Decision weights are generally lower than the corresponding probabilities, except in the range of low probabilities (Kahneman & Tversky, 1979).

Prospect theory enriches the research of behavioral science and decision analysis. Scholars apply prospect theory to many fields, such as project management (Zhang et al., 2018) and operation management (Zhang et al., 2015), decision analysis (Liu et al., 2014), market science (Kuksov & Wang, 2014), and microeconomic analysis (Barberis, 2013), because the model added to prospect theory is more in line with people's real behavior. Prospect theory is integrated into evolutionary game theory and the perceived benefits matrix, which is different from the payoff matrix, is constructed to study the behavior of construction safety management in the study of Zhou et al. (2012). Zhang and Liu (2017) introduced prospect theory to the problem of collusion between local governments and enterprises. Considering the psychological characteristics of behavior subjects in water pollution control, they analysed the impact of the punishment coefficient and aversion loss coefficient on the subject's collusion behavior and then put forward the conditions to effectively reduce the collision between enterprises and local governments. These studies applied prospect theory to model analysis, which effectively relaxed the relevant assumptions, and made the model closer to the real behavior (Tan & Xu, 2020). However, there are few similar studies on the research of collaborative innovation of megaprojects. On the one hand, the existing literature on collaborative innovation of megaprojects mainly uses the expected return theory to establish the model, which is inconsistent with the assumption of bounded rationality. On the other hand, these studies ignore the risk attitude towards gains and losses when decision-makers choose a strategy under uncertainty. Therefore, this paper attempts to apply prospect theory to the evolutionary game model to study the innovative cooperation behavior of megaproject participants to describe, in reality, the participant's cognition and decision-making law.

2. Modelling

2.1. Model assumptions

Assumption 1: A megaproject is generally constructed by multiple contractors due to its large-scale and complex technology. It is assumed that there are two players: Participant A and Participant B in the game of participating in the collaborative innovation of megaprojects. They all have two pure behavioral strategies regarding megaprojects: one is to participate in collaborative innovation (C), and the other is not to participate in collaborative innovation (NC). Due to the information asymmetry between decision-makers and limited by the ability of perception and cognition, they are bounded rational subjects. The players attempt to maximize their profits and they can dynamically adjust their strategies through simulation learning to seek game equilibrium over the whole game process (Li & Zeng, 2021).

Assumption 2: When player A and player B do not participate in the cooperative innovation of megaprojects, it is assumed that their retained earnings are u_1 and u_2, respectively. When both players choose the cooperative innovation strategy, they can not only obtain the retained earnings but also obtain the synergy and transformation benefits of innovation achievements. The synergy benefits depend on the innovation resource input of each player (S_1), (S_2) and the synergy effect coefficient (θ), and thus, the synergy output is $\theta S_1 S_2$, where $0 < \theta < 1$; The benefits brought by the transformation of innovation achievements in the later stage of cooperative innovation depend on the early innovation output and achievement transformation rate (β) and thus the return of achievement transformation is $\beta\theta S_1 S_2$ (Xue et al., 2021). Assume that the share proportion of the collaborative output of entity a is δ ($0 < \delta < 1$), and the share proportion of achievement transformation return is $\delta' \ (0 < \delta' < 1)$.

Assumption 3: The cost of participating in collaborative innovation cooperation consists of two parts: the cost of participating in collaborative innovation (such as human and capital investment) and the risk losses of resource spillover (such as the risk caused by unlimited replication of knowledge resources and the outflow of potential patent resources) (Wu et al., 2017). It is assumed that the cost of player A and player B participating in collaborative innovation is C_1 and C_2, and the risk losses of resource spillover are ($r_1 S_1$) and ($r_2 S_2$) respectively, in which ($0 < r_i < 1$) is the probability of resource overflow.

Assumption 4: In the collaborative innovation led by the client, the participation of the participants has a positive impact on the project construction and the development of innovation. To encourage participants in megaprojects to actively participate in collaborative innovation, the client usually takes certain incentive measures. It is assumed that when one player participates in collaborative innovation (C) and the other player does not participate in collaborative innovation (NC), the player who chooses (NC) will receive a certain amount of punishment (M) as the reward for the player participating in collaborative innovation, and the amount of reward and punishment is less than the input cost of collaborative innovation, i.e., $M < C_1$. When both players choose NC or C, no reward or punishment will be given. Therefore, without considering prospect theory, combined with the above assumptions, the payoff for each player under different strategies can be obtained. When the strategy combination is (C, C), the payoff of player A is $u_1 + \delta\theta S_1 S_2 + \delta'\beta\theta S_1 S_2 - C_1 - r_1 S_1$, and the payoff of player B is $u_2 + (1-\delta)\theta S_1 S_2 + (1-\delta')\beta\theta S_1 S_2 - C_2 - r_2 S_2$. When the strategy combination is (C, NC), the payoff of player A is $u_1 - C_1 - r_1 S_1 + M$, and the payoff of player B is $u_2 - M$. When the strategy combination is (NC, C), the payoff of player A is $u_1 - M$, and the payoff of player B is $u_2 - C_2 - r_2 S_2 + M$. When the strategy combination is (NC, NC), the payoff of player A is u_1, and the payoff of player B is u_2.

Assumption 5: Because players choose a strategy based on the perception of value, not the expected utility value of the strategy itself, prospect theory is used to measure the payoff of the game players to better fit the actor's actual decision (von Neumann & Morgenstern, 1944). It is assumed that the subjective value of each player to the gain and loss of the strategy is V_i determined by the prospect value function $v(\Delta x_i)$ and the weight function $w(p_i)$ (Tversky & Kahneman, 1992). That is $V = \sum_i v(\Delta x_i) \cdot w(p_i)$, where Δx_i

is the difference between actual income x_i and reference point income x_0 of player *i*; $v(\Delta x_i)$ is the subjective value of player i for the difference between actual income and reference point income. p_i is the objective probability of the event; $w(p_i)$ represents the subjective probability of the actor judging the occurrence of the decision event. According to Li and Zeng (2021), $v(\Delta x) = \begin{cases} (\Delta x)^{\alpha}, & \Delta x \geq 0 \\ -\lambda(-\Delta x)^{\beta}, & \Delta x < 0 \end{cases}$; $w(p_i) = \frac{p_i^{\gamma}}{(p_i^{\gamma} + (1-p_i)^{\gamma})^{\frac{1}{\gamma}}}$, where α, β ∈ (0,1) is the concave-convex degree of the value power function of the gain and loss areas respectively, which represents the sensitivity to risk. The greater α or β is, the more sensitive the risk attitude of the player when facing gain or loss. $\lambda(\lambda \geq 1)$ is the loss avoidance coefficient. The larger it is, the more sensitive the player is to the perception of loss compared with the perception of income. The shape of the weight function is inverted "s", and the greater the value of γ is, the smaller the curvature of the function curve.

Assumption 6: Take the payoff of players in the state of strategy combination (NC, NC) as the reference point. Moreover, for the convenience of analysis, it is assumed that the player has the same risk attitude sensitivity to different income or losses.

Assumption 7: During the period, the probability of participant A implementing C strategy is *x*, and then the probability of participant A implementing NC strategy is 1 – *x*, where $x \in [0,1]$. Whereas, the probability of participant B constructing C strategy is *y*, and the probability of participant B constructing NC strategy is 1 – *y*, where $y \in [0,1]$.

2.2. Prospect payoff matrix and parameters

Based on the above assumptions, a prospect payoff matrix on the game process of the participants' cooperative innovation behavior in megaprojects under the reward and punishment mechanism can be built-up, as shown in the table below. For the four cells in Table 1 that delineate the payoffs, the first entry shows the payoff for player A, while the second entry is the payoff for player B. Table 2 explains the meaning of relevant parameters in the prospect payment matrix.

