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Reputation incentive model of open innovation of scientific and technological-based SMEs considering fairness preference

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The participation of external scientific research teams is an important support for the success of open innovation of scientific and technological-based small and medium enterprise (SMEs). The incentive mechanism should not only focus on traditional influencing factors but also on the scientific research innovation team's internal characteristics and external environment. Considering the fairness preference of scientific research innovation teams, this paper constructs an open innovation reputation incentive model for scientific and technological-based SMEs and discusses the impact of relevant factors on the reputation and effort level of scientific research innovation teams under the situation of complete information and incomplete information. The results show that: (1) under the condition of complete information, the fairness preference of scientific research innovation teams is positively related to reputation incentive other than the effort level; (2) under the condition of incomplete information, the fairness preference of scientific research innovation teams has no significant impact on the reputation incentive but is negatively related to the effort level; (3) whether considering the fairness preference or not, the effort level and innovation capability of the scientific research innovation teams are positively correlated with the reputation incentive, while the effort cost, risk aversion coefficient, income distribution coefficient, and variance of external environment variable are negatively correlated with the reputation incentive; (4) the innovation ability of scientific research innovation teams is positively related to the effort level, while the effort cost, risk aversion coefficient, and variance of external environment variable are negatively related to the effort level.

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Introduction

More and more enterprises begin to choose open innovation mode in the context of economic globalization. Because of the externality of innovation, the traditional innovation view is that innovation mainly takes place within enterprises to avoid technology spillover as much as possible (Chesbrough, 2003). However, enterprises can no longer cope with the fierce market competition only through internal research and development that generates new ideas and develops new products with the constant acceleration of innovation. More and more enterprises have begun to break organizational boundaries, cooperate extensively with external organizations, and integrate internal and external resources and knowledge purposefully for the sustainable development of enterprises (Rosenkopf and Nerkar, 2001). Chesbrough (2017) believes that economic activities are becoming more and more complex and diversified and that maintaining a high level of internal R&D has become less important for the success of innovation. Under the open innovation model, enterprises will tend to invest in innovation externally rather than internally. Many studies have found that open innovation activities and investment are growing, accounting for a large share of enterprise innovation. According to the data of IFI CLAIMS Patent Services, IBM was granted for 8682 patents in 2021, ranking first for 29 consecutive years, and also gained rich returns every year through technology licencing, which is closely related to the implementation of its open innovation model. Huawei implemented the innovation research plan, established the HIRP platform, and cooperated with many famous universities and research institutes at home and abroad. Through cooperation with the Hong Kong University of Science and Technology, Huawei has successively obtained more than 60 international patents and standards and completed more than 90 technical solutions. Open innovation has enabled Huawei to lead in a new round of technological revolution and industrial transformation.

Scientific and technological-based small and medium enterprise (SMEs) are the backbone of the national innovation system and play an important role in scientific and technological innovation and transformation. However, the lack of resources and limited innovation ability have restricted the development of scientific and technological-based SMEs. Therefore, enterprises are bound to adopt an open innovation model, obtain innovation resources through external cooperation, reduce the cost of technological innovation, and improve their own innovation performance (Parida, Westerberg, Frishammar, 2012). In recent years, scientific and technological-based SMEs have cooperated with various external innovation organizations, and cooperation with scientific research and innovation teams of universities and research institutes is the most important mode of external cooperation for scientific and technological-based SMEs. However, the cooperation between scientific and technological-based SMEs and scientific research and innovation teams is not all successful, and some cooperation effects are not good or even failed. How to encourage scientific research and innovation teams to participate in open innovation and improve innovation performance has become an important problem faced by scientific and technological-based SMEs.

There are multiple motivations for scientific research innovation teams to participate in open innovation. They not only want to obtain certain benefits but also want to be recognized by enterprises, peers, and society (Dovis and Kirpalani, 2021; Yang et al., 2016). Therefore, scientific and technological-based SMEs should not only provide an income incentive for scientific research innovation teams but also a reputation incentive for them. Reputation incentive is a long-term incentive that generates the social identity that is a direct inducement for scientific research innovation teams to work hard. Reputation incentives can meet the nonmonetary needs of scientific research innovation teams, promote the unity of interests between scientific and technological-based SMEs and scientific research innovation teams, and make long-term and stable cooperative relationships (Kwon and Rupp, 2013; Tang, Bin, Whinston, 2012).

This paper introduces fairness theory into the reputation incentive mechanism, establishes a reputation incentive model based on the principal-agent theory, analyzes the influence of relevant parameters on the reputation incentive mechanism, and draws the corresponding research conclusions and management enlightenment.

Review of the literature

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

Open innovation. Since Professor Chesbrough (2017) put forward the concept of open innovation, the theoretical research on open innovation has become increasingly rich, and scholars have conducted in-depth research on the type, motivation, and role of open innovation.

According to the flow direction of resources and knowledge, open innovation can be divided into inward innovation and outward innovation. Inward innovation means that enterprises learn from and absorb external knowledge and resources, and apply them to their own internal innovation practices; Outward innovation means that enterprises do not carry out innovation activities by themselves after acquiring knowledge, but pass knowledge to external organizations cooperating with them, and make external organizations carry out innovation activities (Brunswicker and Chesbrough, 2018; Bogers et al., 2018). Laursen and Salter (2006) proposed that the open innovation of enterprises can be divided into two dimensions: breadth and depth on the basis of the ways of obtaining external resources. Tina, and Nicolai (2015) divided open innovation into four modes: innovation based on market, innovation based on social group, cooperative innovation, and innovation based on network. According to the form of cooperation, scholars divide open innovation into four types: knowledge sales, technology procurement, collaborative R&D, and R&D outsourcing (Vrande et al., 2009; Dahlander and Gann, 2010).

As for the motivation of open innovation, researchers focus on internal and external motivation, such as obtaining innovative knowledge, reducing R&D risk, shortening the production cycle, expanding existing markets, saving costs, and increasing economic benefits. Externally, open innovation will be affected

by consumer demand and market competition (Colin et al. 2014; Sikimic et al., 2016). The uncertainty of technology and the market will also promote enterprises to implement open innovation (Cuevas-Vargas et al., 2022). Internally, research has shown that open innovation can improve innovation performance and innovation capability, which is also the main motivation of enterprises (Bagherzadeh et al., 2020).

