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INCENTIVE MECHANISMS OF AN EXPERIMENTAL RESOURCE-SHARING PLATFORM CONSIDERING REPUTATION EFFECTS FOR MEGAPROJECTS

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Abstract. Participating in megaproject experimental tasks would significantly improve the laboratories' industry influence and future competitiveness. Thus, this paper introduces the long-term reputation effects of the incentive model of an experimental resource-sharing platform for megaprojects, which could motivate them to consider future benefits and improve their current efforts. The aim is to incentivize laboratories' resource-sharing behavior more effectively and to increase the amount of resources shared by these laboratories on the platform, thus guaranteeing the long-term sustainability of the platform. It constructs the incentive model by combining dual implicit and explicit incentive mechanisms. It analyses the incentive mechanism of a reputation effect on laboratories compared with the pure explicit mechanism so that the primary conditions for reputation incentives can be obtained to achieve Pareto improvement. Finally, the proposed method is validated in combination with data simulation. The results show that although dual implicit and explicit incentive mechanisms could reduce the information asymmetry between the two sides and increase the efforts of laboratories and the benefits of the platform, the platform should not blindly increase the intensity of these incentives and need to consider the influence of the subsidies of these laboratories' upfront inputs, the degree of sharing and their informatization capabilities.

Keywords: incentives, megaprojects, platform, reputation, resource sharing.

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1. Introduction

To promote the demand for global economic development, megaprojects have received increasing amounts of attention. Megaprojects are characterized by high technical difficulty, high-quality requirements, considerable participants, large-scale investment, and sustainable development needs, which bring high complexity, uncertainty, risk, and innovation to their construction (Floricel et al., 2023; Gil, 2023; Machiels et al., 2023; Sovacool et al., 2023; Jin et al., 2022; Love et al., 2022; Zaman et al., 2021; Zhang et al., 2020). During the construction process of these projects, uncertainty and risk require much technological research or experimentation. For example, megaprojects such as the Qinghai-Tibet Railway have highly harsh natural conditions, complex engineering technologies, unusually fragile ecological environments, and rugged construction organizations. Three major problems, namely, cold and oxygen deprivation, multiyear permafrost, and environmental fragility, are severe and pose incredibly high risks to the construction and operation of the project (Lu, 2006; Sun, 2005). Hence, many technical innovations are needed to reduce the risks during construction, such as ensuring the safety of external insulation of electrical equipment at high altitudes, providing ice-covered snow environments, providing disaster mechanisms for internal and external dynamics coupling in highland canyon areas, and focusing on efficient conversion and safe transmission and utilization of clean energy power for the purpose of achieving "carbon peak and carbon neutrality." These technical innovations in megaprojects require numerous and complex experimental projects. In addition, the completion of these technological innovation tasks will involve a large number of cross-disciplinary, cross-organizational, cross-sectoral, and cross-geographical participants, which makes it challenging to create a scale advantage through geospatial aggregation, and it is also easy to lag behind the efficiency of the transformation of applied research results into engineering technology (Lei, 2019; Ministry of Science and Technology of the People's Republic of China [MSTPRC], 2018). Therefore, developed countries have vigorously invested in and set up innovation centers or platforms to integrate these technological innovation resources (Economic Development Administration, 2023; GOV. UK., 2021). This center integrates and aggregates resources for technological innovation, with open and shared characteristics, and that supports and serves scientific research and technological development activities (Sun et al., 2023; Osorno & Medrano, 2022). It builds a link between science and industry and acts as a bridge in the sharing of resources between different participants (Memon et al., 2022). It also provides these participants access to knowledge, technology, experience, and innovation capabilities, which they cannot produce independently (Stezano, 2018). Moreover, its establishment contributes to introducing the market perspective into the design and implementation process of R&D public policy (OECD, 2014). Therefore, developing countries have gradually begun to pay attention to this issue. For example, China has established a new type of nonprofit legal person nature of social service organizations: the National Technology Innovation Center (NTIC) (State Council of the People's Republic of China, 2021).

However, due to the numerous and scattered technological innovation resources needed for megaprojects, it is not enough to rely only on the center for offline organization and management; additionally, it is necessary to make full use of information technology to build a platform for sharing experimental resources among megaprojects to overcome innovation barriers across organizations, regions and disciplines; to effectively utilize and share experimental equipment, venues and talent in such a way as to aggregate resources in the field of megaprojects; and to improve the utilization rate of resources and data interoperability and interconnection. Thus, mutual benefits and win-win situations can be achieved for many parties. The application of the traditional experimental management model has resulted in inefficient coordination and cooperation and high costs in completing experimental tasks for cross-organizational and cross-disciplinary technological innovation in megaprojects. For example, the whole experimental management collaboration process, such as organizing, bidding, screening, matching, supervising and delivering, costs the owner considerable manpower, material resources and time; the experimental tasks involve many laboratories in these technological innovations from many different organizations, disciplines, departments and geographical areas, making coordination and organization complex, difficult and inefficient (Wang et al., 2019); due to the large number and complexity of participating organizations in the screening and matching process, the owner is not sure in advance of the actual experimental capabilities of these laboratories and may not be able to undertake these experimental tasks, thus potentially increasing the cost of trial and error; in conducting these tasks, the owner also invests a large amount of manpower and material resources in performing the corresponding supervision work (He & Song, 2022). With the rapid development of information technology, such as information processing, storage and transmission, especially high-speed broadband networks, cloud computing, big data and 5G, the platform based on this technology could theoretically accommodate almost all supply and demand information from both sides at a marginal cost close to zero and assist both sides in processing transaction information anytime and anywhere. The platform's collaborative innovation and sharing experimental management system and visualization information system are built through these information technology means, and through the platform system for multilaboratory collaborative management, to enhance the experimental capabilities, to complete the user's higher experiment needs; through the system to open up the multilaboratory data interfaces, to realize the unified management of the data; to complete the high quality of the external data; and through comprehensive sharing and to further enhance the laboratory service capabilities, the system can integrate the data, combined with various types of experimental business application requirements through the digital big screen, PC, mobile and other applications to enhance the convenience and ease of use of the platform to provide application and data support for leadership decision-making; the platform is the identification of experimental demand through rapid screening and matching of experimental resources participating in the platform to provide the experimental demand side with reasonable and efficient technological innovation service programs to be decided by the demand side to make. After the decision of the demand side is made, the whole process of experimental management, such as task allocation, supervision and delivery, is carried out, and the results transformation service is ultimately carried out. Therefore, the experimental resource management mode of the platform is used to provide technical support and experimental resource organization and management services throughout the whole process, as shown in Figure 1.