Table 1. Prospect payoff matrix for participant A and participant B

Players		Participant B	
		To participate in collaborative innovation (C) (prob.*y*)	Not to participate in collaborative innovation (NC) (prob. 1 – *y*)
Participant A	To participate in collaborative innovation (C) (prob. *x*)	$(\delta\theta S_1 S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1 S_2)^{\alpha_1} - \lambda_1 C_1^{\beta_1} - \omega(r_1)\lambda_1 S_1^{\beta_1}$, $\left[(1-\delta)\theta S_1 S_2\right]^{\alpha_2} + \omega(p)[(1-\delta^{'})\varphi\theta S_1 S_2]^{\alpha_2} - \lambda_2 C_2^{\beta_2} - \omega(r_2)\lambda_2 S_2^{\beta_2}$	$-\lambda_1 C_1^{\beta_1} - \omega(r_1)\lambda_1 S_1^{\beta_1} + M^{\alpha_1}, -\lambda_2 M^{\beta_2}$
	Not to participate in collaborative innovation (NC) (prob. 1 – *x*)	$-\lambda_1 M^{\beta_1}$, $-\lambda_2 C_2^{\beta_2} - \omega(r_2)\lambda_2 S_2^{\beta_2} + M^{\alpha_2}$	0, 0

Table 2. The definitions of the variables

Symbols	Definitions	Symbols	Definitions
S_1	Innovation resources invested by player A	λ_1	Loss avoidance coefficient of player A
S_2	Innovation resources invested by player B	λ_2	Loss avoidance coefficient of player B
M	Reward and punishment amount of the owner for players to participate in collaborative innovation	P	Achievement transformation probability
C_1	Cost of player A's participation in collaborative innovation	r_1	Probability of spillover of innovation resources invested by player A
C_2	Cost of player B's participation in collaborative innovation	r_2	Probability of spillover of innovation resources invested by player B
δ	Share proportion of the direct output of collaborative innovation	α_1	Risk aversion coefficient of player A to income
δ'	Share proportion of achievements in transformation	α_2	Risk preference coefficient of player B for the loss
φ	Yield coefficient of achievement transformation	β_1	Risk aversion coefficient of player A to income
θ	Synergy coefficient	β_2	Risk preference coefficient of player B for the loss

2.3. Model establishment and solution

The gains of the two players can be analysed according to the prospect payoff matrix of the game between Participant A and Participant B above, combined with the ideas and methods of evolutionary game analysis. It is assumed that during the construction of the megaproject, the expected prospect value when player A chooses to participate in cooperation innovation is U_{1Y}, and the expected prospect value when player A does not participate in cooperation innovation is U_{1N}. The mean expected prospect value for the player is $\overline{U_1}$. The representative equations are as follows:

$$\left.\begin{array}{l} U_{1Y} = y\left[(\delta\theta S_1S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1S_2)^{\alpha_1} - \lambda_1 {C_1}^{\beta_1} - \omega(r_1)\lambda_1 {S_1}^{\beta_1}\right] + \\ (1-y)\left[-\lambda_1 {C_1}^{\beta_1} - \omega(r_1)\lambda_1 {S_1}^{\beta_1} + M^{\alpha_1}\right] \\ U_{1N} = y\left(-\lambda_1 M^{\beta_1}\right) + (1-y)\cdot 0 = y\left(-\lambda_1 M^{\beta_1}\right) \\ \overline{U}_1 = xU_{1Y} + (1-x)U_{1N} \end{array}\right\}. \tag{1}$$

Similarly, it is assumed that during the construction of the megaproject, the expected prospect value when player B chooses to participate in cooperation innovation is U_{2Y}, and the expected prospect value when player B does not participate in cooperation innovation is U_{2N}. The mean expected prospect value for the player is $\overline{U_2}$. The representative equations are as follows:

$$\left.\begin{array}{l} U_{2Y} = x\left\{\begin{array}{l}\left[(1-\delta)\theta S_1S_2\right]^{\alpha_2} + \\ \omega(p)((1-\delta^{'})\varphi\theta S_1S_2)^{\alpha_2} - \lambda_2 {C_2}^{\beta_2} - \omega(r_2)\lambda_2 {S_2}^{\beta_2}\end{array}\right\} + \\ (1-x)\left[-\lambda_2 {C_2}^{\beta_2} - \omega(r_2)\lambda_2 {S_2}^{\beta_2} + M^{\alpha_2}\right] \\ U_{2N} = x\left(-\lambda_2 M^{\beta_2}\right) + (1-x)\cdot 0 = x\left(-\lambda_2 M^{\beta_2}\right) \\ \overline{U}_2 = yU_{2Y} + (1-y)U_{2N} \end{array}\right\}. \tag{2}$$

According to the Malthusian dynamic equation, the dynamic change rate of a player's strategy can be expressed by a dynamic differential equation, and the rate of dynamic changes depends on the speed of learning or imitation.

Based on Equation (1), the replicator dynamics equation that player A chooses to participate in cooperation innovation can be represented by the dynamic differential as follows:

$$F(x) = \frac{dx}{dt} = x(U_{1Y} - \overline{U}_1) = \\ x(1-x)\left\{\begin{array}{l} y\left[(\delta\theta S_1S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1S_2)^{\alpha_1} + (\lambda_1 M^{\beta_1} - M^{\alpha_1})\right] + \\ M^{\alpha_1} - \lambda_1 {C_1}^{\beta_1} - \omega(r_1)\lambda_1 {S_1}^{\beta_1} \end{array}\right\}. \tag{3}$$

Similarly, based on Equation (2), the replicator dynamics equation that player B chooses to participate in cooperation innovation can be represented by the dynamic differential as follows:

$$F(y) = \frac{dy}{dt} = y(U_{2Y} - \overline{U}_{2N}) = \\ y(1-y)\left\{\begin{array}{l} x\left[\begin{array}{l}[(1-\delta)\theta S_1S_2]^{\alpha_2} + \omega(p)[(1-\delta^{'})\varphi\theta S_1S_2]^{\alpha_2} + \\ (\lambda_2 M^{\beta_2} - M^{\alpha_2})\end{array}\right] + \\ M^{\alpha_2} - \lambda_2 {C_2}^{\beta_2} - \omega(r_2)\lambda_2 {S_2}^{\beta_2} \end{array}\right\}, \tag{4}$$

where t is the time. $\frac{dx}{dt}$ is the rate of change of the proportion of player A who chooses to participate in cooperation innovation over time and, $\frac{dy}{dt}$ is the rate of change of the proportion of player B who chooses to participate in cooperation innovation over time.

By synthesizing Equation (3) and Equation (4), a two-dimensional dynamic system can be obtained. Make $F(x) = 0$ and $F(y) = 0$. It is found that there are five local equilibrium points in the two-dimensional dynamic system: O (0, 0), A (1, 0), B (0, 1), C (1, 1), D (x_D, y_D), where

$$x_D = \frac{\lambda_2 {C_2}^{\beta_2} + \omega(r_2)\lambda_2 {S_2}^{\beta_2} - M^{\alpha_2}}{[(1-\delta)\theta S_1S_2]^{\alpha_2} + \omega(p)[(1-\delta^{'})\varphi\theta S_1S_2]^{\alpha_2} + (\lambda_2 M^{\beta_2} - M^{\alpha_2})},$$

and $$y_D = \frac{\lambda_1 {C_1}^{\beta_1} + \omega(r_1)\lambda_1 {S_1}^{\beta_1} - M^{\alpha_1}}{(\delta\theta S_1S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1S_2)^{\alpha_1} + (\lambda_1 M^{\beta_1} - M^{\alpha_1})}.$$

If and only if $0 \le x_D \le 1$, $0 \le y_D \le 1$, there is the fifth equilibrium point.

Based on the method proposed by Friedman (1998), the stability of the equilibrium point can be judged by utilizing the Jacobi matrix of a system. That is, if and only if the determinant $\det J > 0$ and the trace $trJ < 0$, the state of the system is an evolutionary stable strategy (ESS).

Calculate the partial derivatives of x and y for the copied dynamic equation respectively, and the Jacobian matrix of the system can be obtained as follows: $J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(x)}{\partial y} \end{bmatrix}$, where

$$\frac{\partial F(x)}{\partial x} = (1-2x)\left\{\begin{array}{l} y\left[\begin{array}{l}(\delta\theta S_1S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1S_2)^{\alpha_1} + \\ (\lambda_1 M^{\beta_1} - M^{\alpha_1})\end{array}\right] + \\ M^{\alpha_1} - \lambda_1 {C_1}^{\beta_1} - \omega(r_1)\lambda_1 {S_1}^{\beta_1} \end{array}\right\};$$

$$\frac{\partial F(x)}{\partial y} = x(1-x)\left[\begin{array}{l}(\delta\theta S_1S_2)^{\alpha_1} + \omega(p)(\delta^{'}\varphi\theta S_1S_2)^{\alpha_1} + \\ (\lambda_1 M^{\beta_1} - M^{\alpha_1})\end{array}\right];$$

$$\frac{\partial F(y)}{\partial x} = y(1-y)\left[\begin{array}{l}[(1-\delta)\theta S_1S_2]^{\alpha_2} + \omega(p)[(1-\delta^{'})\varphi\theta S_1S_2]^{\alpha_2} + \\ (\lambda_2 M^{\beta_2} - M^{\alpha_2})\end{array}\right];$$

$$\frac{\partial F(x)}{\partial y} = (1-2y)\left\{\begin{array}{l} x\left[\begin{array}{l}[(1-\delta)\theta S_1S_2]^{\alpha_2} + \omega(p)[(1-\delta^{'})\varphi\theta S_1S_2]^{\alpha_2} + \\ (\lambda_2 M^{\beta_2} - M^{\alpha_2})\end{array}\right] + \\ M^{\alpha_2} - \lambda_2 {C_2}^{\beta_2} - \omega(r_2)\lambda_2 {S_2}^{\beta_2} \end{array}\right\}.$$

