Optimal Contract Design in Team Cooperation: An Internal Synergy and External Funding Perspective

Yimei Xie*
School of Mathematics and Statistics, Leshan Normal University, Leshan, Sichuan, China
**Corresponding Author*

Abstract: This study investigates moral hazard in cooperative R&D by developing an optimal incentive contract that maximizes expected project returns. From the perspective of internal cost synergy and external administration support, we examine how these factors shape members' optimal effort, incentive intensity, and welfare outcomes. The analysis reveals that project payoff, optimal incentives, and effort levels increase with the strength of cost synergy. Both ex post and ex ante administration subsidies effectively motivate cooperative participants, yet ex post funding demonstrates higher cost efficiency and yields greater social welfare. The findings highlight that firms should choose partners with stronger cost complementarities and allocate resources more efficiently to mitigate moral hazard. Meanwhile, administrations should improve firm screening and supervision to avoid inefficient subsidies and enhance the effectiveness of public funding. This research provides theoretical insights for designing incentive mechanisms and optimizing strategy instruments that promote sustainable collaborative innovation.

Keywords: Incentive Design; Cooperative R&D; Cost Synergy; administration Funding

1. Introduction

Against the backdrop of rapid socioeconomic development, technological innovation is accelerating, and the new wave of scientific and industrial revolutions is posing new challenges to China's traditional innovation model. In response, an increasing number of enterprises are engaging in cooperative R&D to access heterogeneous resources and enhance their competitiveness [1,2]. This not only concerns the development of individual firms but also relates to the national goal of building an innovation-driven economy [3-5].

However, while cooperative R&D offers opportunities, information asymmetry often leads to opportunistic behaviors and moral hazard among participants, thereby reducing cooperation efficiency [6,7]. The key issue lies in how to design incentive mechanisms that mitigate moral hazard and improve efficiency. Internally, attention must be given to cost synergy effects—where one member's effort can reduce another's cost—while externally, government policies such as financial subsidies, procurement support, and public services also exert significant influence [8-12]. These factors jointly determine the level of incentives, project returns, and success probability. Based on this, the present study examines optimal incentive contracts and the efficiency and welfare effects of different government funding schemes from the perspectives of internal cost synergy and external (ex ante and ex post) subsidies [13-15].

In the study of moral hazard, scholars such as Samuelson, Hellmann, and Pecorino argue that information asymmetry may lead cooperative members to reduce input or free-ride, thereby undermining performance. Zhang Zongming and others also point out that unverifiable effort reduces service performance. Consequently, the literature has focused on how incentive mechanisms or delegated supervision can enhance cooperation stability and success [17,18]. Further research extends to profit distribution under bilateral moral hazard, emphasizing that fairness in distribution is crucial to sustaining cooperation.

Regarding member interaction, Itoh finds that when effort costs are independent and tasks are complementary, proper incentives can induce optimal effort levels [19-21]. Kandel highlights that peer pressure increases individual effort, while Winter and Georgiadis analyze effort observability and incentive effects through principal–agent and dynamic models. Studies also show that knowledge synergy, relational fairness, and durability significantly enhance innovation performance. Therefore, well-designed incentive and distribution mechanisms are key to improving cooperative innovation efficiency [22-25].

As for government funding policies, most scholars agree that the government can correct “market failures” through subsidies, tax incentives, and other measures to foster cooperative innovation and enhance social welfare. Such funding can also alleviate financial constraints and reduce opportunistic behavior [26,27]. However, some studies suggest that policy effects have thresholds or may cause “crowding-out effects,” leading to resource dependence and lower performance.

In summary, existing studies mainly focus on moral hazard and normative analysis, with limited attention to member characteristics and external environments [28,29]. Based on principal–agent theory, this paper comprehensively examines how cost synergy and government funding affect incentive mechanisms in cooperative R&D, compares the allocation efficiency, funding costs, and welfare effects of different subsidy schemes, and provides theoretical insights for optimizing government policies and promoting healthy collaborative innovation among enterprises [30-32].

2. Internal Incentives: Optimal Incentive Contract under Cost Synergy Effects

2.1 Problem Description and Model Assumptions

Consider two risk-neutral members (denoted as Member i=1,2) forming a cooperative team to undertake a technological innovation project together. The relationship between the members is equal, and each faces reciprocal incentive issues, aiming to maximize expected returns [33-35]. During the collaboration, cost synergy effects arise-where the effort of one member reduces the effort cost of the other. In this context, how should the optimal internal incentive contract be designed? How do cost synergies affect project returns, the optimal allocation ratio (incentive level), and the optimal effort levels? These are the core concepts of the model in this section.

According to principal-agent theory, for ease of analysis, the following assumptions are made:

(i) Members are fully rational, and neither party can observe the other's effort level e_i . Only the project's output level Y can be observed. Y is influenced by the efforts of both parties and is fully distributed among the members. Members sign a contract before the project begins: Member 1 receives an income distribution ratio β_1 , Member 2 receives $\beta_2 = 1 - \beta_1$, and both parties have a reservation utility of 0 [36-38].