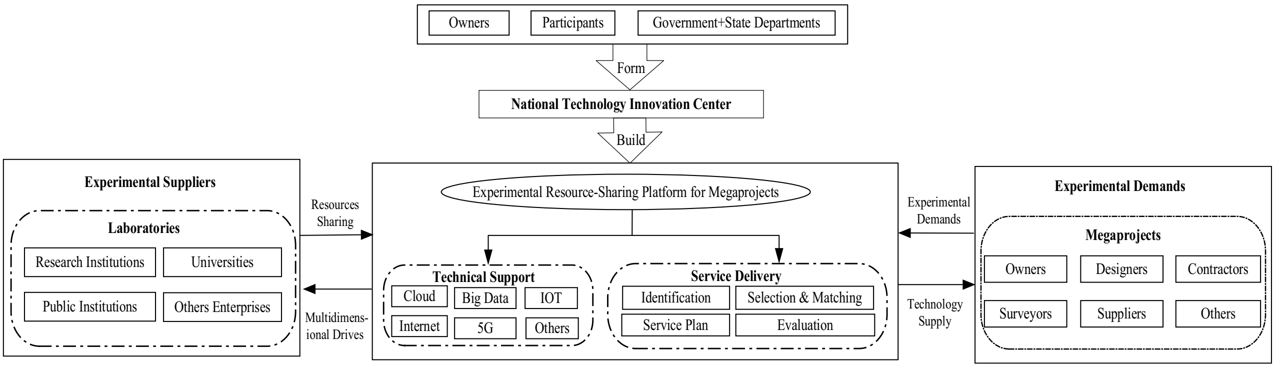


Figure 1. Platform experimental management mode

Of course, such a platform will also play an essential role in the collaborative integration of technological innovation resources in megaprojects. Nevertheless, the depth and breadth of resource sharing among participating experimental resource suppliers (i.e., various types of laboratories) are low, resulting in a large number of idle resources or duplication of inputs (Tian, 2008). In addition, participating laboratories are skeptical about the number of resources invested versus their actual benefits. Although they can cooperate with experimental tasks, they cannot be motivated to invest in sharing more resources on the platform (Kembro et al., 2014). Moreover, the demands of experimental resources do not determine the actual situation of these laboratories' experimental capabilities and information technology levels. It is also difficult for the demand sides to observe the business behavior and the efforts invested by these laboratories (Conrads et al., 2014), which is at an obvious information disadvantage. This also creates an information asymmetry problem that will hinder the long-term sustainable development of the platform. Although explicit incentives (e.g., economic incentives) are helpful for improving the participation of these laboratories in the preconstruction stage of the platform, increasing the number of resources shared, and solving some information asymmetry problems (Kretschmer et al., 2022; Rietveld et al., 2021; Zeng et al., 2021; Xiao & Ke, 2019), direct economic incentives do not always lead to these laboratories' positive sharing behavior (Dur & Tichem, 2015; Wang & Liu, 2015). Hence, such a single incentive seems insufficient for the long-term sustainable development of the platform. Considering the great social and industrial influence of megaprojects and the high degree of uncertainty, risk and innovation in the construction process, the owners of these megaprojects also attach great importance to the reputation effect and include the reputation of the participants in the bidding documents, such as the Hong Kong-Zhuhai-Macao Bridge. The bidding documents for the "Bridge load test for the main project of the Hong Kong-Zhuhai-Macao Bridge" set detailed scoring criteria for the reputation effect of the bidders' credibility and performance (Hong Kong-Zhuhai-Macao Bridge Authority, 2017). Participation in megaprojects is conducive to shaping the industry credibility of these laboratories and significantly improving their future competitiveness, given the tremendous social and industrial impact of such projects, and a great deal of reputation can be gained by participating in and completing experimental tasks in megaprojects. Câmara et al. (2023) argue that the reputation effect plays a crucial role in motivating laboratories' sharing behavior, summarizing their past behavior, and predicting their future behavior. For instance, national authorities evaluate laboratories annually (MSTPRC, 2014), but only laboratories with good evaluation results and above, which means that they will have good reputations; therefore, they can be qualified to be included in the bidding scope of experimental tasks for megaprojects (e.g., large-scale railroad construction projects) (Zheng & Kang, 2023). The research question of this paper is how to incentivize resource sharing behavior and increase the amount of resources shared by laboratories to guarantee the long-term sustainable development of the platform. Therefore, this paper argues that considering the design of an incentive mechanism from the perspective of reputation effects can more effectively drive laboratories to participate in the platform in the long term and actively share more of their resources with the platform, thus guaranteeing the sustainable development of the platform.

2. Literature review

2.1. Incentives

The effectiveness of incentives is often demonstrated through contract design; however, contract design is based on principal-agent theory as the dominant theory and an essential analytical tool (Eisenhardt, 1989). With the rapid development of information technology, megaprojects have also applied many information technology tools, such as platforms. A platform can be regarded as a unique form of organization that can flexibly arrange and transform the organizational structure to integrate resources (Zeng et al., 2021; Cennamo & Santaló, 2019; Saadatmand et al., 2019; Zeng et al., 2019). It also reduces many of the associated costs (Øverby & Audestad, 2021; Goldfarb & Tucker, 2019). Wareham et al. (2014) argue that under multiactor participation in megaproject innovation, it is essential to incentivize participants to jointly invest their efforts in bringing together different experimental resources to develop effective and comprehensive solutions for those needing these resources. In addition, Huang et al. (2013) found that these participants may be reluctant to participate in and share their resources on the platform without seeing any direct economic benefits. As a result, some scholars have sought to incentivize participants to collaborate through explicit economic incentives such as benefit sharing and cost sharing (Liu et al., 2023; Hayrutdinov et al., 2020). Kretschmer et al. (2022) argue that it is essential to design reasonable and adequate incentives for these participants to promote participation and increase the number of resources shared on the platform. However, how can incentives be designed to encourage the involvement of different stakeholders in a megaproject on the platform and the willingness to share their resources? Some scholars have analyzed and classified some influential factors related to participation and willingness to share resources based on organizational governance theory, organizational system theory, rootedness theory, game theory, equity theory, and behavioral incentive theory, forming a comprehensive research framework (Chen et al., 2022; Konhäusner et al., 2021; Wang, 2021; Kathuria et al., 2020; Kuang et al., 2019; Xiao & Ke, 2019).

According to the above literature, the feasibility of the platform constructed by the NTIC can be verified to solve the problems of cross-organizational, cross-geographical, and cross-disciplinary collaboration. However, while few studies have focused on transactional platforms and fewer have focused on nonprofit innovative platforms, such as contribution experimental resource sharing platforms for megaprojects, most of these previous studies on incentive mechanisms are qualitative, such as the classification or analysis of influencing factors; moreover, there is a lack of quantitative research. Many of these studies are based on short-term cooperation, but they do not consider the impact of long-term collaboration on incentives. These studies have considered only explicit economic benefit-sharing or cost-sharing incentives and less consideration has been given to implicit incentives that will have an effect on the future.

2.2. Reputation

Reputation is information about the characteristics that reflect an organization, the impression that an organization's transactional activities leave on other organizations, and an intangible asset that generates positive results for the organization in terms of expectations of future behavior and is an important determinant of the organization's economic value (Behera et al., 2022). However, first, Fama (1980) introduced reputation as an incentive and discovered that such implicit incentives could be an imperfect substitute for explicit incentives. Reputation incentives are vital mechanisms that are implicitly long-term and highly effective (Wang et al., 2020a; Lai et al., 2015). It also provides sustained incentives and constraints, effectively prevents agents' moral hazard and opportunism in the long term and helps to overcome the problem of information asymmetry between both agents and principals. Other scholars have shown that even without explicit incentives, agents strive to improve their reputations and, thus, their future competitiveness (Behera et al., 2022; Hu et al., 2018). Appropriate reputation incentives also motivate agents to invest more resources and energy in achieving sustainable development (Shi et al., 2018).

Furthermore, reputation incentives have also been gradually introduced into engineering projects. For example, Li et al. (2022a) constructed a multiperiod dynamic incentive mechanism based on coupling performance reputation and ratchet effects. Zhu et al. (2020a) incentivize the performance of contractor leaders in megaprojects by establishing a project reputation evaluation system. Zhu et al. (2020b) introduce the reputation effect into the incentive mechanism of crowdsourcing competitions, which could motivate contractors to improve their current efforts to consider future performance benefits. Li et al. (2020) design a dynamic reputation incentive mechanism for engineering contracts, explore the adequate conditions for exerting the reputation incentive effect, and analyze and compare the impacts of explicit and implicit incentives. They believe that the reputation mechanism, as an integral part of contract rules and guidelines, is a further improvement and supplement to engineering contracts. Oladimeji et al. (2020) analyze the four key drivers affecting the reputation of megaprojects. Wang et al. (2020a) propose a reputation incentive mechanism and design rewards and penalties in the benefits-payment function of the reputation factor to motivate participants to engage in good collaborative behavior. Gershon et al. (2020) analyze the relationship between reputation benefits and action costs by testing the relationship in two field experiments and one laboratory experiment. Randeree (2014) emphasizes that reputation tends to be overlooked by participants due to its indirect contribution to the profitability of megaprojects. Thus, the role of reputation needs to be considered, and the reputation of these participants needs to be maintained and enhanced, which can help increase their brand value and competitiveness in the market (He et al., 2021).