Regarding the role of open innovation, many scholars have recognized the dual character of open innovation. On the one hand, open innovation has many benefits. In the process of innovation, enterprises that cooperate closely with the outside can benefit from increasing learning opportunities and knowledge transfer (Liu et al., 2015). Open innovation stimulates innovation enterprise capability (Kafouros and Forsans, 2012) and improves the speed and quality of product development (Faems et al., 2005) leading to excellent project performance (Cheng et al., 2020; Yan and Dooley, 2013). On the other hand, open innovation also has some limitations. The open behavior of organizations reduces the speed, flexibility, and resource control of the decision-making process (Alexy et al., 2018; Gegenhuber and Dobusch, 2017). Transaction costs and knowledge spillover risks brought by innovation will weaken organizational competitiveness to a certain extent (Chiang and Hung, 2010). Bahemia et al. (2017) investigated the participation of 11 different types of external partners in new product development projects and examined open innovation in terms of depth, breadth, and novelty of partners. They found that depth has a negative effect on product innovation, while the last two have a promoting effect on product innovation. Therefore, managers comprehensively consider these three dimensions in open innovation, and an excessive imbalance of openness will lead to a negative effect.

Open innovation adoption for SMEs simply makes sense (Vanhaverbeke et al., 2018). Open innovation offers SMEs resources and other benefits including global reach, revenue generation, market-entry, building credibility, complementing knowledge, and developing capabilities(Audretsch et al., 2020). Many studies have investigated the determinants of product innovation in small firms, suggesting product, firm, market, and innovation process factors are the key drivers of success (West and Kuk, 2016). Different SMEs exhibit heterogeneity in open innovation (Lawrence et al., 2022). Low-medium technology SMEs typically partner with smaller-scale SME partners known to them, whereas for medium-high/high-technology SMEs, there is a tendency to partner with larger-scale, more geographically and cognitively distant partners. Gillian and George (2022) clarified the microfoundations of open innovation (OI) in young innovative companies (YICs) in partnering with large multinational enterprises (MNEs).OI is not easy and presents many challenges and risks (Prashantham and Birkinshaw, 2008; Van et al., 2009). Some scholars (Audretsch, 1995; Oakey, 2013) discussed how small firms compensate for size-related disadvantages. Knowledge protection, intellectual property (IP) negotiation, and the wider learning process (of how to access, connect, and interact with a larger and more powerful organization) affect SMEs open innovation (Minshall et al., 2010; Freel and Robson, 2017).

Reputation incentive. Reputation is a universal, spontaneous, and efficient social control mechanism, which has been studied in social science, management science, and technology science. Fama (1980) first proposed to take implicit incentives as a substitute for explicit incentives in some aspects, that is, agents will also work actively to improve their reputation in the market without explicit incentives to be competitive in the future market. Scholars (Kreps et al., 1982; Milgrom and Roberts, 1982) built a KMRW reputation model and studied the reputation effect based on repeated games, laying a foundation for reputation effect research. Subsequently, scholars conducted a variety of studies based on this reputation model.

Tadelis (2002) designed the reputation incentive mechanism of the principal to the agent based on the repeated game theory. Healy (2007) studied the predictive utility of reputation in the repeated cooperative market. Rahman, Kumaraswamy (2008) pointed out that trust can provide an effective incentive mechanism under relationship contracts. Dodonova (2022) compared the entrepreneurial economy, in which managers are the sole owners of the firms, with the corporate economy, in which managers are hired by shareholders using the overlapping generations model, and found that managerial reputation building can partially resolve the debt–equity conflict and improve efficiency in both economies; however, such improvement is larger in the entrepreneurial economy. To stimulate the workers with long-term high quality, Luo et al. (2021) proposed the incentive mechanism based on the reverse auction and fine-grained ability reputation system. Hong et al. (2016) designed the reputation mechanism to ensure low-skilled workers do not provide low-quality solutions by tracking workers' historical contributions and penalizing those workers having poor reputations, and found that by coupling our reputation mechanism with our incentive mechanism, a requester can collect at least one high-quality solution. Fleckinger et al. (2017) built a model of collective reputation under moral hazard to analyze incentives under collective reputation and found collective reputation can yield higher quality and welfare than individual reputation. While groups unravel in the absence of transfers even when efficient, simple collective reputation contracts implement the First Best.

To sum up, current research on open innovation mainly focus on the concept, classification, role, and motivation of open innovation, while there is little research on open innovation of scientific and technological-based SMEs and innovation incentive. At the same time, scholars generally recognize the role of reputation incentives and deeply discuss the influencing factors and incentive mechanisms. However, few scholars study the reputation incentive mechanism considering the fairness preference of agents. Based on the research results of the above literature, the paper studies an open innovation system composed of a scientific and technological SME and a scientific research innovation team. There is a principal-agent relationship between the scientific and technological SME and the scientific research innovation team. Considering the fairness preference of the scientific research innovation team, the paper constructs a reputation incentive model and analyzes the impact of parameters on the reputation incentive mechanism.

The paper is organized as follows:

Section "Problems and assumptions" describes the problem and gives the research hypothesis;

Section "Reputation incentive model considering fairness preference" presents a reputation incentive model considering fairness preference;

Section "Numerical simulations" gives an algorithm case and analyzes the model parameters;

Section "Conclusions and future studies" finally provides the conclusion, managerial implications, model limitations, and directions for future research.

Problems and assumptions

The principal-agent relationship between the scientific and technological-based SME and the scientific research innovation team. The principal-agent theory is used to study how clients can incentivize and constrain agents through contract

design, in order to ensure that the agent's efforts align with the client's goals in the event of conflicting interests. Dahlander and Gann (2010) classified open innovation into inbound open innovation and outbound open innovation based on the direction of resource flow. Inbound open innovation is when enterprises integrate valuable knowledge, technology, creativity, and other resources from external organizations through formal or informal relationships and apply them. Enterprises commercialize their internal research and development achievements and the enterprise's internal knowledge flows to external entities, which is outbound open innovation.

Scientific and technological-based SMEs collaborate with the scientific research innovation team through R&D outsourcing, industry-university-institute cooperation, and other forms to obtain external innovation resources, which is a typical inbound open innovation. The scientific and technological-based SME entrusts its R&D project to the innovation team of universities or scientific research institutions and provides R&D funds to the innovation team.