(ii) Members' efforts are substitutable, so it is assumed that the project output is a stochastic linear function of both members' efforts:

$$Y = k_1 e_1 + k_2 e_2 + \varepsilon \tag{1}$$

where ε represents random market factors, following a normal distribution $\varepsilon \sim N(0,\sigma^2)$. k_i represents the contribution coefficient of member i 's effort level to the output, and satisfies $k_i > 0$ Other resource inputs of member i influence the final output through the contribution coefficient k_i [39,40].

(iii) There is a mutual cost synergy effect among members during cooperation. This characteristic means that a member's effort cost arises not only from their own effort level but also from the other member's effort level. The effort cost is assumed to be:

$$c_i = \frac{\eta_i}{2}\left(e_i - \varepsilon_{ji} e_j\right)^2 \tag{2}$$

where $\eta_i > 0$ represents the effort cost coefficient of member i , and $\varepsilon_{ij} \in [0,1)$ reflects the strength of the cost synergy effect. Specifically, ε_{ij} represents the influence of member i 's effort on member j 's effort cost, and it satisfies $e_i - \varepsilon_{ji} e_j \geq 0$ to ensure the effectiveness of the cost synergy effect. When $\varepsilon_{ij} = 0$, it indicates that there is no mutual cost synergy effect between members [41-43].

Based on the above assumptions, although the project's output increases with the effort level, the cost also increases with the effort level. Therefore, the important factor is the ratio between the contribution coefficient to output and the cost coefficient for both parties:

$$s_i = k_i / \eta_i \tag{3}$$

This reflects member i 's value creation capability for the project output.

2.2 Model Building and Solution

As neither party can observe the other’s effort, Cooper notes that no allocation contract can achieve Pareto optimality under incomplete information. Accordingly, each party maximizes its own utility, leading to a second-best effort level, technically defined as the maximization of the project's expected returns subject to incentive compatibility and participation constraints.

Therefore, under bilateral moral hazard, the problem becomes a constrained maximization:

$$\max_{e_1,e_2,\beta_1,\beta_2} U = k_1e_1 + k_2e_2 - \frac{\eta_1}{2}\left(e_1 - \varepsilon_{21}e_2\right)^2 - \frac{\eta_2}{2}\left(e_2 - \varepsilon_{12}e_1\right)^2$$

$$s.t.\begin{cases} e_i \in \arg\max \beta_i\left(k_1e_1 + k_2e_2\right) - \frac{\eta_i}{2}\left(e_i - \varepsilon_{ji}e_j\right)^2 \\ \beta_i\left(k_1e_1 + k_2e_2\right) - \frac{\eta_i}{2}\left(e_i - \varepsilon_{ji}e_j\right)^2 \geq 0 \\ \beta_2 + \beta_1 = 1, \beta_1 \geq 0, \beta_2 \geq 0 \end{cases} \tag{4}$$

Since neither party can observe the other's effort, each chooses its effort level based on the maximization of its own expected payoff, following a simultaneous-move Nash equilibrium. Solving the above model yields the agent's optimal compensation and optimal effort as follows:

$$\begin{cases} \beta_1^* = \dfrac{s_2k_1 + \varepsilon_{12}s_2k_2 - \varepsilon_{21}s_1k_1 - s_1k_2\varepsilon_{12}\varepsilon_{21}}{s_1s_2(\eta_1+\eta_2)(1-\varepsilon_{12}\varepsilon_{21})} \\ \beta_2^* = \dfrac{s_1k_2 + \varepsilon_{21}s_1k_1 - \varepsilon_{12}s_2k_2 - s_2k_1\varepsilon_{12}\varepsilon_{21}}{s_1s_2(\eta_1+\eta_2)(1-\varepsilon_{12}\varepsilon_{21})} \\ e_1^{**} = \dfrac{s_1s_2\left(k_1 + \varepsilon_{12}k_2 + \varepsilon_{21}k_2 + \varepsilon_{12}^{\ 2}k_1\right) - \varepsilon_{21}s_1^{\ 2}\left(k_1 + \varepsilon_{12}k_2\right) - \varepsilon_{12}\varepsilon_{21}s_2^{\ 2}\left(k_2 + \varepsilon_{21}k_1\right)}{(s_1k_2 + s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \\ e_2^{**} = \dfrac{s_1s_2\left(k_2 + \varepsilon_{12}k_1 + \varepsilon_{21}k_1 + \varepsilon_{12}^{\ 2}k_2\right) - \varepsilon_{12}\varepsilon_{21}s_1^{\ 2}\left(k_1 + \varepsilon_{12}k_2\right) - \varepsilon_{12}s_2^{\ 2}\left(k_2 + \varepsilon_{21}k_1\right)}{(s_1k_2 + s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \end{cases} \tag{5}$$

2.3 Analysis of the Economic Implications of the Model

Based on the above results, it can be further concluded that in the absence of moral hazard and under moral hazard conditions, the changing trends of optimal effort level, optimal distribution ratio under moral hazard, and optimal revenue with respect to factors such as member cost synergy effects, output coefficients, and unit effort costs are shown in Table 1.