The determinant equation of this Jacobi matrix is:

$$\begin{aligned}&\det J = \frac{\partial F(x)}{\partial x}\cdot\frac{\partial F(x)}{\partial y} - \frac{\partial F(y)}{\partial x}\cdot\frac{\partial F(x)}{\partial y} = \\ &(1-2x)\left\{\begin{array}{l} y\left[(\delta\theta S_1S_2)^{\alpha_1}+\omega(p)(\delta'\varphi\theta S_1S_2)^{\alpha_1}+(\lambda_1M^{\beta_1}-M^{\alpha_1})\right]+ \\ M^{\alpha_1}-\lambda_1C_1^{\beta_1}-\omega(r_1)\lambda_1S_1^{\beta_1}\end{array}\right\} \\ &\times(1-2y)\left\{\begin{array}{l} x\left[\begin{array}{l}[(1-\delta)\theta S_1S_2]^{\alpha_2}+\omega(p)[(1-\delta')\varphi\theta S_1S_2]^{\alpha_2}+\\ (\lambda_2M^{\beta_2}-M^{\alpha_2})\end{array}\right]+\\ M^{\alpha_2}-\lambda_2C_2^{\beta_2}-\omega(r_2)\lambda_2S_2^{\beta_2}\end{array}\right\}-x(1-x) \\ &\left[(\delta\theta S_1S_2)^{\alpha_1}+\omega(p)(\delta'\varphi\theta S_1S_2)^{\alpha_1}+(\lambda_1M^{\beta_1}-M^{\alpha_1})\right]\times \\ &y(1-y)\left[[(1-\delta)\theta S_1S_2]^{\alpha_2}+\omega(p)[(1-\delta')\varphi\theta S_1S_2]^{\alpha_2}+(\lambda_2M^{\beta_2}-M^{\alpha_2})\right].\end{aligned} \tag{5}$$

The trace of this Jacobi matrix is:

$$\begin{aligned}&trJ = \frac{\partial F(x)}{\partial x}+\frac{\partial F(x)}{\partial y} = (1-2x)\left\{\begin{array}{l} y\left[\begin{array}{l}(\delta\theta S_1S_2)^{\alpha_1}+\omega(p)(\delta'\varphi\theta S_1S_2)^{\alpha_1}+\\ (\lambda_1M^{\beta_1}-M^{\alpha_1})\end{array}\right]+\\ M^{\alpha_1}-\lambda_1C_1^{\beta_1}-\omega(r_1)\lambda_1S_1^{\beta_1}\end{array}\right\}+ \\ &(1-2y)\left\{\begin{array}{l} x\left[\begin{array}{l}[(1-\delta)\theta S_1S_2]^{\alpha_2}+\omega(p)[(1-\delta')\varphi\theta S_1S_2]^{\alpha_2}+\\ (\lambda_2M^{\beta_2}-M^{\alpha_2})\end{array}\right]+\\ M^{\alpha_2}-\lambda_2C_2^{\beta_2}-\omega(r_2)\lambda_2S_2^{\beta_2}\end{array}\right\}.\end{aligned} \tag{6}$$

To simplify the analysis, substitute the following formula: $\lambda_1C_1^{\beta_1}+\omega(r_1)\lambda_1S_1^{\beta_1}=L_1$, $(\delta\theta S_1S_2)^{\alpha_1}+\omega(p)(\delta'\varphi\theta S_1S_2)^{\alpha_1}=F_1$, $\lambda_2C_2^{\beta_2}+\omega(r_2)\lambda_2S_2^{\beta_2}=L_2$, $[(1-\delta)\theta S_1S_2]^{\alpha_2}+\omega(p)[(1-\delta')\varphi\theta S_1S_2]^{\alpha_2}=F_2$.

After calculation, it is found that there are four scenarios of system local stability, and each case is as follows:

(1) When $\lambda_1M^{\beta_1}<L_1-F_1$ and $\lambda_2M^{\beta_2}>L_2-F_2$, the local stability of the system is shown in Table 3.

Table 3. Stability of each equilibrium point in scenario 1

Equilibrium points	det	tr	Stability
(0, 0)	+	–	Stable point
(0, 1)	–	±	Saddle point
(1, 0)	+	+	Unstable point
(1, 1)	–	±	Saddle point

In this scenario, a medium-sized reward and punishment factor is set by the client, but due to the unreasonable output distribution ratio of cooperative innovation (δ or δ* too small), player A believes that the gains are far less than the losses of participating in collaborative innovation. Although player B may choose to participate in collaborative innovation at the beginning, after countless games, each player converges stably to the strategy of not participating in collaborative innovation. The evolutionarily stable strategy point of the system is (0, 0). (NC, NC).

(2) When $\lambda_1M^{\beta_1}>L_1-F_1$ and $\lambda_2M^{\beta_2}<L_2-F_2$, the local stability of the system is shown in Table 4.

Table 4. Stability of each equilibrium point in scenario 2

Equilibrium points	det	tr	Stability
(0, 0)	+	–	Stable point
(0, 1)	+	+	Unstable point
(1, 0)	–	±	Saddle point
(1, 1)	–	±	Saddle point

Similar to scenario (1), in this case, a medium-sized reward and punishment factor is set by the client, but due to the unreasonable output distribution ratio of cooperative innovation (δ or δ* too big), player B believes that the gains are far less than the losses of participating in collaborative innovation. Although player A may choose to participate in collaborative innovation at the beginning, after countless games, each player converges stably to the strategy of not participating in collaborative innovation. The evolutionarily stable strategy point of the system is (0, 0). (NC, NC).

(3) When $\lambda_1M^{\beta_1}<L_1-F_1$ and $\lambda_2M^{\beta_2}<L_2-F_2$, the local stability of the system is shown in Table 5.

Table 5. Stability of each equilibrium point in scenario 3

Equilibrium points	det	tr	Stability
(0, 0)	+	–	Stable point
(0, 1)	–	±	Saddle point
(1, 0)	–	±	Saddle point
(1, 1)	+	+	Unstable point

In this scenario, the players are not optimistic about collaborative innovation, and the perceived losses are greater than the gains brought by collaborative innovation. However, a small reward and punishment factor is set by the client, which cannot achieve the effect of encouraging collaborative innovation. The players do not participate in collaborative innovation as the dominant choice. After countless games, each player converges stably to the strategy of not participating in collaborative innovation. The evolutionary stable strategy point of the system is (0, 0). (NC, NC).

(4) When $\lambda_1M^{\beta_1}>L_1-F_1$ and $\lambda_2M^{\beta_2}>L_2-F_2$, the local stability of the system is shown in Table 6.

Table 6. Stability of each equilibrium point in scenario 4

Equilibrium points	det	tr	Stability
(0, 0)	+	–	Stable point
(0, 1)	+	+	Unstable point
(1, 0)	+	+	Unstable point
(1, 1)	+	–	Stable point
(x_D, y_D)	–	0	Saddle point

In this scenario, because a large reward and punishment factor is set by the client, the players all believe that the gains obtained by participating in collaborative innovation are relatively greater than the losses. There are two evolutionary stability strategy points of the system: (0, 0) and (1, 1), i.e., (NC, NC) and (C, C). The specific evolution direction depends on the initial state of the system.

2.4. Results and discussions

According to the above analysis, in scenarios (1)–(3), the system has four equilibrium points in which (NC, NC) is the unique evolutionary stability strategy. In scenario (4), the system has five equilibrium points, in which (NC, NC) and C (C, C) are evolutionary stability strategies. The dynamic process of multiple participants participating in collaborative innovation games in each case is shown in Figure 1.

To explore the influencing factors of the evolutionary stable state in scenario (4), the two-dimensional plane of scenario (4) in Figure 1 is analysed. In the figure, the broken line ADB is the critical line of the system converging to different states and divides the plane into two parts. At the upper right of the broken line, i.e. ADBC area, the system will converge to the ESS of (C, C), and at the lower left of the broken line, i.e., ADBO area, the system will converge to the ESS of (NC, NC). Based on the set probability, the probability that the system converges to the ESS of (C, C) is:

$$P=(1-x_D)(1-y_D)+\frac{x_D(1-y_D)}{2}+\frac{y_D(1-x_D)}{2}=1-\frac{x_D}{2}-\frac{y_D}{2}=$$
$$1-\frac{\lambda_1 {C_1}^{\beta_1}+\omega(r_1)\lambda_1 {S_1}^{\beta_1}-M^{\alpha_1}}{2(\delta\theta S_1 S_2)^{\alpha_1}+\omega(p)(\delta'\varphi\theta S_1 S_2)^{\alpha_1}+2(\lambda_1 M^{\beta_1}-M^{\alpha_1})}-$$
$$\frac{\lambda_2 {C_2}^{\beta_2}+\omega(r_2)\lambda_2 {S_2}^{\beta_2}-M^{\alpha_2}}{2[(1-\delta)\theta S_1 S_2]^{\alpha_2}+\omega(p)[(1-\delta')\varphi\theta S_1 S_2]^{\alpha_2}+2(\lambda_2 M^{\beta_2}-M^{\alpha_2})}. \tag{7}$$

To facilitate the analysis, make $P=1-\frac{F_1}{G_1}-\frac{F_2}{G_2}$. According to the previous assumptions, $F_1 > 0$, $F_2 > 0$, $G_1 > 0$, and $G_2 > 0$ were known. The analysis of the main factors affecting the system convergence to the optimal evolutionary stability strategy point of C (1, 1) is shown as follows:

(1) Analysis of main objective factors

Proposition 1: The higher the cost of participating in collaborative innovation, the smaller the probability of the system converging to the ESS of (C, C).