Relying on the innovation platform of universities or scientific research institutions and the project funds provided by SMEs, the scientific research innovation team carries out targeted technological innovation activities and produces innovative results for the enterprise. At this point, the relationship between the scientific and technological-based SME and scientific research innovation team conforms to a principal-agent relationship. Therefore, using the principal-agent theory to analyze the open innovation reputation incentive mechanism of the scientific and technological-based SME is objective, and based on this, a research hypothesis is constructed.

Model assumptions. Consider an open innovation system composed of a scientific and technological-based SME and a scientific research innovation team, the technology SME is the client, and the scientific research innovation team is the agent. The scientific and technological-based SME designs a reputation incentive mechanism combining explicit contract incentives with implicit reputation incentives, in order to improve the effort level of the innovation team, as shown in Fig. 1. Fully considered the fairness preference and ability level of the scientific research innovation team, as well as the influence of random dependence, the paper makes the following assumptions:

Hypothesis 1: In the open innovation system of scientific and technological-based SMEs,

(1) the enterprise is the client and risk-neutral;
(2) the enterprise sets up the R&D project;
(3) the scientific research and innovation team is an agent and risk-averse;
(4) the scientific research and innovation team undertakes the enterprise's project;
(5) The risk aversion coefficient of the scientific research innovation team is ρ ($\rho > 0$);
(6) the risk cost of a scientific research innovation team is $z(z \geq 0)$.

Hypothesis 2: The reputation incentive coefficient of scientific and technological SME to the scientific research innovation team is p ($0 \leq p \leq 1$).

Hypothesis 3: The scientific research innovation team has a fairness preference. The relative gap in profits between them and the scientific and technological-based SMEs will have an impact on the behavior of the scientific research innovation team. According to the fairness preference model proposed by Fehr and Schmidt (1999), we suppose that the fairness preference coefficient of scientific research and innovation teams is k ($0 \leq k \leq 1$).

Hypothesis 4: The effort cost of the scientific research innovation team is $M = \frac{1}{2}\lambda_1 e_1^2$, λ ($0 \leq \lambda \leq 1$) is the effort cost coefficient, and e is the effort level.

Hypothesis 5: The innovation output of the scientific research innovation team (A) is a linear increasing function of its effort level, and is affected by the external environment variable θ that obeys the normal distribution N (0, δ^2). Referring to the H-M model (Holmstrom and Milgrom, 1985), the innovation output is expressed as $A = \eta e + \theta$, and η ($\eta > 0$) is the innovation ability coefficient of the scientific research innovation team.

Hypothesis 6: The incentive contract for the scientific research innovation team is $S = \alpha + (\beta + p)A$. α is the fixed income of the scientific research and innovation team, which is the fixed project fund provided by the enterprise to the scientific research and innovation team; β ($0 < \beta < 1$) is the open innovation income distribution proportion coefficient of the scientific research innovation team.

The main parameters and meanings of the model are shown in Table 1.

Reputation incentive model considering fairness preference

Benchmark model. The profit function of the scientific research innovation team is:

$$\pi_R = \alpha + (\beta + p)(\eta e + \theta) - \frac{1}{2}\lambda e^2 \quad (1)$$

The following two factors affect the utility function of the scientific research and innovation team:

(1) the fairness preference. The loss of the scientific research innovation team is $-K(\pi_E - \pi_R)$. The greater $K(K \geq 0)$ is the

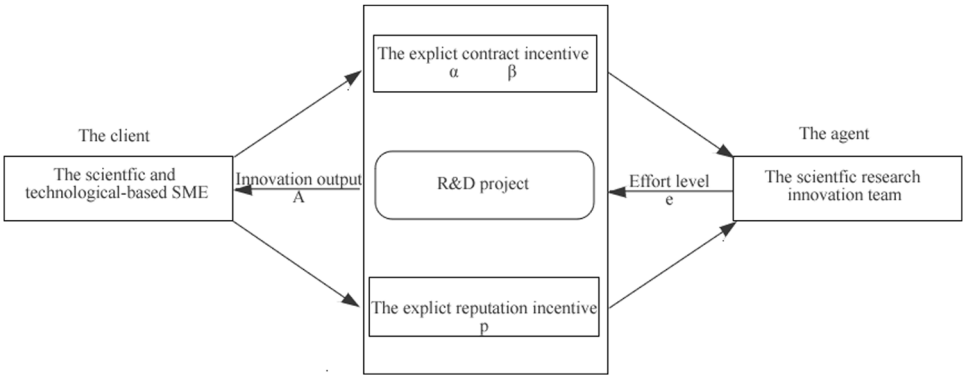


Fig. 1 Open innovation reputation incentive design. The chart illustrates the principal-agent relationship between the scientific and technological-based SME and the scientific research innovation team.

Table 1 Parameters.

Parameter	Meaning
e	The effort level of the scientific research innovation team
A	The innovation output of the scientific research innovation team
λ	The effort cost coefficient of the scientific research innovation team
p	The reputation incentive coefficient of the scientific research innovation team
η	Innovation ability coefficient
α	The fixed project fund provided by the enterprise to the team
θ	The external environment variable
ρ	The risk aversion coefficient
β	The open innovation income distribution proportion coefficient
K	The fairness preference coefficient
z	The risk cost of scientific research innovation team
π_E	The income of scientific and technological SME
π_R	The income of the scientific research innovation team

stronger the fairness preference of the scientific research innovation team. indicates a fair preference unit. if $\pi_E(\bullet) - \pi_R(\bullet) > 0$, the scientific research innovation team has a negative effect of envy, because its income is lower than that of the enterprise; if $\pi_E(\bullet) - \pi_R(\bullet) < 0$, scientific research innovation team will have a positive effect of pride because its income is higher than the enterprise.