Table 1. Variation Trends among Factors

Factors	$\varepsilon_{12}\uparrow$	$\varepsilon_{21}\uparrow$	$k_1\uparrow$	$k_2\uparrow$	$\eta_1\uparrow$	$\eta_2\uparrow$
e_1^{**}	↑	↑	↑		↓	
e_1^{**}	↑	↑		↑		↓
β_1^*	↑		↑		↓	
β_2^*		↑		↑		↓
U^{**}	↑	↑	↑	↑	↓	↓

To more intuitively verify the incentive effects of cost synergy on members, we will proceed with a simple numerical analysis below. Given that: η_i , $k_i > 0$, $0 < \beta_1$, $\beta_2 < 1$, $0 < e_1$, $e_2 < 1$, $0 < 1 - \varepsilon_{21}\varepsilon_{12} < 1$. Figures 1 to 4 depict the trends in how the optimal effort level and project revenue vary with the cost synergy effect under asymmetric information, respectively.

The results indicate that regardless of the scenario, as cost synergy effects strengthen, both the optimal effort level and project revenue increase. This demonstrates that under asymmetric information, members tend to engage in opportunistic behaviors such as "free-riding" and "shirking," leading to lower investments from both parties compared to the scenario without moral hazard. However, when cost synergy exists between members, mutual incentives can mitigate issues like free-riding and shirking.

Under bilateral moral hazard, the cost synergy effect adjusts the distribution ratio of expected project revenue by allocating a greater share to more influential members. This creates effective incentives and helps mitigate moral hazard issues among collaborating partners.

Based on the preceding analysis and conclusions, it is evident that the presence of internal cost synergy effects can indeed incentivize members to exert greater effort, thereby achieving effective motivation and mitigating moral hazard issues. However, collaborative innovation among enterprises is influenced not only by internal incentives but also by external government funding. Therefore, the following section will focus on examining the impact of government funding on member incentives.

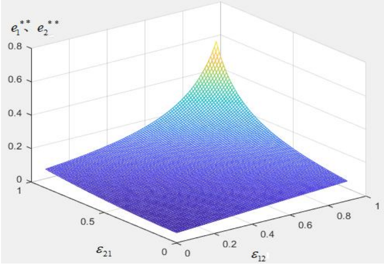

Figure 1. Variation Trend of Optimal Effort with Cost Synergy Effect

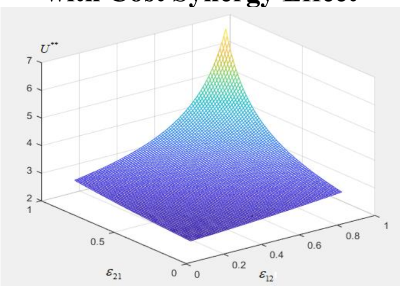

Figure 2. Variation Trend of Project Revenue with Cost Synergy Effect

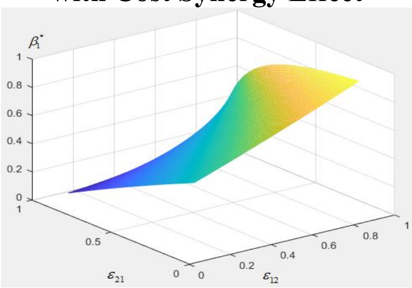

Figure 3. Variation Trend of Member 1's Revenue Distribution Ratio with Cost Synergy Effect

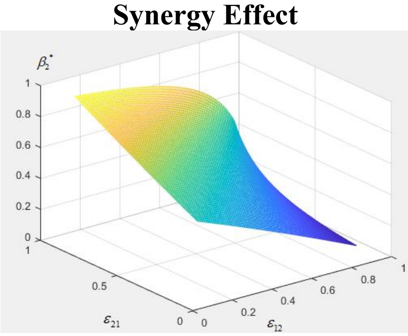

Figure 4. Variation Trend of Member 2's Revenue Distribution Ratio with Cost Synergy Effect

3. External Incentives: Optimal Contract under Government Funding

As the government pays increasing attention to the international competitiveness of China's technological innovation, it has in recent years introduced a large number of policies to encourage enterprises to innovate and develop, such as financial subsidy policies, government procurement policies, and the provision of public supporting services. Thus, can government funding play an incentive role for cooperative members and alleviate the moral hazard problems faced by both parties? Building on the analysis in the previous section, this section compares the incentive effects of different forms of government support on cooperative members as well as their impact on social welfare.