Proof: Taking the first partial derivatives of Equation (7) with respect to C_1 and C_2 respectively, we can obtain that $\frac{\partial P}{\partial C_1}=-\frac{\lambda_1\beta_1 {C_1}^{\beta_1-1}}{G_1}<0$ and $\frac{\partial P}{\partial C_2}=-\frac{\lambda_2\beta_2 {C_2}^{\beta_2-1}}{G_2}<0$. Therefore, the higher the cost of participating in collaborative innovation, the more unfavorable it is for the participants to participate in the collaborative innovation of megaprojects.

Proposition 2: The greater the synergy coefficient of innovation, the greater the motivation of participants to participate in collaborative innovation, and the greater the probability of system evolution into collaborative innovation.

Proof: because $\frac{\partial G_1}{\partial\theta}=2\alpha_1\delta S_1 S_2(\delta\theta S_1 S_2)^{\alpha_1-1}+$

$\alpha_1\omega(p)\delta'\varphi S_1 S_2(\delta'\varphi\theta S_1 S_2)^{\alpha_1-1}>0$, $\frac{\partial G_2}{\partial\theta}=2\alpha_2[(1-\delta)S_1 S_2]\cdot$

$[(1-\delta)\theta S_1 S_2]^{\alpha_2-1}+\omega(p)\alpha_2[(1-\delta')\varphi S_1 S_2][(1-\delta')\varphi\theta S_1 S_2]^{\alpha_2-1}>0$,

$\frac{\partial P}{\partial\theta}=\frac{F_1\cdot\partial G_1/\partial\theta}{{G_1}^2}+\frac{F_2\cdot\partial G_2/\partial\theta}{{G_2}^2}>0$. Therefore, there is a positive correlation between P and θ. With the increase in the synergy coefficient, the probability of system evolution to collaborative innovation increases.

Proposition 3: The greater the reward and punishment factor of innovation participation, the greater the probability of the system converging to the ESS of (C, C).

Proof: because $\frac{\partial F_1}{\partial M}=-\alpha_1 M^{\alpha_1-1}<0$,

$\frac{\partial G_1}{\partial M}=2(\beta_1\lambda M^{\beta_1-1}-\alpha_1 M^{\alpha_1-1})>0$, $\frac{\partial F_2}{\partial M}=-\alpha_2 M^{\alpha_2-1}<0$,

$\frac{\partial G_2}{\partial M}=2(\beta_2\lambda M^{\beta_2-1}-\alpha_2 M^{\alpha_2-1})>0$,

$\frac{\partial P}{\partial M}=-\frac{\partial F_1/\partial M\times G_1-F_1\times\partial G_1/\partial M}{{G_1}^2}-$

$\frac{\partial F_2/\partial M\times G_2-F_2\times\partial G_2/\partial M}{{G_2}^2}>0$ can be calculated.

Therefore, there is a positive correlation between P and M. With the increase in the reward and punishment factor, the probability of system evolution to collaborative innovation increases.

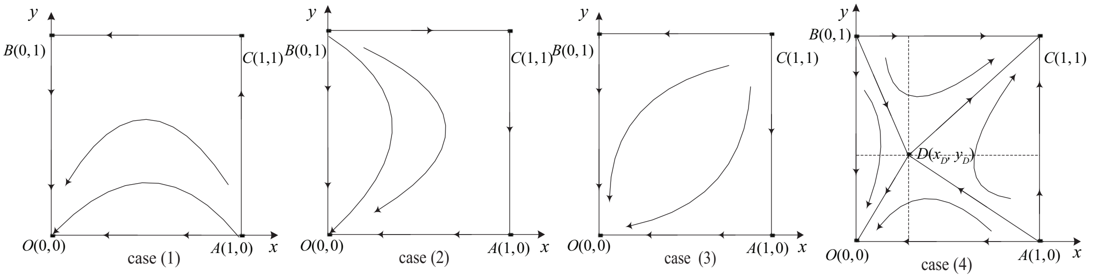

Figure 1. Evolutionary phase diagram of the system in different situations

Proposition 4: There is an optimal cooperative income distribution ratio that maximizes the probability of the system converging to the ESS of (C, C).

Proof: $\frac{\partial G_1}{\partial \delta} = 2\theta S_1 S_2 \alpha_1 (\delta\theta S_1 S_2)^{\alpha_1 - 1} > 0$,

$$\frac{\partial G_2}{\partial \delta} = -2\theta S_1 S_2 \alpha_2 [(1-\delta)\theta S_1 S_2]^{\alpha_2 - 1} < 0 ,$$

$$\frac{\partial P}{\partial \delta} = \frac{F_1 \cdot \partial G_1 / \partial \delta}{G_1{}^2} + \frac{F_2 \cdot \partial G_2 / \partial \delta}{G_2{}^2} .$$

Obviously, the proportion of collaborative revenue sharing δ is not monotonic to the probability that the system evolves into collaborative innovation *P*. Thus, we the second-order partial derivative continues to find:

$$\frac{\partial^2 G_1}{\partial \delta^2} = 2\theta^2 S_1{}^2 S_2{}^2 \alpha_1 (\alpha_1 - 1)(\delta\theta S_1 S_2)^{\alpha_1 - 2} < 0 ,$$

$$\frac{\partial^2 G_2}{\partial \delta^2} = 2\theta^2 S_1{}^2 S_2{}^2 \alpha_2 (\alpha_2 - 1) \cdot [(1-\delta)\theta S_1 S_2]^{\alpha_2 - 2} < 0$$

$$\frac{\partial^2 P}{\partial \delta^2} = \frac{2F_1 G_1 \times \partial^2 G_1 / \partial \delta^2 - F_1 \times (\partial G_1 / \partial \delta)^2}{G_1{}^3} + \frac{2F_2 G_2 \times \partial^2 G_2 / \partial \delta^2 - F_2 \times (\partial G_2 / \partial \delta)^2}{G_1{}^3} < 0.$$

Let $\frac{\partial P}{\partial \delta} = \frac{F_1 \cdot \partial G_1 / \partial \delta}{G_1{}^2} + \frac{F_2 \cdot \partial G_2 / \partial \delta}{G_2{}^2} = 0$, then

$$\frac{F_1 \cdot 2\theta S_1 S_2 \alpha_1 (\delta\theta S_1 S_2)^{\alpha_1 - 1}}{G_1{}^2} = \frac{F_2 \cdot 2\theta S_1 S_2 \alpha_2 \cdot [(1-\delta)\theta S_1 S_2]^{\alpha_2 - 1}}{G_2{}^2}.$$

Thus, there is a maximum point δ*, which makes δ = δ*, and *P* reaches the maximum.

Therefore, the relationship between the probability of system evolution into collaborative innovation and the proportion of income distribution is not monotonous. There is an extreme value δ*. When δ < δ*, with the increase of δ, the probability of system evolution into collaborative innovation increases. On the contrary, When δ > δ*, with the increase of δ, the probability of system evolution into collaborative innovation decreases.

(2) Analysis of behavioral characteristic factors

The decision-makers of the collaborative innovation of megaprojects are affected not only by the main objective factors, such as the cost of participating in collaborative innovation, the output efficiency of collaborative effect, the incentive of innovation participation, and the proportion of innovation income sharing, but are also bounded rational behavior characteristics, especially in the face of some uncertainty. According to prospect theory, decision-makers have different risk attitudes towards losses and gains, and they are more sensitive to losses. Moreover, it is easy to underestimate probabilistic return events, while overestimating probabilistic loss events, which can affect the evolution results of the system.

1) Megaproject technology innovation is guided by project objectives, and its purpose is to solve the technical and management problems faced in the process of project implementation. Due to the one-time characteristics of engineering projects, the high complexity of megaprojects, and the high complexity of technology, participants tend not to be optimistic about the application prospects of future achievements, which underestimate the conversion rate of innovation achievements, so $\omega(p) < p$.

2) There are many stakeholders involved in the collaborative innovation of megaprojects. From the perspective of interorganizational trust, each participant is affected by initial trust in strategy selection, which mainly comes from the perception of each other's ability and moral obligation. Compared with enterprise innovation, there is a low degree of trust between megaproject collaborative innovation organizations with high information asymmetry, which makes innovation subjects underestimate the other party's innovation resource investment and overestimate the spillover risk of their own investment in innovation resources, so $\left[\delta\theta S_1 S_2\right]^{\alpha_1} < \delta\theta S_1 S_2$ and $\omega(r_1) > r_1$.