(2) The risk aversion. As the scientific research innovation team is risk-averse, it will pay a certain risk-averse cost in the R&D process, which is expressed as $z = \frac{1}{2}\rho[(\beta+p)+2K(\beta+p)-K]^2\delta^2$. With reference to the risk aversion measurement model, the fairness preference is nested in the certainty equivalence income of the scientific research innovation team considering risk aversion. The expected income and the certainty equivalence income of the scientific research innovation team are respectively expressed as:

$$E(\pi_R) = \left[(\beta+p)+2K(\beta+p)-K\right]\bullet(\eta e+\theta) + \alpha(1+2K) - \tfrac{1}{2}(1+K)\lambda e^2 \tag{2}$$

$$CE_R = \eta e\left[(\beta+p)+2K(\beta+p)-K\right] + \alpha(1+2K) - \tfrac{1}{2}(1+K)\lambda e^2 - \tfrac{1}{2}\rho\left[(\beta+p)+2K(\beta+p)-K\right]^2\delta^2 \tag{3}$$

As the client, the scientific and technological SME is fair and neutral and only pursues the maximum value of its interest. Since the enterprise is risk-neutral and has no risk aversion cost, its expected utility is equal to the expected income, expressed as:

$$E(U_E) = E(\pi_E) = \eta e\left[1-(\beta+p)\right] - \alpha \tag{4}$$

On the premise of satisfying the participation constraints (IR) and incentive compatibility (IC) of the scientific research innovation team, the following principal-agent model is constructed to maximize the expected utility of the scientific and technological SME:

$$\begin{aligned} &Max\, E(U_E) = E(\pi_E) = \eta e\left[1-(\beta+p)\right] - \alpha \\ &\text{s.t.} \\ &\begin{cases} (IR)\ \eta e\left[(\beta+p)+2K(\beta+p)-K\right] + \alpha(1+2K) \\ -\frac{1}{2}(1+K)\lambda e^2 - \frac{1}{2}\rho\left[(\beta+p)+2K(\beta+p)-K\right]^2\delta^2 \geq \pi_0 \\ (IC)\ Max\, E(\pi_R) = \eta e\left[(\beta+p)+2K(\beta+p)-K\right] \\ +\alpha(1+2K) - \frac{1}{2}(1+K)\lambda e^2 - \frac{1}{2}\rho\left[(\beta+p)+2K(\beta+p)-K\right]^2\delta^2 \end{cases} \end{aligned} \tag{5}$$

Reputation incentive model under complete information. Complete information is used to describe an economic phenomenon so that all participants are able to access all information about other participants. Under the condition of complete information, the information between the scientific and technological-based SME and the scientific research innovation team is symmetrical without information barriers. Scientific and technological-based SMEs can observe the effort level of the scientific research innovation team. The reputation incentive model of open innovation of the scientific and technological-based SME is:

$$\begin{aligned} &Max\, E(U_E) = E(\pi_E) = \eta e\left[1-(\beta+p)\right] - \alpha \\ &\text{s.t.} \\ &\begin{cases} (IR)\eta e\left[(\beta+p)+2K(\beta+p)-K\right] + \alpha(1+2K) \\ -\frac{1}{2}(1+K)\lambda e^2 - \frac{1}{2}\rho\left[(\beta+p)+2K(\beta+p)-K\right]^2\delta^2 \geq \pi_0 \end{cases} \end{aligned} \tag{6}$$

Under the optimal condition, the conditions for participation constraints of the scientific research innovation team are met, thus:

$$\alpha = \frac{1}{1+2K}\left[\pi_0 - \eta e\left[(\beta+p)+2K(\beta+p)-K\right] + \frac{1}{2}(1+K)\lambda e^2 + \frac{1}{2}\rho\left[(\beta+p)+2K(\beta+p)-K\right]^2\delta^2\right] \tag{7}$$

Introducing Eq. (7) into the objective function, and making $\partial E(\pi_E)/\partial p = 0$, the optimal reputation incentive coefficient of the scientific research innovation team can be obtained:

$$p^* = \frac{K}{1+2K} - \beta \tag{8}$$

Introducing Eq. (8) into the objective function, and making $\partial E(\pi_E)/\partial e = 0$, the optimal effort level of the scientific research innovation team is obtained:

$$e^* = \frac{\eta}{\lambda} \tag{9}$$

The partial derivative of Eq. (8) is as follows:

$$\frac{\partial p}{\partial K} = \frac{1}{(1+2K)^2} > 0 \tag{10}$$

Conclusion 1: According to Eq. (10), under the condition of complete information, the fairness preference coefficient of the scientific research innovation team is positively correlated with the reputation incentive coefficient.

Conclusion 2: According to Eq. (9), under the condition of complete information, the effort level of the scientific research innovation team is positively related to the coefficient of innovation ability, and negatively related to the coefficient of effort cost.

Reputation incentive model under incomplete information. Incomplete information indicates participants do not possess all

knowledge of a certain economic environment state, which means they don't know all the information about other participants under the condition of incomplete information, the information between the scientific and technological SME and the scientific research innovation team is asymmetric with information barriers. The scientific and technological SME cannot observe the effort level of the scientific research innovation team. The scientific research innovation team can pursue the maximization value of its own benefit and then adopt speculative behavior. The reputation incentive model of open innovation of the scientific and technological SME is defined as follows:

$$\begin{aligned} &Max\, E(U_E) = E(\pi_E) = \eta e[1-(\beta+p)] - \alpha \\ &\qquad s.t. \\ &\begin{cases} (IR)\ \eta e[(\beta+p)+2K(\beta+p)-K]+\alpha(1+2K) \\ -\frac{1}{2}(1+K)\lambda e^2 - \frac{1}{2}\rho[(\beta+p)+2K(\beta+p)-K]^2\delta^2 \geq \pi_0 \\ (IC)\ e = \frac{\eta[(\beta+p)+2K(\beta+p)-K]}{\lambda(1+K)} \end{cases} \end{aligned} \tag{11}$$

Under the optimal condition, the conditions for participation constraints of the scientific research innovation team are met, thus:

$$\begin{aligned} \alpha = \frac{1}{1+2K}\big[\pi_0 - \eta e[(\beta+p)+2K(\beta+p)-K] + \frac{1}{2}(1+K)\lambda e^2 \\ + \frac{1}{2}\rho[(\beta+p)+2K(\beta+p)-K]^2\delta^2\big] \end{aligned} \tag{12}$$

Equation (IC) is the incentive constraint condition for the scientific research innovation team, that is, they choose the behavior of maximizing their own interests. Introducing equation (IC) and Eq. (12) into the objective function, and making $\partial E(\pi_E)/\partial p = 0$, the optimal reputation incentive coefficient of the scientific research innovation team can be obtained as:

$$p^* = \frac{\eta^2(1+2K)+\rho\delta^2\lambda K(1+K)}{\left[\eta^2(1+2K)+\rho\delta^2\lambda(1+K)(1+2K)\right]} - \beta \tag{13}$$