3.1 Spillover Effects of the Project

Through cooperation, technological innovation projects ultimately achieve technological breakthroughs at the industry level, leading to product upgrading and optimization and significant comprehensive social benefits. In other words, the project not only generates returns for the cooperating members but also creates additional social benefits. We define this spillover effect as follows [6]:

$$V(e_1,e_2)=\lambda Y(e_1,e_2),\lambda>0 \tag{6}$$

Here, λ denotes the magnitude of the spillover effect, and the project's total expected social benefit at this point is:

$$U=(1+\lambda)(k_1e_1+k_2e_2)-\frac{\eta_1}{2}(e_1-\varepsilon_{21}e_2)^2-\frac{\eta_2}{2}(e_2-\varepsilon_{12}e_1)^2 \tag{7}$$

Therefore, from the perspective of overall social optimality, the members' optimal effort level should be:

$$e_{1EX}^{**}=\frac{(1+\lambda)\left[s_1s_2\left(k_1+\varepsilon_{12}k_2+\varepsilon_{21}k_2+\varepsilon_{21}{}^2k_1\right)-\varepsilon_{21}s_1{}^2\left(k_1+\varepsilon_{12}k_2\right)-\varepsilon_{12}\varepsilon_{21}s_2{}^2\left(k_2+\varepsilon_{21}k_1\right)\right]}{(s_1k_2+s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \tag{8}$$

Compared with the case without government support, we have $e_1^{**}<e_{1EX}^{**},e_2^{**}<e_{2EX}^{**}$, which indicates that when the innovation project generates spillover effects, the members' privately optimal effort levels are lower than the socially optimal level, i.e., there is under-investment or "market failure." At this point, a certain degree of government intervention is necessary, such as providing public supporting services or subsidies and other preferential policies [42,43]. In what follows, we consider two main types of government subsidies, analyze their incentive effects on cooperative members, and compare their impacts on social welfare.

3.2 Ex post Subsidies

For innovation projects, ex post government subsidies are generally provided after the project has been implemented and completed, with the government granting support in proportion to the returns generated by the project. Suppose the amount of the government's ex post subsidy for this project is:

$$M_{AF} = \theta Y\left(e_1, e_2\right), \theta > 0 \tag{9}$$

where θ denotes the proportion of subsidy the government provides to the project. The expected return of the project then becomes:

$$U = \left(1+\theta\right)\left(k_1 e_1 + k_2 e_2\right) - \frac{\eta_1}{2}\left(e_1 - \varepsilon_{21} e_2\right)^2 - \frac{\eta_2}{2}\left(e_2 - \varepsilon_{12} e_1\right)^2 \tag{10}$$

At this point, the cooperative members face a constrained maximization problem (referred to as Model 3), which is:

$$\max_{e_1, e_2} U = \left(1+\theta\right)\left(k_1 e_1 + k_2 e_2\right) - \frac{\eta_1}{2}\left(e_1 - \varepsilon_{21} e_2\right)^2 - \frac{\eta_2}{2}\left(e_2 - \varepsilon_{12} e_1\right)^2$$
$$s.t.\begin{cases} e_i \in \arg\max \beta_i \left(1+\theta\right)\left(k_1 e_1 + k_2 e_2\right) - \frac{\eta_1}{2}\left(e_i - \varepsilon_{ji} e_j\right)^2 \\ \beta_i \left(k_1 e_1 + k_2 e_2\right) - \frac{\eta_1}{2}\left(e_i - \varepsilon_{ji} e_j\right)^2 \ge 0 \\ \beta_1 + \beta_2 = 1, \beta_1 \ge 0, \beta_2 \ge 0 \end{cases} \tag{11}$$

Then the optimal effort levels, the optimal allocation ratio, and the project payoff are, respectively:

$$\begin{cases} e_{1AF}^{\;**} = \dfrac{\left(1+\theta\right)\left[s_1 s_2 \left(k_1 + \varepsilon_{12} k_2 + \varepsilon_{21} k_2 + \varepsilon_{21}{}^2 k_1\right) - \varepsilon_{21} s_1{}^2 \left(k_1 + \varepsilon_{12} k_2\right) - \varepsilon_{12}\varepsilon_{21} s_2{}^2 \left(k_2 + \varepsilon_{21} k_1\right)\right]}{(s_1 k_2 + s_2 k_1)(1 - \varepsilon_{12}\varepsilon_{21})^2} \\ e_{2AF}^{\;**} = \dfrac{\left(1+\theta\right)\left[s_1 s_2 \left(k_2 + \varepsilon_{12} k_1 + \varepsilon_{21} k_1 + \varepsilon_{12}{}^2 k_2\right) - \varepsilon_{12}\varepsilon_{21} s_1{}^2 \left(k_1 + \varepsilon_{12} k_2\right) - \varepsilon_{12} s_2{}^2 \left(k_2 + \varepsilon_{21} k_1\right)\right]}{(s_1 k_2 + s_2 k_1)(1 - \varepsilon_{12}\varepsilon_{21})^2} \\ \beta_{1AF}^{\;*} = \dfrac{s_2 k_1 + \varepsilon_{12} s_2 k_2 - \varepsilon_{21} s_1 k_1 - s_1 k_2 \varepsilon_{12}\varepsilon_{21}}{s_1 s_2 (\eta_1 + \eta_2)(1 - \varepsilon_{12}\varepsilon_{21})} \\ \beta_{2AF}^{\;*} = \dfrac{s_1 k_2 + \varepsilon_{21} s_1 k_1 - \varepsilon_{12} s_2 k_2 - s_2 k_1 \varepsilon_{12}\varepsilon_{21}}{s_1 s_2 (\eta_1 + \eta_2)(1 - \varepsilon_{12}\varepsilon_{21})} \\ U_{AF}^{\;**} = \dfrac{\left(1+\theta\right)^2 \left[\left(s_1 s_2 - \varepsilon_{21} s_1{}^2\right)\left(k_1 + \varepsilon_{12} k_2\right)^2 + \left(s_1 s_2 - \varepsilon_{12} s_2{}^2\right)\left(k_2 + \varepsilon_{21} k_1\right)^2\right]}{(s_1 k_2 + s_2 k_1)(1 - \varepsilon_{12}\varepsilon_{21})^2} \end{cases} \tag{12}$$