3) The subject of collaborative innovation in megaprojects has the characteristics of dynamic replacement. The proportion of revenue sharing is uncertain and may be adjusted due to the participation of other subjects in the innovation process. Each subject's perception of his or her own income distribution will affect his or her decision-making behavior. Especially when the leader of collaborative innovation of megaprojects is not clear, the innovation subject has a conservative attitude towards the proportion of income distribution, that is $\left[\delta\theta S_1 S_2\right]^{\alpha_1} < \delta\theta S_1 S_2$, $\left[\delta' \varphi\theta S_1 S_2\right]^{\alpha_1} < \delta' \varphi\theta S_1 S_2$.

4) According to prospect theory, decision-makers of bounded rationality are more sensitive to losses than gains. To a certain extent, the innovation subject can overestimate the participation cost and risk loss but underestimate the collaborative output and achievement transformation. That is, when $v = c$, $v^{\alpha} < \lambda c^{\beta}$, so $\lambda C_1{}^{\beta_1} > C_1$, $\lambda_1 S_1{}^{\beta_1} > S_1$, $M^{\alpha_1} < M < \lambda_1 M^{\beta_1}$.

In summary, through comprehensive (1) (2) (3) (4) analysis, it can be found that the output of the synergy effect, achievement conversion rate, and income sharing ratio are underestimated by decision-makers, and the occurrence probability of resource spillover risk events and the cost of participating in collaborative innovation are overestimated by decision-makers, which hinders participants from choosing cooperative innovation strategies. The effect of the innovation incentive is underestimated for the rewarded and overestimated for the punished, which encourages the participants to choose cooperative innovation strategies. Therefore, reward and punishment incentive measures of collaborative innovation have a positive impact on participants' choice of cooperative innovation strategy from both objective and behavioral factors. The incentive measure can effectively encourage all participants to participate in collaborative innovation, which reflects the importance of the reward and punishment incentive mechanism.

3. Influencing factors and simulation analysis

Numerical simulation is often used as a supplement to game analysis, which can not only display the results of the model intuitively but also judge the changing trend between variables by drawing function graphics (Zhou & Liu, 2021). In order to more intuitively analyze the impact of the main objective factors such as participation innovation cost, collaborative innovation participation incentive, collaborative income sharing proportion, achievement transformation income sharing proportion and the main behavioral characteristic factors such as risk aversion coefficient, the loss sensitivity coefficient on the evolution results of collaborative innovation behavior in megaprojects, in this section, MATLAB R2018a software for simulation analysis was used. According to the basic assumptions of the theoretical model, the initial values of each parameter are set as follows: $S_1 = 40$, $S_2 = 30$, $C_1 = 50$, $C_2 = 50$, $M = 10$, $\delta = 0.4$, $\delta' = 0.6$, $\theta = 0.5$, $\varphi = 0.5$, $p = 0.3$, $r_1 = r_2 = 0.5$; and initial value of system evolution $x_0 = 0.5$, $y_0 = 0.5$. In addition, according to the results of Tversky and Kahneman (1992), the relevant parameters of prospect theory are $\alpha_1 = \alpha_2 = \beta_1 = \beta_2 = 0.88$, $\lambda_1 = \lambda_2 = 2.25$, $\gamma_1 = 0.61$, $\gamma_2 = 0.69$.

(1) Impact of the cost of participation in collaborative innovation on the evolutionary result

Figure 2 shows that with the continuous increase in parameter C_1 (from 30 to 70 in turn), the system gradually changes from the evolution result of 1 to the evolution result of 0. There is a critical value between 50–60. When the cost of participating in innovation C_1 is less than the critical value, the system converges to 1. When it is greater than this critical value, the system converges to 0. This shows that the probability of the system converging to cooperative innovation has a negative correlation with the cost of participating in innovation, that is, the greater the cost of innovation subjects participating in collaborative innovation, the more unfavorable it is to the formation of a multiagent cooperative relationship. Therefore, reducing the cost of participating in innovation and improving efficiency can promote the enthusiasm of participants' collaborative innovation. For instance, with the rapid development of the internet, potential participants hold online meetings to reduce communication costs in the preparation stage of collaborative innovation, which is conducive to the formation of cooperation.

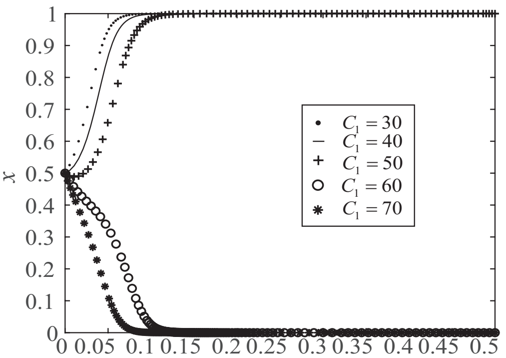

Figure 2. The impact of the cost of participation in collaborative innovation on the evolutionary result

(2) Impact of collaborative innovation participation incentive on the evolutionary result

Figure 3 shows that with the continuous increase in M, the system gradually changes from the evolution result of 0 to the evolution result of 1. There is a critical value between 5–10. When the reward and punishment amount M for participating in innovation is less than the critical value, the system converges to 0. When M is greater than this critical value, the system converges to 1. This shows that the reward and punishment mechanism of innovation participation can affect the decision-making of each participant to a certain extent. Therefore, setting a reasonable innovation incentive mechanism can improve the participation enthusiasm of potential collaborative innovation subjects and promote the formation of a multiagent cooperative relationship. For instance, the use of informatization is included in the assessment indicators in some megaprojects. If contractors do not meet the requirement, they will be issued a red card or yellow card warning, making the participants pay more attention to innovation.

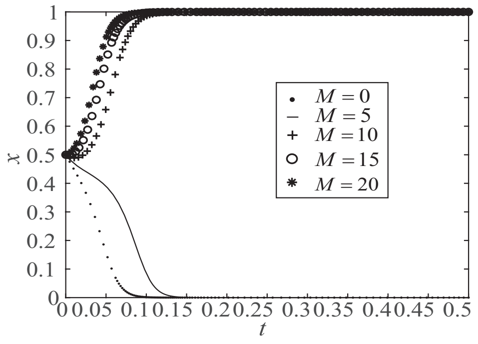

Figure 3. The impact of the reward and punishment amount M on the evolutionary result

(3) Impact of synergy coefficient of collaborative innovation on the evolutionary result

Figure 4 shows that with the continuous increase in the collaborative output coefficient θ, the system gradually changes from the evolution result of 0 to the evolution result of 1. There is a critical value between 0.4–0.5. When the synergy coefficient θ is less than the critical value, the system converges to 0. When θ is greater than this critical value, the system converges to 1, and the greater the value of θ is, the faster the convergence speed. This shows that the probability of system convergence to cooperative innovation is positively correlated with the synergy coefficient. Therefore, improving the synergy coefficient can promote the collaborative innovation behavior of participants in megaprojects. In the collaborative innovation of megaprojects, the stronger the innovation ability of partners, the more confident they are in innovation, and the more willing they are to cooperatively participate.

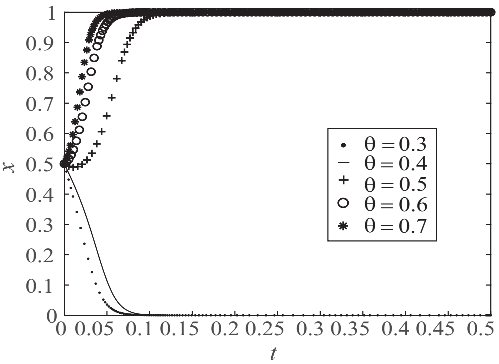

Figure 4. The impact of the synergy coefficient θ on the evolutionary result

(4) Impact of share proportion of the direct output of collaborative innovation on the evolutionary result

Figure 5 shows that when the share proportion in the direct output of collaborative innovation δ is very small (δ = 0.1), the system evolves to 0. When the share proportion of direct output δ is moderate (δ = 0.3, δ = 0.5, δ = 0.7), the system evolves to 1. When the share proportion of direct output δ is very large (δ = 0.9), the system evolves to 0. There are two critical values between 0.1–0.2 and 0.8–0.9. When δ is between the upper and lower critical values, the system will converge to 1. This shows that a reasonable distribution proportion of collaborative benefit output should be set. Too low or too high of a sharing proportion of one participant is not conducive to cooperative innovation in the megaproject. In the collaborative innovation of megaprojects, increasing attentions is being paid to the fairness, objectivity and rationality of benefit distribution to mobilize the enthusiasm of all participants.