In brief, these studies have defined reputation and extended it to the field of megaprojects and studied its role and benefits for engineering project management; however, most of them have applied only market-perceived definitions of reputation without considering the impact of the efforts of these participants. In addition, quantitative research on the incentive mechanism of introducing reputation effects on experimental resource-sharing platforms in megaprojects still needs to be completed. This paper aims to provide a quantitative framework for determining the reputation incentive mechanism of experimental resource-sharing platforms in megaprojects. This approach will also help the NTIC design appropriate incentive mechanisms to help laboratories maximize the sharing of their technological innovation resources on the platform and ensure the sustainable development of the platform. Therefore, to fill the above research gap, this paper discusses two incentive mechanisms based on information asymmetry between supply and demand, organized as follows. First, it designs and solves an explicit incentive model without considering the reputation effect. Then, an incentive model is developed that considers the reputation effect from the platform perspective, and how the incentive affects laboratories' resource-sharing efforts and the platform's benefits is investigated. In addition, it compares the results of incentive models without and with the consideration of reputation effects. Finally, through numerical examples, the rationality of introducing reputation effects is verified, which provides a theoretical basis for policymakers to develop incentive policies.

3. Methodology

Principal-agent theory is one of the main elements of contract theory in institutional economics, and the principal-agent relationship mainly refers to one or more actors (i.e., principals) appointing and hiring other actors (i.e., agents) to serve them according to an explicit or implicit contract while granting the latter certain decision-making rights and paying the latter according to the quantity and quality of the services they provide (Jensen & Meckling, 1976). It was developed by a number of economists who studied in depth the problem of information asymmetry and incentives within the firm. The central task of the theory is to allow the principal to design the optimal contract to incentivize the agent and to solve the principal-agent problem between the two parties in the case of conflicting interests and information asymmetry. Since there is information asymmetry between the platform (i.e., principal) and the experimental resource supplier (i.e., agent) studied in this paper and since the agent has an information advantage, the agent may appear to make behaviors detrimental to the principal's interests from the goal of maximizing his or her own interests (Wang et al., 2020b), which leads to the principal-agent problem of conflicting interests and information asymmetry. To solve this problem and further mobilize these suppliers to participate in the platform and maximize the contribution of their resource sharing to the platform while also considering the possibility of the failure of explicit economic incentives, the implicit incentive mechanism between the agent and the principal does not exist in the true sense of the "contract", which could prevent the contract from being fulfilled. Therefore, based on principal-agent theory, this paper introduces the reputation effect to realize long-term incentives; avoids the short-term opportunistic behavior of the agent due to the pursuit of short-term interests by introducing "time" (Fudenberg et al., 1990; Kreps et al., 1982); and constructs a dual incentive model combining explicit and implicit incentive models, which uses backward induction to model and solve the incomplete information game. First, the research problem is described in light of previous studies and the actual situation of the project. Second, the parameters of the incentive models are assumed; second, the explicit incentive model of sharing experimental resources without introducing the reputation effect and the implicit incentive model of sharing experimental resources with the introduction of the reputation effect are constructed; and third, there is a comparative analysis of the optimal level of effort in the laboratory, shared incentive benefits and fixed funding as well as the platform's expected utility for the two incentive models. The research framework of this paper is shown in Figure 2.

3.1. Problem description

The NTIC is an organization that builds and operates under the physical line, while the platform is an online platform constructed by the NTIC using information technology. The NTIC can only guarantee long-term sustainable development by attracting more laboratories to participate and sharing more of their resources on the platform. Therefore, it is necessary to design corresponding incentive mechanisms to guide laboratories to participate in the platform and maximize the sharing of their resources so that the center can create more excellent value for the actual needs of megaprojects (Rietveld et al., 2021). According to Le et al. (2018), the application of informatization means that it can accurately and completely record participants' contributions to project construction in real time, making it possible to assess their contributions to the project based on their sharing of resources on the platform. The experimental resources studied in this paper include personnel, experimental instrumentation, information systems, experimental process data, and experimental results. Hence, the NTIC combines actual experimental tasks and incorporates an assessment of laboratories' contributions to the project by sharing their resources on the platform with the project contract. The assessment result is linked to the laboratories' bidding for the relevant projects, so their resource-sharing behavior is related to future business acquisitions in the current project. Taking the experimental demand of megaprojects as a traction, more laboratories are attracted to participate, and cooperation is carried out in the form of center coconstruction units, contracted network laboratories, and joint undertakings of projects to gather these experimental resources, jointly build a synergistic R&D experimental system and promote the industrialization of scientific and technological achievements. This paper combines explicit and implicit incentives to construct a dual incentive model that uses inverse induction to model and solve the incomplete information game. This connects with the actual situation of the project. The model mainly considers two sides involved in the main body: the platform (it represents the NTIC, i.e., the demand side of experimental resources) and laboratories (i.e., the supply side of

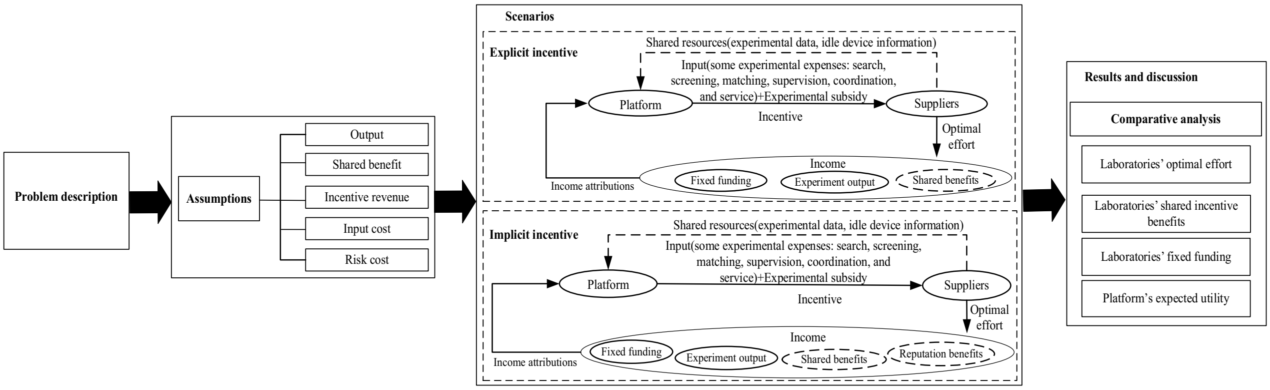


Figure 2. Research framework of the methodology

experimental resources, including laboratories of scientific research institutes, laboratories of colleges and universities, and laboratories of enterprises). Since the platform is nonprofit, it is assumed that its input cost problem is not considered. The platform is the demand side of experimental resources, i.e., the principal, while the participating laboratories are the agents. For ease of presentation, this paper discusses two incentive scenarios: not considering reputation effects and considering reputation effects.