Introducing Eq. (13) into the objective function, and making $\partial E(\pi_E)/\partial e = 0$, the optimal effort level of the scientific research innovation team is obtained as follows:

$$e^* = \frac{\eta^3(1+2K)}{\lambda\left[\eta^2(1+2K)+\rho\delta^2\lambda(1+K)(1+2K)\right]} \tag{14}$$

The partial derivative of Eq. (13) about K can be obtained as follows:

$$\frac{\partial p}{\partial K} = \frac{\left[\rho\delta^2\lambda(1+K)^2 - 2K(1+K)\eta^2\right]\rho\delta^2\lambda}{\left[\eta^2(1+2K)+\rho\delta^2\lambda(1+K)(1+2K)\right]^2} \tag{15}$$

It is difficult to intuitively analyze the impact of the fairness preference coefficient of the scientific research innovation team on the reputation incentive coefficient from Eq. (15). Therefore, the impact of the fairness preference coefficient of the scientific research innovation team on the reputation incentive coefficient is analyzed through numerical simulation in Section "The influence of fairness preference on reputation incentive and effort level of the scientific research innovation team". From this, we can get:

Conclusion 3: Under the condition of incomplete information, the fairness preference coefficient of the scientific research innovation team has no significant effect on the reputation incentive coefficient.

From the IC constraint in Eq. (11), we can get:

$$p = \frac{\lambda e(1+K)}{\eta(1+2K)} + \frac{K}{1+2K} - \beta \tag{16}$$

The partial derivative of Eq. (16) is as follows:

$$\frac{\partial p}{\partial e} = \frac{\lambda(1+K)}{\eta(1+2K)} > 0 \tag{17}$$

Conclusion 4: According to Eq. (17), under the condition of incomplete information, whether considering the fairness preference, the effort level of the scientific research innovation team is positively correlated with the reputation incentive coefficient.

Calculating the partial derivative of Eq. (13) about η、λ、ρ、δ^2、β, and we can get:

$$\frac{\partial p}{\partial \eta} = \frac{2\eta\rho\delta^2\lambda(1+K)^2}{(1+2K)\left[\eta^2+\rho\delta^2\lambda(1+K)\right]^2} > 0 \tag{18}$$

$$\frac{\partial p}{\partial \lambda} = -\frac{\eta^2\rho\delta^2(1+K)^2}{(1+2K)\left[\eta^2+\rho\delta^2\lambda(1+K)\right]^2} < 0 \tag{19}$$

$$\frac{\partial p}{\partial \rho} = -\frac{\eta^2\delta^2\lambda(1+K)^2}{(1+2K)\left[\eta^2+\rho\delta^2\lambda(1+K)\right]^2} < 0 \tag{20}$$

$$\frac{\partial p}{\partial \delta^2} = -\frac{\eta^2\rho\lambda(1+K)^2}{(1+2K)\left[\eta^2+\rho\delta^2\lambda(1+K)\right]^2} < 0 \tag{21}$$

$$\frac{\partial p}{\partial \beta} = -1 < 0 \tag{22}$$

Conclusion 5: According to Eq. (18), under the condition of incomplete information, whether considering the fairness preference or not, the innovation ability coefficient of the scientific research innovation team is positively correlated with the reputation incentive coefficient.

Conclusion 6: According to Eqs. (19), (20), (21), and (22), whether considering the fairness preference or not, the effort cost coefficient of the scientific research innovation team, the risk aversion coefficient, the variance of the external environment variable, and the income distribution proportion coefficient are negatively related to the reputation incentive coefficient.

Calculating the partial derivative of Eq. (14) about η, we can get:

$$\frac{\partial e}{\partial \eta} = \frac{\eta^2(1+2K)^2\left[\eta^2+3\rho\delta^2\lambda(1+K)\right]}{\lambda\left[\eta^2(1+2K)+\rho\delta^2\lambda(1+K)(1+2K)\right]^2} > 0 \tag{23}$$

Conclusion 7: According to Eq. (14), under the condition of incomplete information, the effort level of the scientific research innovation team is negatively correlated with the effort cost coefficient, risk aversion coefficient, and variance of the external environment variable.

Conclusion 8: According to Eq. (23), under the condition of incomplete information, the effort level of the scientific research innovation team is positively correlated with the innovation capability coefficient.

Numerical simulations

In this section, numerical simulation for the reputation incentive model of open innovation is conducted with MATLAB, and the impact of relevant parameters on reputation incentive and effort level is analyzed to verify the correctness, feasibility, and reliability of the research conclusions. In order to make the numerical analysis closer to reality, we investigated the open innovation model, innovation funds, benefit distribution mechanism,