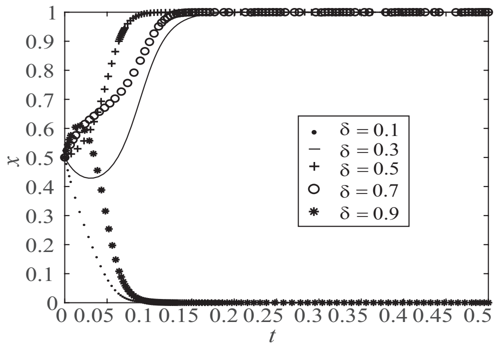

Figure 5. The impact of the share proportion of direct output δ on the evolutionary result

(5) Impact of share proportion of achievement transformation on the evolutionary result

Figure 6 shows that the change in the share proportion of achievement transformation (from 0.1 to 0.9) does not affect the final evolution result of the system, but the convergence speed of the system increases with the increase in δ', and the larger δ' is, the more conducive it is for the system to converge to the optimal state. Compared with Figure 5 and Figure 6, it can be found that the impact of the share proportion of the direct output of collaborative innovation δ on the system is much greater than that of the share proportion of achievement transformation δ' on the system, which shows that all players pay more attention to the reasonable benefit distribution in the innovation process. This phenomenon that the share proportion of achievement transformation in the future has little impact on the decision-maker's strategy choice reflects that under prospect theory, the actor is not sensitive to long-term income with occurrence probability due to the influence of bounded rationality. For instance, in the collaborative innovation of major projects, an important reason for the long-standing existence of intellectual property problems is the unclear division of long-term benefits in the initial stage of cooperation.

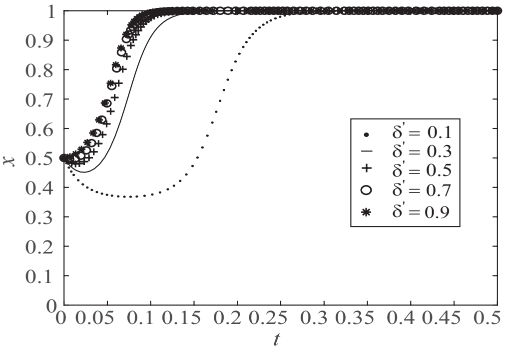

Figure 6. The impact of share proportion of achievement transformation δ' on the evolutionary result

(6) Impact of spill-over probability of innovation resources on the evolutionary result

Figure 7 shows that with the continuous increase in the occurrence probability of resource overflow risk r_1, the system gradually changes from the evolution result of 1 to the evolution result of 0, and there is a critical value between 0.6 and 0.7. When the spillover probability r_1 is less than the critical value, the system converges to 1. When r_1 is greater than this critical value, the system converges to 0. It shows that the probability of the system converging to cooperative innovation is negatively correlated with the occurrence probability of resource spill-over risk. Therefore, taking measures to control the risk of resource spill-over is conducive to all participants in megaprojects participating in cooperative innovation. The participants in the collaborative innovation of megaprojects are dynamic, and resource spill-over will weaken the competitiveness of enterprises. Therefore, the participants will measure the risk of resource spill-over when making collaborative innovation decisions. The smaller the probability of risk occurrence is, the higher their enthusiasm to participate in collaborative innovation.

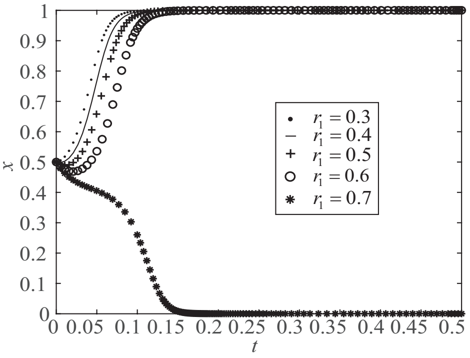

Figure 7. The impact of spill-over probability of innovation resources r_1 on the evolutionary result

(7) Impact of the risk aversion coefficient facing benefits on the evolutionary result

According to prospect theory, the decision-maker is risk averse when facing benefits. A smaller α_1 means a greater degree of risk aversion. Figure 8 shows that with the continuous increase in the risk aversion coefficient α_1, the system gradually changes from the evolution result of 0 to the evolution result of 1, and there is a critical value between 0.7 and 0.8. When α_1 is greater than this critical value, the system converges to 1. When α_1 is less than the critical value, the system converges to 0. This shows that the greater the risk aversion coefficient is, the more rational the participants are in the face of benefits, which is more conducive to the choice of "participating in collaborative innovation" strategy.

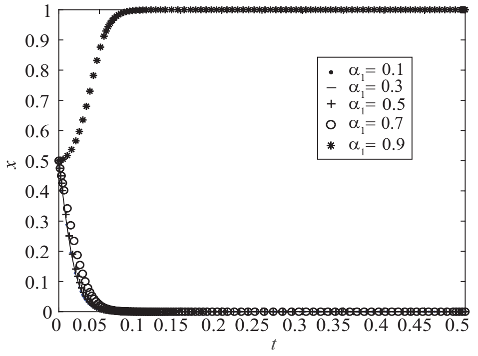

Figure 8. The impact of the risk aversion coefficient α_1 on the evolutionary result

(8) Impact of the risk preference coefficient facing losses on the evolutionary result

According to prospect theory, the decision-maker is risk preference when facing losses. A smaller β_1 means a more obvious risk preference. Figure 9 shows that the smaller β_1 is, the faster the system converges to 1. Therefore, the greater the risk preference of facing losses in participants (the smaller the β_1), the more conducive they are to choosing the strategy of "participating in collaborative innovation". Compared with Figure 8 and Figure 9, it can be found that the risk aversion coefficient facing benefits has a greater impact on the behavior strategies than the risk preference coefficient facing losses.

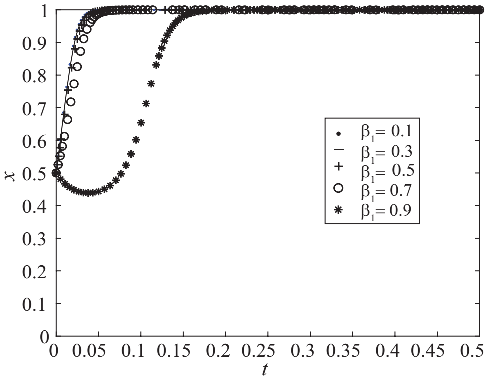

Figure 9. The impact of the risk preference coefficient β_1 on the evolutionary result

(9) Impact of the loss sensitivity coefficient on the evolutionary result

According to prospect theory, most people are more sensitive to losses than benefits, so the loss sensitivity coefficient $\lambda_1 > 1$. Figure 10 shows that with the continuous increase in the loss sensitivity coefficient λ_1, the system gradually changes from the evolution result of 1 to the evolution result of 0, and there is a critical value between 0.2 and 0.25. When λ_1 is less than the critical value, the system converges to 1. When λ_1 is greater than this critical value, the system converges to 0. This shows that the smaller the loss sensitivity coefficient of the participants is, the more conducive they are to choosing the strategy of "participating in collaborative innovation".

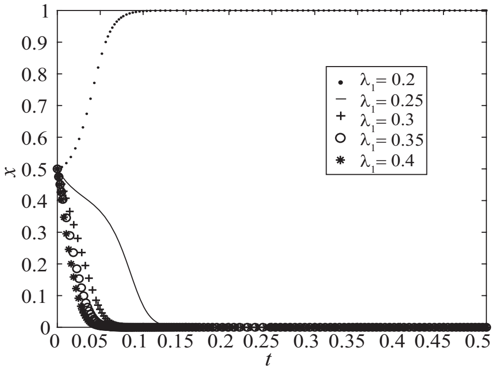

Figure 10. The impact of the loss sensitivity coefficient λ_1 on the evolutionary result

Conclusion, discussion and expectations

Megaprojects are characterized by significant environmental uncertainty and technical complexity, which bring great challenges to engineering construction and increase the demand for technological innovation. It is difficult to make a great breakthrough in the innovation of megaprojects by relying on only one agent. Solving the technical problems faced in megaprojects requires collaborative innovation across organizations, departments, industries, and regions. Because the participants are most familiar with the actual situation of the construction site and understand the innovation needs, their participation will increase innovation efficiency. Moreover, as the main users of innovative products, the participation of participants in collaborative innovation is conducive to the application and promotion of innovative achievements. However, participants often have low enthusiasm to participate in collaborative innovation, which is not conducive to the integration of megaproject construction and scientific and technological innovation. The client plays a leading role in the construction and collaborative innovation of megaprojects and can set certain measures to stimulate the innovation behavior of the participants. Therefore, we study the collaborative innovation behavior of the participants under the client's reward and punishment mechanism. Due to the long construction period of megaprojects and the uncertainty of the construction environment, the participants will dynamically adjust their innovation strategies over time. This paper examines the behavior choices of the participants with limited rationality as a dynamic game process and constructs an evolutionary game model combined with prospect theory to explore the strategy choice of the participants.