Compared with the case without subsidies, we have $e_i^{**} < e_{iAF}^{\;**}$, $\beta_i^{**} = \beta_{iAF}^{\;**}$, $U^{**} < U_{AF}^{\;**}$, and the conditions $\dfrac{\partial e_{1AF}^{\;**}}{\partial \theta} > 0, \dfrac{\partial e_{2AF}^{\;**}}{\partial \theta} > 0$ are satisfied. This indicates that as the government's ex post subsidy rate θ increases, the members' optimal effort levels rise, and the project's payoff also increases. Although the members' relative allocation ratios remain unchanged, the absolute amounts of income allocated to each cooperative member increase with the project's payoff, implying that the government's ex post subsidies provide effective incentives to the members. By comparing the optimal effort levels under ex post subsidies with those under the socially optimal welfare level, we can see that to achieve the social optimum, it is sufficient to set $\theta = \lambda$. At this point, the government's ex post subsidy cost is:

$$M_{AF}^{\;*} = \lambda Y\left(e_1, e_2\right) = \frac{\lambda\left[\left(s_1 s_2 - \varepsilon_{21} s_1{}^2\right)\left(k_1 + \varepsilon_{12} k_2\right)^2 + \left(s_1 s_2 - \varepsilon_{12} s_2{}^2\right)\left(k_2 + \varepsilon_{21} k_1\right)^2\right]}{(s_1 k_2 + s_2 k_1)(1 - \varepsilon_{12}\varepsilon_{21})^2} \tag{13}$$

This shows that ex post subsidies are essentially a way for the government to return social spillovers to enterprises in the form of subsidies, thereby internalizing the project's spillover effects. Therefore, under this type of support, the government can effectively incentivize both cooperating parties and ultimately achieve the socially optimal outcome.

3.3 Ex Ante Subsidies

For innovation projects, ex ante government subsidies are generally provided indirectly by offering public supporting services, which is equivalent to supplying high-quality public goods to reduce the project's total cost [6]. Since the government must also incur costs to provide these public goods and related services for the project, we define this cost as $M_{BF}=R+h(\phi)$, where $R\geq 0$ denotes the basic expenses incurred. The conditions $h'(\phi)<0$ and $h''(\phi)>0$ indicate that the government's cost increases as its support for the project expands. At this point, the effort cost function of cooperative members becomes $c_i^{BF}=\frac{\phi\eta_i}{2}\left(e_i-\varepsilon_{ji}e_j\right)^2$, where $0<\phi<1$ reflects the discount in members' effort costs after receiving government support. In this case, the cooperative members face a constrained maximization problem (denoted as Model 4), which is:

$$\max_{e_1,e_2} U=\left(k_1e_1+k_2e_2\right)-\frac{\phi\eta_1}{2}\left(e_1-\varepsilon_{21}e_2\right)^2-\frac{\phi\eta_2}{2}\left(e_2-\varepsilon_{12}e_1\right)^2$$
$$\begin{cases} e_i\in\arg\max\beta_i\left(k_1e_1+k_2e_2\right)-\frac{\phi\eta_1}{2}\left(e_i-\varepsilon_{ji}e_j\right)^2 \\ \beta_i\left(k_1e_1+k_2e_2\right)-\frac{\phi\eta_1}{2}\left(e_i-\varepsilon_{ji}e_j\right)^2\geq 0 \\ \beta_1+\beta_2=1,\beta_1\geq 0,\beta_2\geq 0 \end{cases} \tag{14}$$