3.2. Model assumptions

To understand the model for better analysis, the following assumptions are made in this paper:

Assumption 1. Since the resource sharing effort output of the laboratories in this paper exhibits a linear pattern, based on Laffont and Tirole (1933), the effort output function of the laboratories in this paper by sharing their resources on the platform can be expressed as $Q = de + (1 - d)\varepsilon$, where e is the laboratories' efforts at resource sharing and $e \geq 0$. The resource sharing effort level of laboratories refers to the personnel, equipment, time, and work motivation invested in; $e = 0$ indicates that laboratories do not put in efforts to share resources, and $e < 0$ may even indicate "free-riding" or lazy behavior (Mu et al., 2020; Li et al., 2017; Ma et al., 2016). d is the resource-sharing degree, and $0 \leq d \leq 1$ (Li et al., 2022b; Xu et al., 2021; Zaheer & Trkman, 2017; Zhou et al., 2017). ε is the error due to random factors. Its probability of occurrence obeys a normal distribution, i.e., $\varepsilon \sim N(0, \sigma^2)$, $\mathrm{var}(Q) = (1 - d)^2\sigma^2$, and the larger the value of the resource-sharing degree (d) is to make both sides' information more transparent, the smaller the error is, and vice versa.

Assumption 2. As the supply and demand sides of experimental resources are in an information asymmetry (Holmstrom & Milgrom, 1987), the platform designs incentives to give laboratories linear incentive gains based on their shared effort outputs as $W = \alpha + \gamma Q$, where α ($\alpha \geq 0$) is the fixed funding paid to laboratories in the contract. The fixed funding refers to the input of some of the experimental resources of these laboratories before they participate in the platform, and the platform pays the fee as a subsidy for their preliminary input, which is to maintain the guarantee of their basic input in the early stage and psychologically give them a basic sense of stability and certainty to make the behavior of experimental resource sharing go smoothly (Li & Gao, 2019; Xin et al., 2022); thus, when $\alpha > 0$, these laboratories will have the guarantee of their basic inputs; γD is the performance gain based on the laboratories' shared resources on the platform, and $0 \leq \gamma \leq 1$ (Shang et al., 2016).

Assumption 3. Since the costs of the laboratory inputs studied in this paper exhibit nonlinearity, according to the theoretical model of Hosseinian et al. (2020), the cost of resource-sharing effort inputs in laboratories can be monetized; thus, the cost function of the sharing effort inputs is $G(e)=\frac{e^2}{2h}$, where h is the coefficient of informatization capabilities and $h \geq 0$, and where the cost (G) is positively correlated with the effort level (e) and negatively correlated with the informatization capabilities coefficient (h) (Chu & Gong, 2016), satisfying $G(e) \geq 0$, $G'(e) \geq 0$ and $G''(e) \geq 0$.

Assumption 4. In practice, the platform is nonprofit, so it has a greater capacity to take risks. However, laboratories are more aware of risk factors. Thus, based on Grossman and Hart's (1983) research framework of principal-agent theory, the platform is assumed to be risk neutral, and the laboratories are risk averse. According to Arrow-Pratt's conclusions, the absolute risk aversion measure (ρ) is defined as the degree of risk aversion of these laboratories, $\rho > 0$, and the cost of risk they bear as $L=\frac{1}{2}\rho\,\mathrm{var}(W)$.

3.3. Model establishment and solution

This paper describes the experimental incentive models in two scenarios: an explicit incentive model for experimental resource sharing without considering reputation effects and an implicit incentive model for experimental resource sharing considering reputation effects.

3.3.1. Explicit incentive model

The laboratories' benefits are $W_1 = \alpha_1 + \gamma_1 Q_1$, and the cost of risk they bear is

$$L=\frac{1}{2}\rho\gamma_1^2(1-d)^2\sigma^2.$$

The laboratories' expected utility is $E(U_1) = E(W_1 - G_1) - L_1$. Under the above assumptions, the laboratories' deterministic equivalent payoff function on its risk aversion is expressed as

$$E(U_1)=\alpha_1+\gamma_1 de_1-\frac{e_1^2}{2h}-\frac{1}{2}\rho\gamma_1^2\sigma^2.$$

Since the platform is risk neutral, its expected utility is equal to its expected return; thus, the platform's expected utility is $E(V_1) = E(Q_1 - W_1)$. According to the above assumptions, the equation is expressed as $E(V_1) = de_1 - \gamma_1 de_1 - \alpha_1$. In addition, based on the above assumptions and the payment relationship, the number of cooperation periods is assumed to be t. The discount rate is δ (Cai & Fu, 2020), and the larger the discount rate is, the more laboratories value long-term cooperation with the platform (Li et al., 2017). The long-term explicit incentive mechanism designed for the retention utility of laboratories without considering the reputation effect can be used to solve the following models:

$$\max\ E(V_1)=\sum_{t=1}^{\infty}\delta^t(de_1-\gamma_1 de_1-\alpha_1); \tag{1}$$

$$\text{IR: } E(U_1)\geq\overline{U}; \tag{2}$$

$$\text{IC: } \max E(U_1). \tag{3}$$

Introducing the parameters into Equations (1) to (3) above and obtaining:

$$\max \mathrm{E}(V_1) = \gamma_1 d^2 h - \frac{\gamma_1^2 d^2 h}{2} - \frac{\rho\gamma_1^2 (1-d)^2 \sigma^2}{2} - \frac{\overline{U}(1-\delta)}{1-\delta^t}; \quad (4)$$

$$\text{IR: } \mathrm{E}(U_1) = \sum_{t=1}^{\infty} \delta^t \left(\alpha_1 + \gamma_1 d e_1 - \frac{e_1^2}{2h} - \frac{\rho\gamma_1^2 (1-d)^2 \sigma^2}{2}\right) \ge \overline{U}; \quad (5)$$

$$\text{IC: } \max E(U_1) = \sum_{t=1}^{\infty} \delta^t \left(\alpha_1 + \gamma_1 d e_1 - \frac{e_1^2}{2h} - \frac{\rho\gamma_1^2 (1-d)^2 \sigma^2}{2}\right). \quad (6)$$

By solving the models, the optimal shared incentive coefficient (γ_1^*) and the optimal effort level of the laboratories (e_1^*) can be obtained as follows:

$$\gamma_1^* = \frac{d^2 h}{d^2 h + (1-d)^2 \rho\sigma^2}; \quad (7)$$

$$e_1^* = \frac{d^3 h^2}{d^2 h + (1-d)^2 \rho\sigma^2}. \quad (8)$$

3.3.2. Implicit incentive model

The reputation effect, as an intangible capital commitment, is the discounting of future earnings, which dynamically influences the development of an organization in the long term (Ravasi et al., 2018; Shi et al., 2018). Unlike the explicit incentives established based on contracts in the previous section, the incentives created by the reputation effect are implicit. In an actual project, the more effort a laboratory spends and the more quickly the platform can obtain real experimental information and resources, the better the reputation of the laboratory will be. Therefore, their resource-sharing effort levels determine whether laboratories have good or bad reputations. A good reputation for laboratories involved in the experimental tasks will bring them intangible income, giving them a more significant advantage in bidding and more incentive benefits during cooperation and enhancing their competitiveness in the future market (Fombrun & Shanley, 1990; Shi et al., 2017). Thus, this paper expresses the reputation effect as $R(e) = ke^2$, where k is the reputation impact coefficient (Han et al., 2022; Cai & Fu, 2020; Li et al., 2017). The reputation effect is a quadratic function of the effort level rather than a primary function because it is not exactly the ideal state that one point of effort reaps one point of reputation in reality. Nevertheless, the only way to enjoy a lasting reputation is to make continuous efforts and long-term accumulation. Hence, the reputation effect is a quadratic function of the level of effort. Nevertheless, the reputation effect of laboratories has a lag, with a one-period lag, i.e., the reputation effect of laboratories is not considered in the first period of cooperation.