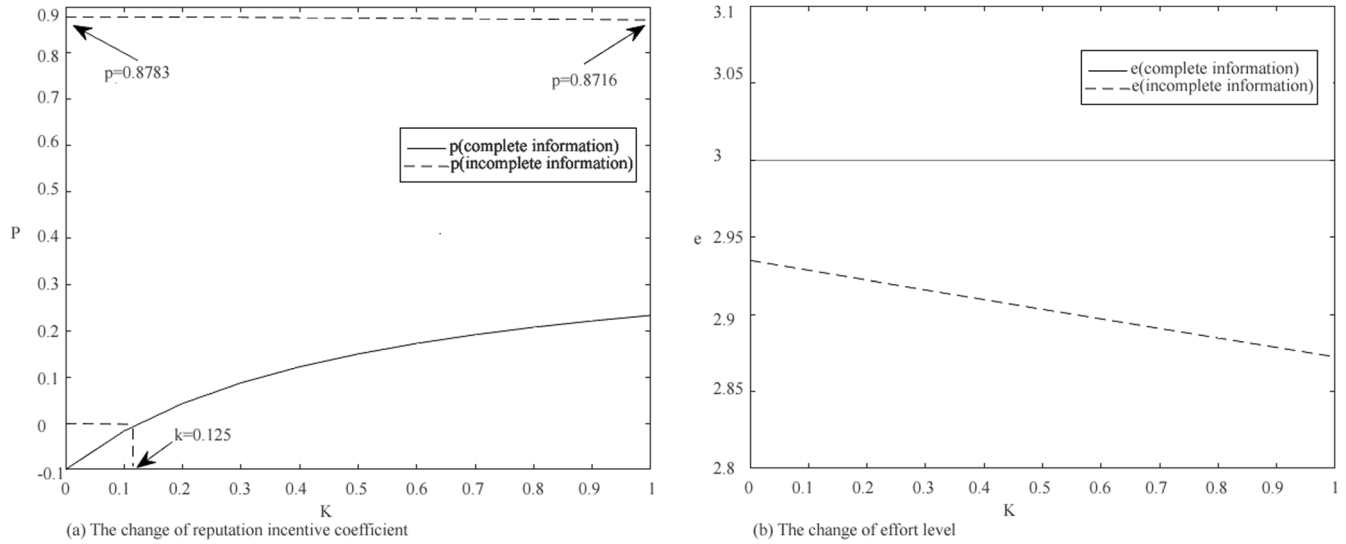


Fig. 2 The influence of the fairness preference on the reputation incentive coefficient and effort level of the scientific research innovation team. **a** Graph reflects the change in the reputation incentive coefficient of the scientific research innovation team with fairness preference. **b** Graph reflects the change in the effort level of the scientific research innovation team with fairness preference.

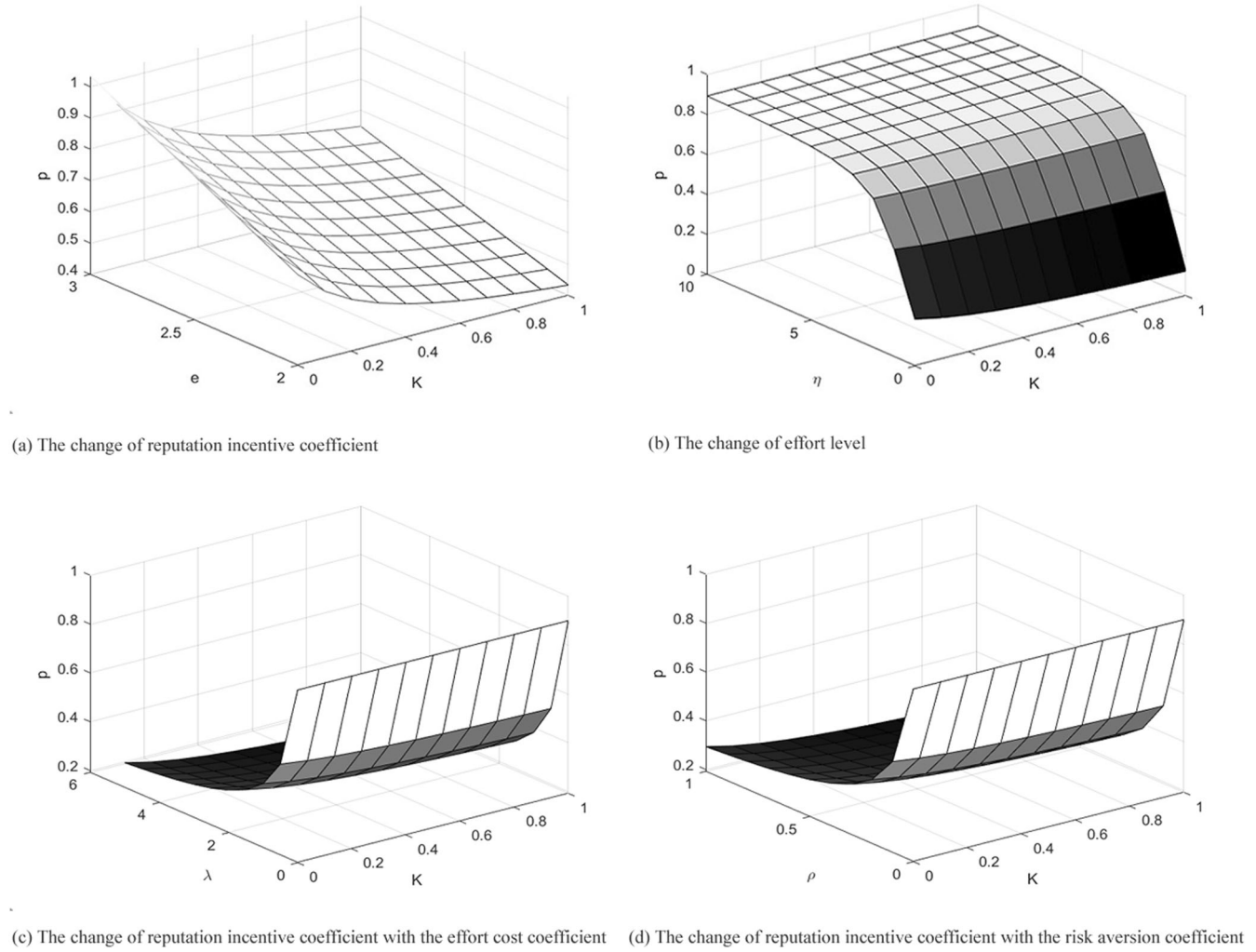
incentive mechanism, etc. of China's scientific and technological-based SME. By referring to the research and data in existing literature, the initial parameters are set as $\beta = 0.1$, $\eta = 6$, $\lambda = 2$, $\delta = 1$, $\rho = 0.4$, $K_1 = K_2 = K$, and relevant parameters will be adjusted in each part.

The influence of fairness preference on reputation incentive and effort level of the scientific research innovation team. Figure 2a reflects the change in the reputation incentive coefficient of the scientific research innovation team with fairness preference. Under the condition of complete information, the reputation incentive coefficient of the scientific research innovation team is positively correlated with the fairness preference coefficient. At this time, the higher the fairness preference coefficient of the scientific research innovation team is, the more they pay attention to the innovation income of the enterprises When the income distribution proportion coefficient is certain, in order to appease the envy of the scientific research innovation team, the scientific and technological SME must increase the reputation incentive for the scientific research innovation team to encourage the scientific research innovation team to carry out project research. Under the condition of incomplete information, the fairness preference coefficient of the scientific research innovation team has no significant effect on the reputation incentive coefficient. At this moment, scientific and technological-based SMEs cannot observe the effort level and fairness preference of the scientific research innovation team, and cannot adjust the reputation incentive coefficient with the change of fairness preference of the scientific research innovation team. With the same fairness preference, the reputation incentive coefficient of the scientific research innovation team under complete information is less than that under incomplete information.