Through the research, the following conclusions have been found, which deduce some management enlightenments: 1) the evolution system of collaborative innovation behavior of megaproject participants has two evolutionary stability strategies (ESS), that is (to participate in collaborative innovation, to participate in collaborative innovation) and (not participating in collaborative innovation, not to participate in collaborative innovation). The specific evolution result is affected by the initial value and the size of each parameter. 2) The probability *P* is negatively correlated with the cost of participating in collaborative innovation, so reducing the early participation cost can promote the collaborative innovation behavior of the participants. Therefore, the client can build a collaborative innovation network platform for the megaproject through the application of emerging technologies such as the Internet of Things and 5G, to reduce the initial cost investment of collaborative innovation, such as communication costs, which can improve the enthusiasm of megaproject participants to participate in collaborative innovation. 3) The probability *P* is positively correlated with the synergy coefficient of collaborative innovation, so improving the innovation synergy coefficient can promote the collaborative innovation behavior of the participants. Therefore, for megaprojects with complex construction environments and strong innovation demands, the client can consider taking into account the innovation ability evaluation index of participants during bidding, which will help the participating units participate in collaborative innovation in the process of project implementation. 4) The relationship between the probability *P* of that the system converges to the evolutionary stability strategy of (C, C) and the proportion of collaborative revenue sharing is not monotonous, but there is an optimal proportion of cooperative revenue distribution, which maximizes the probability of system convergence to (C, C). Therefore, a scientific and reasonable benefit distribution mechanism for the collaborative innovation of megaprojects should be established. In the process of collaborative innovation in megaprojects, the unequal potential of participants due to kinship should be avoided. The willingness of participants to engage in collaborative innovation can be improved through reasonable benefit distribution. 5) There is a positive correlation between the probability *P* of the system converging to the evolutionary stability strategy of (C, C) and the reward and punishment factor of innovation participation. Moreover, for decision-making with bounded rationality, the innovation incentive value is underestimated by rewarders who participate in collaborative innovation and overestimated by punishers who do not participate in collaborative innovation. The results show that innovation incentive measures have a positive impact on participants' choice of cooperative innovation strategy from the two aspects of objective factors and behavioral factors, which also reflects the importance of the reward and punishment incentive mechanism of cooperative innovation. 6) In the process of collaborative innovation decision-making, the greater the risk aversion coefficient (that is the more rationally facing gains), the more conducive it is to the occurrence of collaborative innovation. 7) The smaller the risk preference coefficient of participants in the face of loss is, the more conducive it is to collaborative innovation. This is because the participants of bounded rationality will ignore many uncertainties to pursue risk benefits. Therefore, participants should pay attention to preventing the occurrence of risk events such as resource spill-overs. 8) The smaller the loss sensitivity coefficient is (that is loss effect), the more it can promote the collaborative innovation behavior of the participants. Therefore, the client can hire organizational behavior experts or professional venture investors to adjust the psychological consciousness of the participants, and improve their enthusiasm for collaborative innovation by reducing the emotional response of the participants to the losses.

In recent years, with the massive construction of megaprojects and the increasing demand for technological innovation and management innovation, there has been a growing interest in this area of innovation management in megaprojects. Throughout the relevant research of innovation management in megaprojects, more cases have been used to analyse the way and importance of innovation, innovative activities, governance logic and the drivers, inputs, enablers, barriers, benefits, and impacts, e. g. Ozorhon (2013); Ozorhon and Ora (2016); Dodgson et al. (2015); Sergeeva and Zanello (2018); Chen et al. (2020a). Some scholars have also applied the game model to study the innovation governance of megaprojects. For instance, Liu and Ma (2020) studied the incentive and supervision mechanism of the client to R&D institutions in megaprojects by constructing a principal-agent model; Zeng et al. (2019) based on the principal-agent relationship between the client and the supplier, studied the incentive mechanism for supplier development in megaprojects by constructing the principal-agent model and Stackelberg game model; Xue et al. (2021) studied the design of a collaborative innovation incentive the contract between contractor and collaborative enterprises under moral hazard by establishing the principal-agent model. The main differences between this study and previous research are as follows: 1) In terms of the research perspective, we focused on the important role of the participants in the collaborative innovation of megaprojects and the situation of participants' negative attitudes towards innovation. Based on the principal-agent relationship between the client and the participants, the collaborative innovation behavior of the participants under the reward and punishment mechanism was studied. 2) In terms of research methods, on the one hand, the hypothesis of a rational person in most previous studies was broadened to include an analysis of the strategy choice of participants with bounded rationality. On the other hand, considering that there were many uncertain factors in megaproject innovation, prospect theory was integrated into the game model to analyse the impact of behavioral factors such as risk preference on decision-making behavior. This research revealed the law of collaborative innovation behavior of participants in megaprojects. These conclusions can produce some management enlightenment to provide some new insights for the improvement of the collaborative innovation efficiency of megaprojects and the smooth implementation of the whole megaproject.

It is worth noting that the collaborative innovation behavior of megaproject participants under the reward and punishment mechanism is analysed from the perspective of constructing theoretical models. As a supplement to the game analysis, the purpose of the numerical simulation in this paper is to intuitively show the results of the game model and learn the impact of the main factors on the collaborative innovation behavior of the participants. Although the data in the numerical simulation is not the real data in practice, the numerical simulation results can fully reflect the research rules and verify the validity of the model. From another research perspective, with the development of advanced technology, psychology and behavioral economics in the future, we can track and obtain the fluctuation frequency of participation in collaborative innovation and the behavioral preferences of participants, though they are difficult to observe at present. Therefore, how the behavioral characteristics of megaproject participants affect their collaborative innovation decisions can be empirically analysed in future research. In addition, with the increase in data involving participants in the collaborative innovation of megaprojects, the impact of participants' participation in collaborative innovation on the innovation performance and construction performance of megaprojects can also be discussed through case studies and empirical analysis in the future.

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Author contributions

Nana Liu conceived the study and was responsible for the research design and methodology. Guohua Zhou was responsible for editing the first draft of the article.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Bahadorestani, A., Karlsen, J. T., & Farimani, N. M. (2020). Novel approach to satisfying stakeholders in megaprojects: balancing mutual values. *Journal of Management in Engineering*, *36*(2), 4019047. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000734

Barberis, N. C. (2013). Thirty years of prospect theory in economics: a review and assessment. *Journal of Economic Perspectives*, *27*(1), 173–195. https://doi.org/10.1257/jep.27.1.173

Becker, S. W., & Brownson, F. O. (1964). What price ambiguity? Or the role of ambiguity in decision-making. *Journal of Political Economy*, *72*, 62–73. https://doi.org/10.1086/258854

Brockmann, C., Brezinski, H., & Erbe, A. (2016). Innovation in construction megaprojects. *Journal of Construction Engineering and Management*, *142*(11), 4016059. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001168

Bruzelius, N., Flyvbjerg, B., & Rothengatter, W. (2002). Big decisions, big risks. Improving accountability in mega projects. *Transport Policy*, *9*(2), 143–154. https://doi.org/10.1016/S0967-070X(02)00014-8

Cantarelli, C. C. (2022). Innovation in megaprojects and the role of project complexity. *Production Planning & Control*, *33*(9–10), 943–956. https://doi.org/10.1080/09537287.2020.1837934

Chen, H., Jin, Z., Su, Q., & Yue, G. (2020a). The roles of captains in megaproject innovation ecosystems: the case of the Hong Kong–Zhuhai–Macau Bridge. *Engineering, Construction and Architectural Management*, *28*(3), 662–680. https://doi.org/10.1108/ECAM-01-2020-0076

Chen, H., Zeng, S., & Su, Q. (2020b). Towards management of panoramic innovation in megaprojects: the case of Hong Kong–Zhuhai–Macau Bridge project. *Management World*, *36*(12), 212–227.