The laboratories' benefits are $W_2 = \alpha_2 + \gamma_2 Q_2$, and the cost of risk they bear is

$$L_2 = \frac{1}{2}\rho\gamma_2^2 (1-d)^2 \sigma^2.$$

The laboratories' expected utility is $\mathrm{E}(U_2) = \mathrm{E}(W_2 + R - G_2) - L_2$. Under the above assumptions, the laboratories' deterministic equivalent payoff function on their risk aversion is expressed as

$$\mathrm{E}(U_2) = \sum_{t=1}^{\infty} \delta^t \left[\alpha_2 + \gamma_2 d e_2 - \frac{e_2^2}{2h} - \frac{1}{2}\rho\gamma_2^2 (1-d)^2 \sigma^2\right] + \sum_{t=2}^{\infty} \delta^t k e_2^2 .$$

Since the platform is risk neutral, its expected utility equals its expected return, and its expected utility is $\mathrm{E}(V_2) = \mathrm{E}(Q_2 - W_2)$. According to the above assumptions, the equation is expressed as $\mathrm{E}(V_2) = de_2 - \gamma_2 de_2 - \alpha_2$. As both sides try to maximize their respective returns, which depend on the laboratories' resource-sharing effort levels (e), this effort level is determined by α and γ in the returns. Thus, the platform steers the shared effort levels of the laboratories by setting α and γ. When the platform sets the laboratories' gain incentives, it should satisfy the following:

a) The individual rationality constraints (IR), where the laboratories' expected utility cannot be lower than the retained utility ($\overline{U}$); otherwise, the commissioned business will be terminated (Hart & Holmstrom, 1987);

b) The incentive compatibility constraint (IC), where the laboratories adjust their effort levels to maximize utility.

When information is asymmetric, the platform cannot fully observe its resource-sharing effort levels (Hosseinian & Carmichael, 2014). The platform's expected utility can be achieved only through laboratories' utility-maximizing behavior. The incentives can be designed to address the following models:

$$\max \mathrm{E}(V_2) = \sum_{t=1}^{\infty} \delta^t (de_2 - \gamma_2 de_2 - \alpha_2); \quad (9)$$

$$\text{IR: } \mathrm{E}(U_2) \ge \overline{U}; \quad (10)$$

$$\text{IC: } \max E(U_2). \quad (11)$$

Introducing the parameters into Equations (9) to (11) above and obtaining:

$$\max \mathrm{E}(V_2) = \frac{\gamma_2 d^2 h}{1-2kh} - \frac{\gamma_2^2 d^2 h}{2(1-2kh)^2} - \frac{k\gamma_2^2 d^2 h^2}{(1-2kh)^2} - \frac{\rho\gamma_2^2 (1-d)^2 \sigma^2}{2} - \frac{\overline{U}(1-\delta)}{1-\delta^t}; \quad (12)$$

$$\text{IR: } \mathrm{E}(U_2) = \sum_{t=1}^{\infty} \delta^t \left[\alpha_2 + \gamma_2 d e_2 - \frac{e_2^2}{2h} - \frac{1}{2}\rho\gamma_2^2 (1-d)^2 \sigma^2\right] + \sum_{t=2}^{\infty} \delta^t k e_2^2 \ge \overline{U}; \quad (13)$$

$$\text{IC: } \max \mathrm{E}(U_2) = \sum_{t=1}^{\infty} \delta^t \left[\alpha_2 + \gamma_2 d e_2 - \frac{e_2^2}{2h} - \frac{1}{2}\rho\gamma_2^2 (1-d)^2 \sigma^2\right] + \sum_{t=2}^{\infty} \delta^t k e_2^2. \quad (14)$$

Since the derivation of e in Equation (14) yields $e_2^* = -\frac{\gamma dh}{1-2kh}$. Based on previous assumptions and related research (Xin et al., 2022; Li & Gao, 2019), $e \ge 0$, $0 \le d \le 1$, and $h \ge 0$, so $k \le 0.5$. In addition, for the characteristics of the megaprojects studied in this paper, which are characterized mainly by positive reputation effects (Han et al., 2022; Li et al., 2020; Shi et al., 2018), $0 \le k \le 0.5$.

By solving the models, the optimal shared incentive coefficient (γ_2^*) and the optimal effort level of the laboratories (e_2^*) can be obtained as follows:

$$\gamma_2^* = -\frac{d^2h}{2kh\rho(1-d)^2\sigma^2 - (1-d)^2\rho\sigma^2 - d^2h}. \quad (15)$$

$$e_2^* = -\frac{d^2h^3}{(1-2kh)[2kh\rho(1-d)^2\sigma^2 - (1-d)^2\rho\sigma^2 - d^2h]}. \quad (16)$$

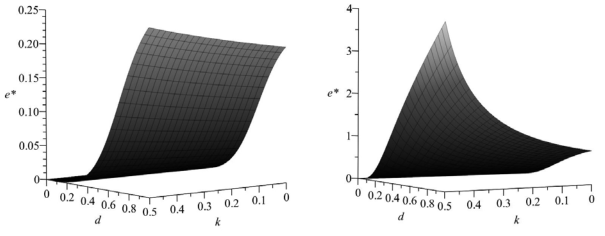
4. Results and discussion

4.1. Laboratories' optimal effort

$$e_1^* = \frac{d^3h^2}{d^2h + (1-d)^2\rho\sigma^2};$$

$$e_2^* = -\frac{d^2h^3}{(1-2kh)[2kh\rho(1-d)^2\sigma^2 - (1-d)^2\rho\sigma^2 - d^2h]}.$$

Due to $e_1^* - e_2^* < 0$, after considering the reputation effect, as the degree of platform sharing and the coefficient of reputation impact increase, the optimal effort levels of the laboratories increase accordingly. The relationships between the three factors are shown in Figure 3a and 3b.



a) h = 0.2 **b)** h = 0.8

Figure 3. Relationships between e^* and d and k

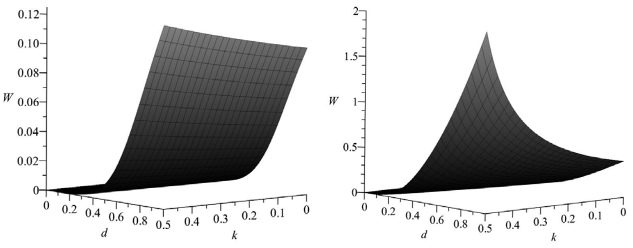
4.2. Laboratories' shared incentive benefits

The laboratories' sharing incentive gains are $W = \alpha + \gamma Q$, obtained by substituting Equations (7), (8), (15), and (16):

$$E(W_1^*) = \frac{d^6h^3}{2[\rho(1-d)^2\sigma^2 + d^2h]^2} + \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[\rho(1-d)^2\sigma^2 + d^2h]^2} + \frac{\overline{U}(1-\delta)}{1-\delta^t}; \quad (17)$$

$$E(W_2^*) = -\frac{d^6h^3}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2} + \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2} - \frac{kd^6h^4}{[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2} + \frac{\overline{U}(1-\delta)}{1-\delta^t}. \quad (18)$$

Since $E(W_1^*) - E(W_2^*) < 0$, it can be concluded that increasing the degree of platform sharing and the reputation impact coefficient can increase the benefits of laboratories. The relationships between the three factors are shown in Figure 4a and 4b.



a) h = 0.2 **b)** h = 0.8

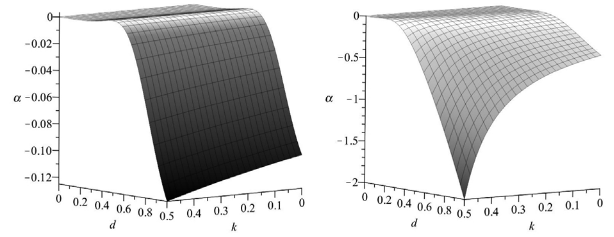
Figure 4. Relationships between W and d and k

4.3. Laboratories' fixed funding

Since $\alpha_1 - \alpha_2 > 0$, it can be concluded that as the reputation impact coefficient and the degree of platform sharing increase, the fixed funding paid by the platform decreases while the incentive coefficient increases. This finding implies that the platform is lowering the subsidy to the laboratories for the upfront investment while giving it a higher performance commission. This suggests that the future earnings of laboratories can be influenced by adjustments to the fixed funding in the contract (Shi et al., 2017). The relationships between the three factors are shown in Figure 5a and 5b.