When the government adopts ex ante subsidies, the members' optimal effort levels, allocation ratios, and project payoff are respectively:

$$e_{1BF}^{**}=\frac{s_1s_2\left(k_1+\varepsilon_{12}k_2+\varepsilon_{21}k_2+\varepsilon_{21}^2k_1\right)-\varepsilon_{21}s_1^2\left(k_1+\varepsilon_{12}k_2\right)-\varepsilon_{12}\varepsilon_{21}s_2^2\left(k_2+\varepsilon_{21}k_1\right)}{\phi(s_1k_2+s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \tag{15}$$

$$e_{2BF}^{**}=\frac{s_1s_2\left(k_2+\varepsilon_{12}k_1+\varepsilon_{21}k_1+\varepsilon_{12}^2k_2\right)-\varepsilon_{12}\varepsilon_{21}s_1^2\left(k_1+\varepsilon_{12}k_2\right)-\varepsilon_{12}s_2^2\left(k_2+\varepsilon_{21}k_1\right)}{\phi(s_1k_2+s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \tag{16}$$

$$\beta_{1AF}^{*}=\frac{s_2k_1+\varepsilon_{12}s_2k_2-\varepsilon_{21}s_1k_1-s_1k_2\varepsilon_{12}\varepsilon_{21}}{s_1s_2(\eta_1+\eta_2)(1-\varepsilon_{12}\varepsilon_{21})} \tag{17}$$

$$\beta_{2AF}^{*}=\frac{s_1k_2+\varepsilon_{21}s_1k_1-\varepsilon_{12}s_2k_2-s_2k_1\varepsilon_{12}\varepsilon_{21}}{s_1s_2(\eta_1+\eta_2)(1-\varepsilon_{12}\varepsilon_{21})} \tag{18}$$

$$U_{BF}^{**}=\frac{\left[\left(s_1s_2-\varepsilon_{21}s_1^2\right)\left(k_1+\varepsilon_{12}k_2\right)^2+\left(s_1s_2-\varepsilon_{12}s_2^2\right)\left(k_2+\varepsilon_{21}k_1\right)^2\right]}{\phi(s_1k_2+s_2k_1)(1-\varepsilon_{12}\varepsilon_{21})^2} \tag{19}$$

Compared with the optimal effort levels without subsidies, we still have $e_1^{**}<e_{1BF}^{**}$, $e_2^{**}<e_{2BF}^{**}$, indicating that ex ante subsidies for the project can continue to provide incentives to the cooperative members. When $\phi=(1+\lambda)^{-1}$, the social optimum is again achieved. At this point, the government's optimal ex ante subsidy for the project is

$$M_{BF}^{*}=R+h(\phi)=R+h\left[(1+\lambda)^{-1}\right] \tag{20}$$

In summary, the government's ex ante subsidies likewise internalize the spillover effects generated by the project into the members' decision-making, provide effective incentives for the members, and ultimately realize the social optimum.

3.4 Numerical Comparative Analysis

To gain a more intuitive understanding of how different government subsidy schemes affect members' optimal effort levels, government subsidy costs, and overall social welfare, we now conduct a numerical comparative analysis.

(i) Micro-level incentive effects of government subsidies on members

Assume $h(\phi)=1/\phi^2$, and under the conditions $0<\beta_i<1$ and $0<e_i<1$, randomly take $k_i=1$、$\eta_i=2$、$\varepsilon_{ij}=0.5$、R=0. Then the members' optimal efforts under the two subsidy schemes are obtained as shown in Table 2. The trends in members' optimal efforts with changes in the government's ex post subsidy rate and ex ante subsidy amount are illustrated in Figure 5.

Table 2. Variation Trends among Factors

Parameter	Value
Cost coefficients	$\eta_1=\eta_2=2$
Contribution coefficients	$k_1=k_2=1$
Cost coordination coefficients	$\varepsilon_{12}=\varepsilon_{21}=0.5$
Basic cost of ex ante subsidy	$R=0$
Ex post subsidy	$e_{AF1}^{**}=e_{AF2}^{**}=(1+\theta)/2$
Ex ante subsidy	$e_{BF1}^{**}=e_{BF2}^{**}=\frac{1}{2\phi}=\frac{1}{2}\sqrt{M_{BF}^{*}}$