Davies, A., MacAulay, S., DeBarro, T., & Thurston, M. (2014). Making innovation happen in a megaproject: London's Crossrail suburban railway system. *Project Management Journal*, *45*(6), 25–37. https://doi.org/10.1002/pmj.21461

Dodgson, M., Gann, D., & Phillips, N. W. (2014). *The Oxford handbook of innovation management*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199694945.001.0001

Dodgson, M., Gann, D., MacAulay, S., & Davies, A. (2015). Innovation strategy in new transportation systems: the case of Crossrail. *Transportation Research Part A: Policy and Practice*, *77*, 261–275. https://doi.org/10.1016/j.tra.2015.04.019

Ercan, T. (2019). New three-part model of innovation activity in construction companies. *Journal of Construc-*

tion Engineering and Management, *145*(5), 4019022. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001645

Fan, K., & Hui, E. C. M. (2020). Evolutionary game theory analysis for understanding the decision-making mechanisms of governments and developers on green building incentives. *Building and Environment*, *179*, 106972. https://doi.org/10.1016/j.buildenv.2020.106972

Flyvbjerg, B., Garbuio, M., & Lovallo, D. (2009). Delusion and deception in large infrastructure projects: two models for explaining and preventing executive disaster. *California Management Review*, *51*(2), 170–193. https://doi.org/10.2307/41166485

Friedman, D. (1998). On economic applications of evolutionary game theory. *Journal of Evolutionary Economics*, *8*(1), 15–43. https://doi.org/10.1007/s001910050054

Gao, R., & Liu, J. (2019). Selection of government supervision mode of PPP projects during the operation stage. *Construction Management and Economics*, *37*(10), 584–603. https://doi.org/10.1080/01446193.2018.1564347

Gil, N., Miozzo, M., & Massini, S. (2012). The innovation potential of new infrastructure development: an empirical study of Heathrow airport's T5 project. *Research Policy*, *41*(2), 452–466. https://doi.org/10.1016/j.respol.2011.10.011

He, H., Zheng, L., & Zhou, G. (2022). Linking users as private partners of utility tunnel public–private partnership projects. *Tunnelling and Underground Space Technology*, *119*, 104249. https://doi.org/10.1016/j.tust.2021.104249

Hemström, K., Mahapatra, K., & Gustavsson, L. (2017). Architects' perception of the innovativeness of the Swedish construction industry. *Construction Innovation*, *17*(2), 244–260. https://doi.org/10.1108/CI-06-2015-0038

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, *4*(3), 305–360. https://doi.org/10.1007/978-94-009-9257-3_8

Kahneman, D., & Tversky, A. (1979). Prospect theory: an analysis of decision under risk. *Econometrica*, *47*(2), 263–291. https://doi.org/10.1142/9789814417358_0006

Kuksov, D., & Wang, K. (2014). The bright side of loss aversion in dynamic and competitive markets. *Marketing Science*, *33*(5), 693–711. https://doi.org/10.1287/mksc.2014.0847

Li, B. Z., & Zeng, J. W. (2021). An analysis of the evolution of government and enterprise interaction in the perspective of resource endowment. *Operations Research and Management Science*, *30*(4), 163–171.

Liu, J., & Ma, G. (2020). Study on incentive and supervision mechanisms of technological innovation in megaprojects based on the principal-agent theory. *Engineering, Construction and Architectural Management*, *28*(6), 1593–1614. https://doi.org/10.1108/ECAM-03-2020-0163

Liu, N., & Zhou, G. (2023). Evolutionary analysis of resource sharing of collaborative innovation in major infrastructure projects based on prospect theory. *Journal of Industrial Engineering and Engineering Management*, *37*(3), 69–79.

Liu, Y., Fan, Z., & Zhang, Y. (2014). Risk decision analysis in emergency response: a method based on cumulative prospect theory. *Computers and Operations Research*, *42*(2), 75–82. https://doi.org/10.1016/j.cor.2012.08.008

Ma, G., & Liu, J. (2020). Incentive problem of collaborative technology innovation in mega projects considering fairness preference. *Journal of Shanghai University (Natural Science Edition)*, *5*(26), 756–768. https://www.journal.shu.edu.cn/EN/10.12066/j.issn.1007-2861.2122

Manley, K. (2006). The innovation competence of repeat public sector clients in the Australian construction industry. *Construction Management and Economics*, *24*(12), 1295–1304. https://doi.org/10.1080/01446190600934953

Maynard Smith, J., & Price, G. R. (1973). The logic of animal conflict. *Nature*, *246*(5427), 15–18. https://doi.org/10.1038/246015a0

Owolabi, H. A., Oyedele, L. O., Alaka, H. A., Ajayi, S. O., Akinade, O. O., & Bilal, M. (2020). Critical success factors for ensuring bankable completion risk in PFI/PPP megaprojects. *Journal of Management in Engineering*, *36*(1), 4019032. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000717

Ozorhon, B. (2013). Analysis of construction innovation process at project level. *Journal of Management in Engineering*, *29*(4), 455–463. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000157

Ozorhon, B., & Ora, K. (2016). Drivers of innovation in construction projects. *Journal of Construction Engineering and Management*, *143*(4), 4016118. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001234

Romestant, F. (2020). Sustainability agencing: the involvement of stakeholder networks in megaprojects. *Industrial Marketing Management*, *89*, 535–549. https://doi.org/10.1016/j.indmarman.2019.09.005

Sergeeva, N., & Zanello, C. (2018). Championing and promoting innovation in UK megaprojects. *International Journal of Project Management*, *36*(8), 1068–1081. https://doi.org/10.1016/j.ijproman.2018.09.002

Simon, H. A. (1955). A behavioral model of rational choice. *Quarterly Journal of Economics*, *69*(1), 99–118. https://doi.org/10.2307/1884852

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, *124*(3), 226–231. https://doi.org/10.1061/(ASCE)0733-9364(1998)124:3(226)

Smith, J. M. (1974). The theory of games and the evolution of animal conflicts. *Journal of Theoretical Biology*, *47*(1), 209–221. https://doi.org/10.1016/0022-5193(74)90110-6

Song, Y., Elsner, W., Zhang, Z., & Berger, R. (2020). Collaborative innovation and policy support: the emergence of trilateral networks. *Applied Economics*, *52*(34), 3651–3668. https://doi.org/10.1080/00036846.2019.1708254

Tan, D., & Xu, H. (2020). Evolutionary equilibrium analysis of mass emergency derived from environmental pollution based on prospect theory. *Operations Research and Management Science*, *29*(5), 161–170.

Tatum, C. B. (2018). Learning construction engineering: why, what, and how. *Journal of Construction Engineering and Management*, *144*(3), 4018004. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001436

Turner, J. R., & Müller, R. (2003). On the nature of the project as a temporary organization. *International Journal of Project Management*, *21*(1), 1–8. https://doi.org/10.1016/S0263-7863(02)00020-0

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, *5*(4), 297–323. https://doi.org/10.1007/BF00122574

van Marrewijk, A., Clegg, S. R., Pitsis, T. S., & Veenswijk, M. (2008). Managing public–private megaprojects: paradoxes, complexity, and project design. *International Journal of Project Management*, *26*(6), 591–600. https://doi.org/10.1016/j.ijproman.2007.09.007

von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton University Press.

Winch, G. M. (2013). Escalation in major projects: lessons from the channel fixed link. *International Journal of Project Management*, *31*(5), 724–734. https://doi.org/10.1016/j.ijproman.2013.01.012

Worsnop, T., Miraglia, S., & Davies, A. (2016). Balancing open and closed innovation in megaprojects: insights from Crossrail. *Project Management Journal*, *47*(4), 79–94. https://doi.org/10.1177/875697281604700407

Wu, J., Wu, X., Li, P., Sheng, Y., & Shi, Q. (2017). Evolutionary game analysis of knowledge transfer in industry alliance based on cumulative prospect theory. *Operations Research and Management Science*, *26*(3), 92–99.

Xue, F., Chen, G., Xie, H., & Zhang, L. (2021). Incentive contract design for collaborative innovation of megaproject under moral hazard. *Systems Engineering*, *39*(4), 49–55.

Zeng, W., Wang, H., Li, H., Zhou, H., Wu, P., & Le, Y. (2019). Incentive mechanisms for supplier development in mega construction projects. *IEEE Transactions on Engineering Management*, *66*(2), 252–265. https://doi.org/10.1109/TEM.2018.2808169

Zhang, H., Wang, J., & Tao, H. (2018). Research the decision-making behavior of investors based on prospect theory in the PPP Project. *Soft Science*, *32*(8), 129–133. https://doi.org/10.13956/j.ss.1001-8409.2018.08.28

Zhang, J., & Liu, M. (2017). Supervise management on collusion between government and enterprise in water pollution control based on prospect theory. *System Engineering*, *35*(2), 45–50.

Zhang, Y., Donohue, K., & Cui, T. H. (2015). Contract preferences and performance for the loss-averse supplier: buyback versus revenue sharing. *Management Science*, *62*(6), 1734–1754. https://doi.org/10.1287/mnsc.2015.2182

Zhao, D., Ji, S., Wang, H., & Jiang, L. (2021). How do government subsidies promote new energy vehicle diffusion in the complex network context? A three-stage evolutionary game model. *Energy*, *230*, 120899. https://doi.org/10.1016/j.energy.2021.120899

Zhou, G., Zhang, Y., Li, Y., & Zhao, G. (2012). Evolutionary game analysis of the behavior of construction safety management based on prospect theory. *Journal of Systems and Management*, *21*(4), 501–509. https://doi.org/10.3969/j.issn.1005-2542.2012.04.009

Zhou, Y., & Liu, J. (2021). Influence of government credit risk on PPP projects in operation stage. *International Journal of Strategic Property Management*, *25*(3), 216–227. https://doi.org/10.3846/ijspm.2021.14552

Zhu, Y. (2017). *The Sichuan—Tibet railway construction challenges and countermeasures*. China Communications Press.