$$\alpha_1 = \frac{\overline{U}(1-\delta)}{1-\delta^t} - \frac{d^6h^3}{2[\rho(1-d)^2\sigma^2 + d^2h]^2} + \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[\rho(1-d)^2\sigma^2 + d^2h]^2};$$

$$\alpha_2 = \frac{\overline{U}(1-\delta)}{1-\delta^t} - \frac{d^6h^3}{[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)} + \frac{d^6h^3}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2} + \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2} - \frac{kd^6h^4}{[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2}.$$



a) h = 0.2 **b)** h = 0.8

Figure 5. Relationships between α and d and k

4.4. Platform's expected utility

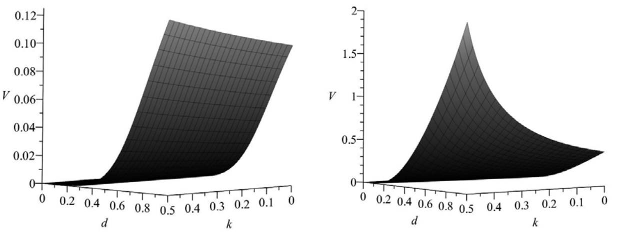
The expected utility of the platform is $E(V) = E(Q - W)$, which is obtained by substituting Equations (7), (8), and (15) into (18):

$$E(V_1^*) = -\frac{d^6h^3}{2[\rho(1-d)^2\sigma^2 + d^2h]^2} + \frac{d^4h^2}{\rho(1-d)^2\sigma^2 + d^2h} - \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[\rho(1-d)^2\sigma^2 + d^2h]^2} - \frac{\overline{U}(1-\delta)}{1-\delta^t};$$

$$\mathrm{E}(V_2^*) = -\frac{d^6h^3}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2} - \frac{d^4h^2}{(2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h)(1-2kh)} - \frac{\rho d^4h^2(1-d)^2\sigma^2}{2[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2} + \frac{kd^6h^4}{[2kh\rho(1-d)^2\sigma^2 - \rho(1-d)^2\sigma^2 - d^2h]^2(1-2kh)^2} - \frac{\overline{U}(1-\delta)}{1-\delta^t}.$$

Due to $\mathrm{E}(V_1^*) - \mathrm{E}(V_2^*) < 0$, it can be concluded that the higher the degree of platform sharing and the reputation impact coefficient are, the greater the expected utility the platform obtains. The reason for this is that the platform can obtain more information about the effort levels of these laboratories through their reputation information so that the platform can make better decisions to improve its profit. The relationships between the three factors are shown in Figure 6a and 6b.

In summary, by comparing the platform's expected utility, the laboratories' incentive gains, and their optimal effort levels under these two scenarios, it is found that both sides gain more from considering the reputation effect.



a) h = 0.2 **b)** h = 0.8

Figure 6. Relationships between V and d and k

5. Influencing factors and simulation analysis

The R&D base of the NTIC in Chengdu plans to invest a total of 2 billion RMB, with a total construction area of approximately 220,000 square meters. It plans to build four types of R&D laboratories, namely, "Digital Laboratory", "Geography and Geology Laboratory", "Intelligent Construction Laboratory", and "Disaster Warning, Prevention, and Control Laboratory". The platform will work with

Table 1. Numerical simulation

d		0.3	0.4	0.5	0.6	0.7
				h = 0.2		
k = 0.1	α	0.0005717105412	0.001790364584	0.003153835064	0.0005853277837	–0.0137487143
	e^*	0.004443127963	0.01302083333	0.03063725490	0.06048387096	0.1012157696
	W	0.0006664691943	0.002604166667	0.007659313725	0.01814516129	0.03542551936
	V	0.0006664691946	0.002604166668	0.007659313727	0.01814516130	0.03542551937
	γ	0.071090047	0.15625	0.294118	0.48387	0.694051
k = 0.2	α	0.0006164456491	0.001904209429	0.003243901466	0.0002126397254	–0.0152028571
	e^*	0.004822978813	0.01408202781	0.03293807642	0.0645007167	0.1069802258
	W	0.0007234468222	0.002816405563	0.008234519104	0.019350215	0.03744307903
	V	0.0007234468223	0.002816405564	0.008234519106	0.01935021501	0.03744307905
	γ	0.073952	0.161943	0.30303	0.49451	0.703013
k = 0.3	α	0.0006666127341	0.002028618933	0.002028618933	–0.000232408672	–0.0168312148
	e^*	0.00525373599	0.01527883881	0.03551136363	0.06894790604	0.1133060254
	W	0.0007880603985	0.003055767762	0.008877840908	0.02068437181	0.03965710887
	V	0.0007880603982	0.00305576776	0.008877840906	0.0206843718	0.03965710887
	γ	0.077055	0.168067	0.3125	0.50562	0.712209
k = 0.4	α	0.0007231212964	0.00216479109	0.003406669641	–0.000764396127	–0.0186612109
	e^*	0.005744925314	0.01663547515	0.03840245776	0.07389162562	0.1202749141
	W	0.0008617387974	0.00332709503	0.00960061444	0.02216748768	0.04209621993
	V	0.0008617387974	0.003327095031	0.009600614441	0.02216748769	0.04209621993
	γ	0.080429	0.174672	0.322581	0.51724	0.721649
k = 0.5	α	0.000787077474	0.002314049587	0.003472222222	–0.001401384083	–0.0207259412
	e^*	0.006308411215	0.01818181818	0.04166666666	0.07941176470	0.1279850746
	W	0.0009462616822	0.003636363637	0.01041666667	0.02382352940	0.04479477612
	V	0.0009462616822	0.003636363638	0.01041666667	0.02382352941	0.04479477612
	γ	0.08411214954	0.1818181818	0.3333333334	0.5294117648	0.7313432836

End of Table 1

d		0.3	0.4	0.5	0.6	0.7
$h = 0.8$						
$k = 0.1$	α	0.005349920664	0.002902470502	–0.02431502028	–0.0864030053	–0.1753794028
	e^*	0.07405121876	0.174648656	0.31225605	0.4633204633	0.6080347448
	W	0.01110768281	0.0349297312	0.07806401248	0.138996139	0.2128121608
	V	0.01110768282	0.03492973121	0.0780640125	0.138996139	0.2128121607
	γ	0.2591792657	0.4584527721	0.6557377049	0.8108108112	0.9120521176
$k = 0.2$	α	0.00633397496	–0.00107597061	–0.04164177213	–0.1215210165	–0.2286453579
	e^*	0.1065036241	0.2405562864	0.4127966976	0.5937328202	0.7638985552
	W	0.01597554361	0.04811125728	0.1031991744	0.1781198461	0.2673644943
	V	0.01597554361	0.04811125727	0.1031991744	0.1781198461	0.2673644943
	γ	0.3017602682	0.5111821086	0.701754386	0.8411214952	0.9275911024
$k = 0.3$	α	0.006945301614	–0.01103584344	–0.0739381658	–0.1808914058	–0.3156175479
	e^*	0.1666538077	0.3554568177	0.580551524	0.8065720688	1.016258657
	W	0.02499807113	0.07109136349	0.145137881	0.2419716206	0.3556905299
	V	0.02499807114	0.07109136352	0.145137881	0.2419716207	0.35569053
	γ	0.3610832498	0.5776173285	0.7547169811	0.873786408	0.9436687528
$k = 0.4$	α	0.004544880697	–0.03868926346	–0.143458744	–0.2975206612	–0.4813382921
	e^*	0.2996254681	0.5901337023	0.9070294785	1.212121212	1.493821112
	W	0.04494382022	0.1180267404	0.2267573696	0.3636363636	0.522837389
	V	0.04494382023	0.1180267405	0.2267573696	0.3636363637	0.5228373891
	γ	0.4494382022	0.663900415	0.8163265304	0.9090909088	0.960313572
$k = 0.5$	α	–0.02035926507	–0.1401070791	–0.3456790123	–0.6103047091	–0.9150022699
	e^*	0.7140495869	1.248780488	1.777777778	2.273684211	2.737157107
	W	0.107107438	0.2497560976	0.4444444444	0.6821052631	0.9580049875
	V	0.107107438	0.2497560976	0.4444444445	0.6821052632	0.9580049875
	γ	0.5950413223	0.7804878049	0.8888888888	0.9473684208	0.9775561096