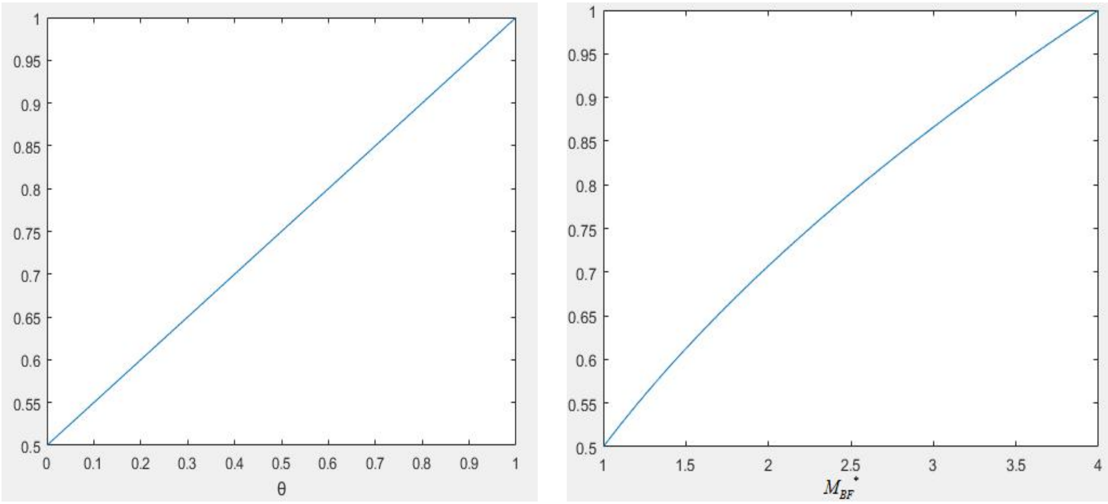

Figure 5. Trend of Members' Optimal Effort with Changes in the Government'S Ex Post Subsidy Ratio θ and the Ex Ante Subsidy Amount M_{BF}^*

The numerical results show that the cooperative members' optimal effort levels are positively correlated with government subsidies. Whether the government adopts ex post or ex ante subsidies, both can provide effective incentives for the cooperative members, and they will choose the socially optimal effort level.

(ii) Comparison of subsidy costs and social welfare

Under the parameter values given in Table 2, we further select two basic ex ante subsidy costs, R_1=0 and R_2=0.5. The government's costs and total social welfare under the two subsidy schemes are reported in Table 3, and their comparisons are illustrated in Figures 6 and 7, respectively.

Table 3. Government Costs and Social Welfare under Two Subsidy Schemes

Item	Expression
Cost coefficients	$\eta_1=\eta_2=2$
Contribution coefficients	$k_1=k_2=2$
Cost coordination coefficients	$\varepsilon_{12}=\varepsilon_{21}=0.5$
Ex post subsidy: government cost	$M_{AF}^*=4\lambda$
Ex post subsidy: social welfare	$U_{BF1}^*=4\left(1+\lambda+\lambda^2\right)$
Ex ante subsidy (R_1 = 0): government cost	$M_{BF1}^*=\left(1+\lambda\right)^2$
Ex ante subsidy (R_1 = 0): social welfare	$U_{BF1}^*=2\lambda-\lambda^2+3$
Ex ante subsidy (R_2 = 0.5): government cost	$M_{BF2}^*=0.5+\left(1+\lambda\right)^2$
Ex ante subsidy (R_2 = 0.5): social welfare	$U_{BF1}^*=2\lambda-\lambda^2+2.5$

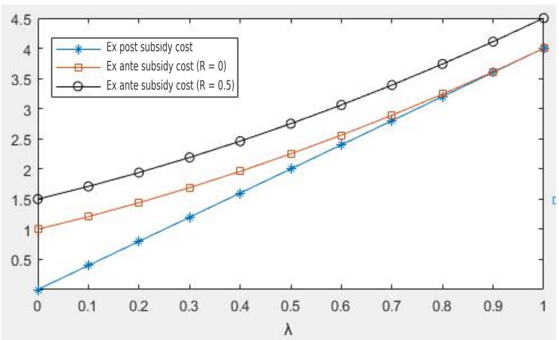

Figure 6. Comparison of Government Costs under the Two Subsidy Schemes

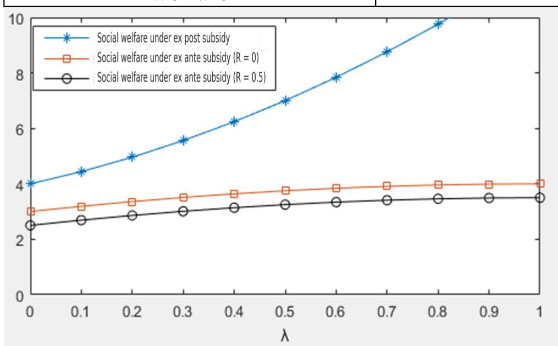

Figure 7. Comparison of Social Welfare under the Two Subsidy Schemes

The numerical results show that when members choose the socially optimal effort level, the government's ex post subsidy always has a lower cost than the ex ante subsidy, regardless of the magnitude of the spillover intensity . Moreover, the cost of an ex ante subsidy rises with the basic expenditure . It is not hard to see that, under an ex ante subsidy, if the government's basic expenditure is relatively high, social welfare will be reduced and may even become negative. By contrast, under an ex post subsidy social welfare is always guaranteed to be positive. Comparing the government's ex post and ex ante subsidies for the project, their differences can be summarized as follows:

①From the perspective of the incentive

mechanism, both subsidy schemes internalize the project's externalities into members' investment decisions, provide effective incentives, and ultimately achieve the social optimum.

②In terms of how the incentive is implemented, the ex post subsidy is paid in proportion to project revenue, whereas the ex ante subsidy works by improving public supporting services to reduce the project's total cost.