Figure 2b reflects the change in the effort level of the scientific research innovation team with fairness preference. Under the condition of complete information, the effort level of the scientific research innovation team is not related to the fairness preference coefficient, but only related to the innovation ability coefficient and the effort cost coefficient. Under the condition of complete information, because scientific and technological SMEs can observe the effort level of the scientific research innovation team, the scientific research innovation team cannot be lazy. In order to continue cooperation and to maintain their own reputation, the scientific research innovation team should try their best to carry out research and development. At this time, their effort level is only related to their innovation capability and effort costs. Under the condition of incomplete information, the effort level of the scientific research innovation team is negatively correlated with the fairness preference coefficient. Under the condition of incomplete information, the enterprise cannot observe the situation of the scientific research innovation team. When the income distribution proportion coefficient and reputation incentive coefficient are basically unchanged, with the increase of fairness preference, the scientific research innovation team adopts speculative behavior to reduce its own effort level. With the same fairness preference, the effort level of the scientific research innovation team under complete information is much higher than that under incomplete information. At this time, the scientific research innovation team will adjust their effort level according to fairness preference to maximize their interests.

Influence of parameters on the reputation incentive coefficient under incomplete information. Figure 3a reflects the change in the reputation incentive coefficient with the effort level of the scientific research innovation team. Whether considering the fairness preference of the scientific research innovation team or not, the effort level of the scientific research innovation team is positively correlated with the reputation incentive coefficient. The harder the scientific research innovation team carries out innovation activities, the more likely it is to obtain innovative achievements. When the income distribution proportion coefficient is certain, scientific and technological SMEs will strengthen reputation incentives and improve the reputation incentive coefficient.

Figure 3b reflects the change in the reputation incentive coefficient with the innovation capability coefficient of the scientific research innovation team. The innovation capability coefficient of the scientific research innovation team is positively correlated with the reputation incentive coefficient. The innovation capability coefficient of a scientific research innovation team represents its innovation level and the effectiveness of innovation achievements. Scientific and technological SMEs are bound to provide a high-level reputation incentive to the scientific research



(a) The change of reputation incentive coefficient

(b) The change of effort level

(c) The change of reputation incentive coefficient with the effort cost coefficient

(d) The change of reputation incentive coefficient with the risk aversion coefficient

Fig. 3 The influence of parameters on reputation incentive coefficient. a Graph reflects the change in reputation incentive coefficient with the effort level of the scientific research innovation team. **b** Graph reflects the change in reputation incentive coefficient with the innovation capability coefficient of the scientific research innovation team. **c** Graph reflects the change of reputation incentive coefficient with the effort cost coefficient of the scientific research innovation team. **d** Graph reflects the change in the reputation incentive coefficient with the risk aversion coefficient of the scientific research innovation team.

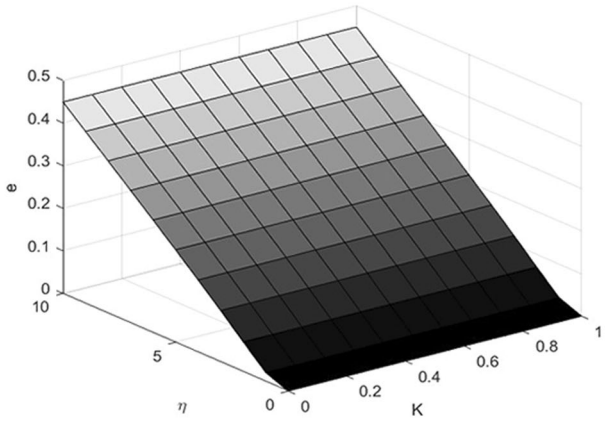
innovation team that has high innovation ability and can produce high-value innovation achievements.

Figure 3c reflects the change of the reputation incentive coefficient with the effort cost coefficient of the scientific research innovation team. The effort cost coefficient of the scientific research innovation team is negatively correlated with the reputation incentive coefficient. When the effort cost coefficient of the scientific research innovation team increases, the difficulty of innovation increases. The scientific research innovation team may adopt a speculative strategy to reduce the effort level. At this time, innovation efficiency will decline, and the reputation of the scientific research innovation team will also be affected. Scientific and technological SMEs will reduce the reputation incentive coefficient.

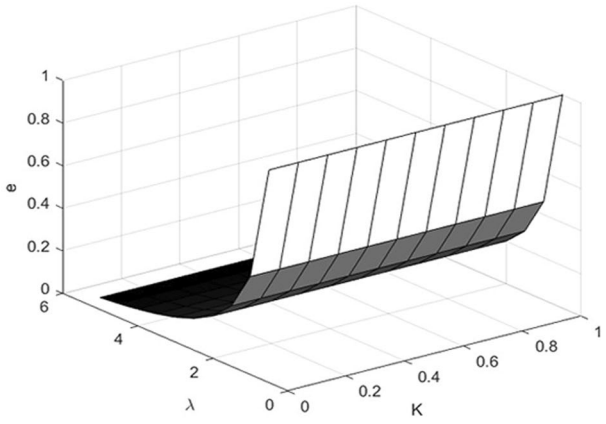
Figure 3d reflects the change in the reputation incentive coefficient with the risk aversion coefficient of the scientific research innovation team. The risk aversion coefficient of the scientific research innovation team is negatively correlated with the reputation incentive coefficient. As the risk aversion coefficient of the scientific research innovation team increases, it is difficult for the scientific research innovation team to resist the risk of innovation failure. The scientific research innovation team may give up and reduce its effort level. Scientific and technological SMEs will reduce the reputation incentives coefficient.

The Influence of parameters on the effort level of the scientific research innovation team under incomplete information. Figure 4a reflects the change in the effort level of the scientific research innovation team with the innovation capability coefficient. The innovation ability coefficient of the scientific research innovation team is positively related to the effort level. The higher the innovation capability coefficient of the scientific research innovation team is, the higher the effectiveness of its innovation achievements is. The scientific research and innovation team is willing to work harder to achieve innovative results.