self-built or existing internal laboratories within the Group and external laboratories of universities, enterprises, and research institutions to accomplish the experimental tasks of megaprojects. In 2022, the Chengdu R&D base of the NTIC invested an additional 148.802 million RMB in the construction of the platform. The investment cost of the digital laboratory was 42.05 million RMB, that of the intelligent construction laboratory was 11 million RMB, that of the disaster warning and prevention and control laboratories was 27.611 million RMB, that of the geography and geology laboratories was 61.501 million RMB, and that of the other laboratories was 6.64 million RMB.

To better assess the changes and influence of various parameters and to better understand the incentive models used in this paper, it combined the actual situation of this project and related literature (Wang et al., 2020b; Zhou & Liu, 2021; Li et al., 2022a; Liu & Zhou, 2022) through numerical simulation of different scenarios to analyze the impact of the degree of sharing (d) and the reputation impact coefficient (k) on the laboratories' optimal effort level (e^*), fixed funding (α), benefits (W) and the platform's benefits (V). To validate the previous related conclusions, the random perturbations caused by external factors are assumed to obey the $N(0, 1)$ standard normal distribution. This paper numerically simulates two main cases: a supplier with weak informatization capability (i.e., $h = 0.2$) and a supplier with strong informatization capability (i.e., $h = 0.8$). Based on the recorded results of the platform for the degree of sharing of these laboratories, this paper takes the value of 0 to 1 for the degree of sharing (d). Based on the studies of Xie (2021), Li et al. (2020) and Shi et al. (2018), this paper takes the value of 0 to 0.5 for the reputation impact coefficient (k) with $\rho = 1$ and $\sigma^2 = 0.5$; the utility given by this platform to these laboratories is 5 million RMB, then $\overline{U} = 0.5$; at this stage, this platform is running on the experimental demand of a large-scale railroad project, and the duration of this project is expected to be 10 years, then $t = 10$.

5.1. Influence of optimal effort and incentive benefits and platform benefits

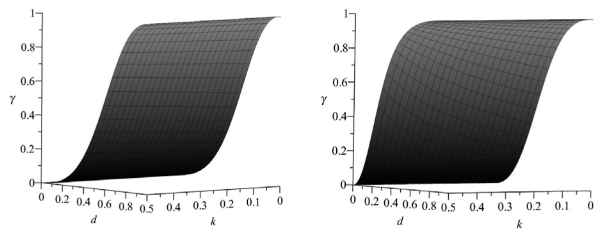
A comparison of the horizontal and vertical data is shown in Table 1. The optimal effort level (e^*), benefit (W), and platform benefit (V) are directly proportional to the degree of sharing (d) and the reputation impact coefficient (k). However, laboratories with high or low informatization capabilities also play an essential role. Laboratories with increased informatization capabilities (i.e., when $h = 0.8$) have significantly greater optimal effort levels, benefits, and platform benefits than laboratories with weak informatization capabilities (i.e., when *h* = 0.2). These laboratories with high informatization capabilities will also reduce the platform's investment in improving their informatization capabilities. Therefore, although both explicit and implicit incentives can directly increase laboratories' effort levels and benefits, their informatization capabilities need to be considered when screening laboratories if the platform's benefits are to be maximized simultaneously.

5.2. Influence of fixed funding

Table 1 and Figure 5 show that fixed funding (α) decreases as the degree of sharing (*d*) and reputation impact coefficient (*k*) increase. While fixed funding decreases, the platform increases the intensity of explicit and implicit incentives. In reality, because of megaprojects, platforms tend to be irrational and unconsciously increase incentive intensity for many reasons (Shi et al., 2018). However, Li and Gao (2019) state that fixed funding guarantees maintain the primary inputs of laboratories upfront. In addition, such fixed funding subsidizing the upfront is also more likely to psychologically give laboratories a sense of stability and certainty. This approach is also fundamental for ensuring that individuals exhibit experimental resource-sharing behavior. If the laboratories' informatization capabilities are strong (i.e., when h = 0.8), when $d < 0.4$, $k > 0.4$ and $\gamma > 0.67$, $\alpha < 0$, which means that the laboratories are out of guarantee of the essential inputs, there is no guarantee that the laboratories' resource-sharing behavior can be carried out smoothly; if the laboratories' informatization capabilities are weak (i.e., when h = 0.2), when $d < 0.6$, $k > 0.2$ and $\gamma > 0.51$, $\alpha < 0$. At this point, laboratories cannot guarantee essential inputs. For reputation incentives, when the reputation impact coefficient accounts for a more significant proportion of the impact, laboratories take the initiative to invest resources to increase their reputation, and the platform's subsidy for their upfront investments will be reduced accordingly. At this time, the benefits of the platform are positively correlated. Nevertheless, the comprehensive benefits of laboratories will negatively benefit from an increase in the reputation impact coefficient. The reason is that laboratories are affected by a competitive market environment and by the need to improve their reputation, thus increasing the cost of investment in reputation; when the investment is too significant, it will affect their return. Although this approach could maximize the benefits of the platform in the short term, it is not suitable for ensuring the sustainability of its construction in the long term. First, laboratories will reduce their enthusiasm for participation for a long time because their returns continue to fall short of their expectations, which may lead laboratories to consider withdrawing from participation. When the coefficient of reputation influence reaches the maximum extreme, a few laboratories will monopolize the business phenomenon, which is also unfavorable for the construction and promotion of the platform in the long term. Therefore, when the reputation impact coefficient is not high, it is better to increase the cost investment of some laboratories and reduce their enthusiasm for participation; rather, it is too low to achieve the incentive effect. Overall, when setting the incentives, the platform should fully consider fixed funding and laboratories' informatization capabilities and should not blindly increase the intensity of the incentives. To ensure that the resource-sharing behavior of the laboratory can be carried out smoothly and to satisfy the basic guarantee of the laboratory's upfront investment (i.e., $\alpha > 0$), if the laboratories' informatization capabilities are strong, the setting of the shared incentive coefficient should be less than 0.67, while the reputation impact coefficient should be less than 0.4. Thus, this approach could give their sharing behavior a basic guarantee; if the laboratories' informatization capabilities are weak, the setting of the shared incentive coefficient should be less than 0.51, while the reputation impact coefficient should be less than 0.2.

5.3. Influence of incentive coefficient and reputation impact coefficient

From the data in Table 1 and Figures 7a and 7b, it can be found that the sharing incentive coefficient (γ) of laboratories increases with their sharing degree (*d*) and reputation impact coefficient (*k*). Second, laboratories with strong informatization capabilities receive more incentives than do those with weak capabilities. When the informatization capabilities of the laboratories are strong (i.e., when h = 0.8), the input cost is relatively low. Therefore, to stimulate their sharing motivation, platforms must increase the intensity of their sharing incentives and actively combine the influence of reputation effects to ensure that they share more experimental resources on the platform. For laboratories with weak informatization capabilities (i.e., when h = 0.2), the input cost is greater in the early stage. Then, the platform must increase the subsidy for early-stage investment to enhance its informatization capabilities.



a) h = 0.2 **b)** h = 0.8

Figure 7. Influence of *d* and *k* on γ

5.4. Management implications

The reputation effect is particularly prominent in megaprojects and is highly valued by construction project owners and participants, such as the Hong Kong-Zhuhai-Macao Bridge (Shi et al., 2017). Therefore, this paper provides managerial insights into platform governance based on the reputation effect.