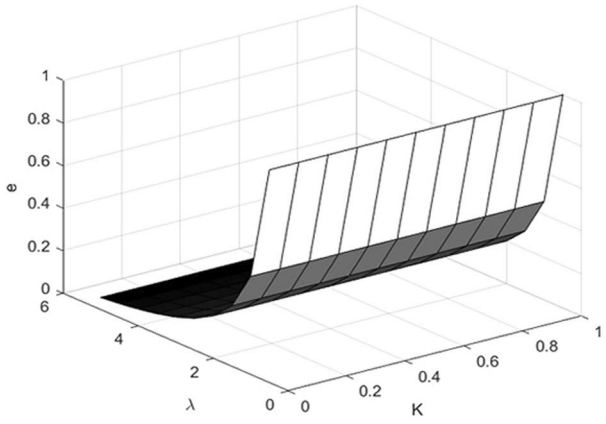
Figure 4b reflects the change in the effort level of the scientific research innovation team with the effort cost coefficient. The effort cost coefficient of the scientific research innovation team is negatively related to the effort level. The higher the effort cost coefficient of the scientific research innovation team, the higher the innovation cost. After obtaining the fixed R&D fund, the scientific research innovation team will take a negative R&D strategy to reduce the effort level for their own interests.



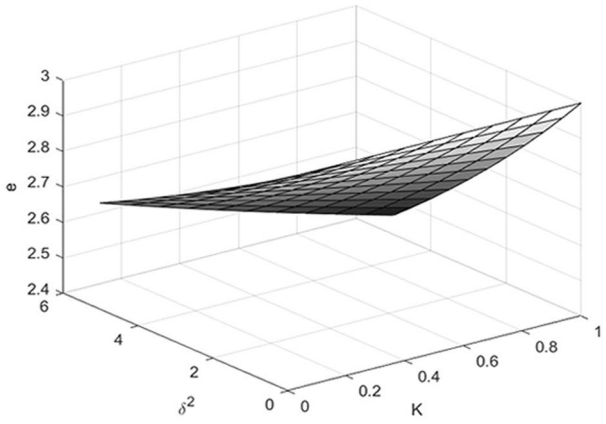
(a) The change of the effort level with the innovation capability coefficient



(b) The change of the effort level with the effort cost coefficient



(c) The change of effort level with risk aversion coeffi-cient



(d) The change of the effort level with the variance of the external environment variables

Fig. 4 The influence of parameters on the effort level. a Graph reflects the change of the effort level of the scientific research innovation team with the innovation capability coefficient. **b** Graph reflects the change of the effort level of the scientific research innovation team with the effort cost coefficient. **c** Graph reflects the change in the effort level of scientific research innovation team with risk aversion coefficient. **d** Graph reflects the change in the effort level of the scientific research innovation team with the variables of the variance of the external environment.

Figure 4c reflects the change in the effort level of the scientific research innovation team with the risk aversion coefficient. Whether or not the fairness preference is considered, the risk aversion coefficient of the scientific research innovation team is negatively related to the effort level. The increase in the risk aversion coefficient of the scientific research innovation team means that the risk cost of the scientific research innovation team to resist innovation failure has increased. The scientific research innovation team will reduce the R&D cost by reducing the level of effort.

Figure 4d reflects the change in the effort level of the scientific research innovation team with the variables of the variance of the external environment. The variance of external environment variables of the scientific research innovation team is negatively correlated with the effort level. As the variance of external environment variables of scientific research and innovation teams increases, the uncertainty of R&D activities increases, and the possibility of innovation failure increases. The scientific research innovation team can take a negative attitude and reduce the effort level.

Conclusions and future studies

In an open innovation system, scientific and technological-based SMEs should not only provide income incentives for the innovation teams but also provide reputation incentives for them. In this paper, fairness theory is introduced into the research on the reputation incentive mechanism. Considering the fairness preference coefficient, innovation ability coefficient, and other parameters of a scientific research innovation team, a reputation incentive model is built based on the principal-agent theory, and the impact of these parameters on the reputation incentive mechanism is analyzed via numerical simulation. The following research conclusions are obtained.

(1) Under the condition of complete information, the fairness preference coefficient of the scientific research innovation team is positively related to the reputation incentive coefficient, but not to the effort level.
(2) Under the condition of incomplete information, the fairness preference coefficient of the scientific research innovation team has no significant impact on the reputation incentive coefficient and is negatively related to the effort level.
(3) Whether considering the fairness preference or not, the effort level and innovation capability coefficient of the scientific research innovation team is positively correlated with the reputation incentive coefficient, while the effort cost coefficient, risk aversion coefficient income

distribution coefficient, and variance of the external environment variable are negatively correlated with the reputation incentive coefficient.

(4) The innovation ability coefficient of the scientific research innovation team is positively related to the effort level, while the effort cost coefficient, risk aversion coefficient, and variance of external environment variables are negatively related to the effort level.

Based on the above conclusions, we have the following management implications.

(1) Scientific and technological-based SMEs should design reputation incentive mechanisms considering the fairness preference of scientific research innovation teams, and create a fair, just, and open environment to reduce the risks caused by information asymmetry. The enterprise should recognize and reward the scientific research innovation teams with strong innovation ability and high service level, publicize the achievements of scientific research innovation teams through various channels, and enhance the popularity and the sense of fulfillment of the team for maximizing innovation effectiveness.

(2) Scientific and technological-based SMEs should scientifically evaluate the project value, and effectively combine explicit contractual incentives such as fixed project funds and income distribution with implicit reputation incentives. Enterprises may maintain a relatively stable long-term cooperative relationship with scientific research and innovation teams through a series of short-term contracts. That is to say, enterprises will adopt the method of phased assessment and phased payment and determine the follow-up cooperation according to the performance of the scientific research innovation teams to avoid the defects of one-time contract incentives.

(3) The establishment of a reputation mechanism is a long-term process. The enterprise may cooperate with the government to establish a science and technology service market with a good reputation effect and develop a scientific and reliable reputation evaluation system. Enterprises should entrust the project to the innovation team with a good reputation and pay more rewards to truly play the role of reputation incentive in encouraging research innovation teams.

In the open innovation system, it is assumed that both scientific and technological-based SMEs and scientific research innovation teams are rational and pursue the maximization of their own profits, without considering the impact of their irrational behaviors on the final decision. Therefore, in future research, irrational factors of the participants should be considered in the reputation incentive model. In addition, this paper studies the reputation incentive mechanism of single-stage formal cooperation between scientific and technological-based SMEs and scientific research innovation teams, and the design of incentive mechanism under multi-stage cooperation between two sides should also be focused in future research.

Data availability

Data sharing is not applicable to this article.

Code availability

Code sharing is not applicable to this article.

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Author contributions

All authors contributed equally to this work.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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