The NTIC builds a platform and should vigorously publicize megaprojects' social and industrial impact. This approach could create an excellent industrial reputation for the participating laboratories. The results of this study could guide the resource-sharing behavior of these laboratories to improve their informatization capabilities, future competitiveness, and reputation in the industry, allowing them to fully exploit the incentive effect of reputation. In addition, the research projects undertaken by the NTIC are all major special projects or critical projects at the provincial or national level (Zheng & Kang, 2023); therefore, it is also necessary to use this reputation to attract laboratories to participate and share their resources on the platform. This could also expand the incentive effect of reputation. Moreover, when selecting laboratories, those with strong informatization capabilities are given priority, and through the design of reasonable incentive mechanisms, their input resource-sharing effort levels increase, thus increasing their participation in the platform and the number of resources shared. However, when laboratories have strong comprehensive experimental levels, even if their informatization capabilities are weak. In that case, the subsidies for the initial investment or the intensity of explicit incentives can be increased to improve their motivation to share more resources on the platform. The bid evaluation method can be found in the tender document titled "Bridge load test for the main project of Hong Kong-Zhuhai-Macao Bridge", which provides specific scoring provisions for reputation impact factors, such as the bidder's performance (25 points) and performance reputation (10 points), which account for 70% of the total score. Therefore, for the platform used in screening laboratories, according to the actual situation of the project and combined with the conclusions of this paper, if the laboratory information capability is strong, the score on the reputation-related terms of the laboratory accounts for approximately 40% of the entire score; if the capability is weak, the score on the reputation-related terms accounts for approximately 20% of the entire score. Furthermore, when designing incentives, instead of blindly increasing the intensity of sharing incentives and reputation incentives, further consideration of the factors affecting laboratories' upfront subsidies, such as the degree of sharing and their informatization capabilities, is needed. To better leverage the advantages generated by considering reputation incentives, the NTIC should reduce the uncertainty in assessing reputation and observing laboratories' effort levels in resource sharing. In practice, the realization of the degree of sharing (d) depends on a variety of factors, such as trust (Lee et al., 2022; Li & Fang, 2022), attitudes toward collaboration (Yang & Maxwell, 2011), organizational culture and policies (Khan et al., 2022; Kar & Navin, 2021), and imbalances of power (Zaheer & Trkman, 2017). Hence, collaboration with laboratories on exploratory research projects about the development and maintenance of the platform is recommended. This approach could transform the gaming relationship between the platform and laboratories into a partnership. The system could also be used to understand and satisfy the actual needs of these laboratories. Moreover, this approach could improve the efficiency of the platform application.

Participating laboratories should strive to improve their resource-sharing output, reduce their input cost of effort, and reduce risk aversion to obtain greater incentive benefits. In addition, with the continuous development of information technology, there are already many remote or virtual laboratories (El-Haleem et al., 2023; Silva et al., 2023; Anirban et al., 2022; Caetano et al., 2022; Jamshidi & Milanovic, 2022). To improve their information technology levels, laboratories need to have the qualifications and capabilities to participate, and in doing so, they are also enhancing their good reputation.

6. Conclusions

The platform plays a vital role in breaking down the barriers of experimental resources in megaprojects across regions, disciplines, and organizations; gathering and integrating these innovative resources to create scale advantages; and improving the efficiency of transforming applied research results into engineering technology. The platform needs to attract more laboratories to participate and actively share more of their resources with the platform to ensure its long-term development and thus enable it to play a better and more sustainable role in megaprojects. Laboratories with a good reputation have a more significant advantage in bidding and obtain more incentive benefits in the cooperation process, which could enhance their future market competitiveness. Therefore, the utility of long-term incentives for laboratories can be better realized by combining the long-term explicit incentives of laboratories' resource-sharing behavior with the long-term implicit incentives of more future gains that the reputation effect can bring. To this end, this paper uses game theory and principal-agent theory to construct a dual long-term incentive model that combines implicit and explicit incentives. It analyses the incentive mechanism of reputation effects on laboratories and studies the influence of critical parameters on reputation incentives. It also obtained adequate equilibrium conditions for the reputation incentive mechanism and primary conditions for realizing Pareto improvement through comparative analysis with the explicit incentive model without considering reputation effects. Finally, the reputation incentive mechanism is further analyzed via data simulation to verify the relevant conclusions. The results show that dual long-term incentives that involve both explicit and implicit incentives can reasonably and effectively drive laboratories' resource-sharing behavior. In addition, under certain conditions, reputation incentives can provide better incentives for laboratories and ensure the platform's benefits.

6.1. Contributions

The research analyses and findings in this paper also contribute to related theory and practice, which can be summarized as follows:

This paper establishes the concept of a new experimental management mode based on an experimental resource-sharing platform for megaprojects to illustrate the role of the platform in collaboration; furthermore, it proposes combining the long-term implicit reputation incentive model and the long-term explicit economic incentive model to analyze the factors influencing the interests of the relevant stakeholders in the process of the platform's application and the change in experimental resource-sharing behavior in different scenarios; and provides a theoretical basis for an in-depth study of the incentive mechanism for the application and promotion of the platform.

This paper provides a quantitative perspective for understanding the long-term implicit reputation effect of incentivizing laboratories to participate in and share more resources with this platform; it tries for the first time to introduce the long-term reputation effect to incentivize the resource-sharing behavior of laboratories, which contradicts previous research from the perspective of the explicit incentive mechanism alone and enriches the research on incentive mechanisms for guaranteeing the sustainable development of platforms.

This paper simulates the performance of laboratories under different strategies in terms of platform application through the actual context of the project. Based on the simulation results, several important insights are drawn, and the upper limit of the dual long-term incentive intensity is proposed to avoid irrational behavior of the platform, which provides practical help for the platform to formulate more reasonable and adequate incentives to promote the application and promotion of the platform; the model can be modified and further applied in experimental programmes similar to megaprojects in China.

6.2. Limitations and future directions

As seen in practice, laboratories involved in megaprojects are organizations of different natures, and the NTIC needs to implement other reputation incentive mechanisms for laboratories with other characteristics, which is a complex issue for further research. In addition, the reputation effect studied in this paper only appears as an influence coefficient; to evaluate the implicit reputation, this paper needs to carry out a detailed study. Therefore, a credit system for laboratories should be constructed and improved gradually, and reputation should be formed into an institutionalized evaluation standard to promote standardized operation (Shi et al., 2017), which will constitute the next research direction. The evaluation standards could refer to the open-sharing evaluation assessment of equipment and instruments about laboratories and the evaluation rules of national critical laboratories promulgated by some countries (MSTPRC, 2014, 2022); in the future, the evaluation of resource-sharing behavior of these laboratories can also be incorporated into the credit evaluation system of megaprojects to promote their sharing behavior more effectively. Furthermore, although the data in the numerical simulation are not actual data in practice, the numerical simulation results can fully reflect the research laws and verify the validity of the models (Bravo et al., 2023; Ding et al., 2023; Liu et al., 2023; Zheng & Li, 2023); with the increase in the data used in this experimental resource-sharing platform, case studies and empirical analyses will be conducted to explore the impact of laboratories' participation in the platform on the innovation performance and construction performance of megaprojects; competition will be introduced as a means of coordination, which is similar to the "invisible hand" in the market environment and can incentivize resource-sharing behavior in these laboratories (Gilpatric et al., 2015).

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Author contributions

Yuying Wang 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

The authors declare that they have no conflict of interest.

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