③From the viewpoint of government subsidy cost and social welfare, the two schemes differ markedly. The ex post subsidy is proportional to project revenue and is thus a linear subsidy; if the project fails, no payment is required. Under the ex ante scheme, however, regardless of the project's eventual output and revenue, the government must provide support at the outset. The subsidy cost does not vary with project revenue, and as members' costs fall, the subsidy cost increases nonlinearly, leading to serious losses in social welfare.

Based on the above analysis, we conclude that when a project exhibits spillover effects, both ex post and ex ante subsidies can motivate members and solve the problem of under-investment, inducing them to choose the socially optimal effort level. However, in terms of overall social welfare, the ex post subsidy is superior to the ex ante subsidy.

4. Conclusion

Based on the principal–agent framework and the theory of incentive-mechanism design, this paper examines the characteristics of cost synergy within a cooperative team and the external government subsidy policies, and constructs a decision model under moral hazard. We derive the optimal contract, analyze the effects of internal and external incentive factors on optimal effort, optimal allocation and social welfare, and further verify the results by numerical analysis. The findings are as follows: first, both cost synergy and government subsidies can provide effective incentives for team members; second, cost synergy adjusts the share of project returns, assigning a greater share of income to members with higher influence; third, both ex post and ex ante government subsidies can effectively motivate members and eventually achieve the social optimum, but in terms of social welfare, ex post subsidies are superior to ex ante subsidies.

On the basis of these conclusions, we put forward several suggestions. First, in partner selection, firms should choose members whose resources are highly complementary as collaborators, so that members can form an integrated cooperative body, fully realize cost synergy, and thereby increase returns. Second, in terms of benefit sharing, firms should establish a sound benefit-distribution mechanism to optimize members' levels of resource input and mitigate the harm caused by moral hazard. Third, at the policy level, governments can encourage technological innovation by enterprises through providing the necessary public supporting services for projects or offering ex post subsidies and other subsidy schemes, while at the same time strengthening ex ante screening and supervision so as to avoid blind and inefficient subsidization.

References

[1] Chen Haifeng, Xin Chong, Chen Xin, et al. Effect of geographical dispersion in cooperative innovation networks on product innovation. Management Science, 2020, 33(2):50–62.

[2] Zheng Junjun, Li Chengzhi. Impact of individual trust cognition on cooperative behavior in games. China Management Science, 2016, 24(10):164–170.

[3] Wang Simeng, Jing Runtian, Shao Yunfei. Mechanism through which alliance routines affect firms' ambidextrous innovation capabilities. Management Science, 2019, 32(2):19–32.

[4] Edmans A, Goldstein I, Zhu J. Contracting with synergies. CEPR Discussion Paper No.9559, 2013.

[5] Dang Wenjuan, Luo Qingfeng. Innovation incentive mechanisms for SMEs under government leadership—Evidence from Chongqing. Science Research Management, 2020, 41(7):50–60.

[6] Wang Yu, Zhu Fei, Luo Yue. Incentive effects and welfare analysis of government subsidies in venture capital projects. Systems Engineering – Theory & Practice, 2019, 39(10):2249–2258.

[7] Ding Chuan, Li Aimin. Allocation of control rights in venture capital and entrepreneurial incentives: A quality-effort and management-effort perspective. Science Research Management, 2020, 41(5):213–230.

[8] Samuelson P A, Nordhaus W D. Economics. New York: McGraw-Hill, 1998.
[9] Hellmann T. Financial structure and control in venture capital. Stanford Graduate School of Business, Stanford University, 1994.
[10]Pecorino P. Can by-product lobbying firms compete?. Journal of Public Economics, 2001, 82(3):377–397.
[11]Zhang Zongming, Du Rong, Liao Xiuwu. Service outsourcing contract design from the perspective of cooperative production. Management Science, 2014, 27(6):77–89.
[12]Holmström B. Moral hazard in teams. Bell Journal of Economics, 1982, 13(2):324–340.
[13]Alchian A A, Demsetz H. Production, information costs, and economic organization. IEEE Engineering Management Review, 1972, 62(2):777–795.
[14]Bergmann R, Friedl G. Controlling innovative projects with moral hazard and asymmetric information. Research Policy, 2008, 37(9):1504–1514.
[15]Bai Jingyu, Liu Zhongquan, Wang Yingjie. Dynamic mechanism of innovation consortia based on game theory. Science Research Management, 2020, 41(10):105–113.
[16]Hoffmann W H, Schlosser R. Success factors of strategic alliances in small and medium-sized enterprises—An empirical survey. Long Range Planning, 2001, 34(3):357–381.
[17]Dai Jiansheng, Meng Weidong. Design of benefit-sharing mechanisms in team production. China Management Science, 2010, 18(1):120–127.
[18]Iton H. On incentives to help in multi-agent situations. Kyoto: Faculty of Economics, Kyoto University, 1988.
[19]Kandel E, Lazear E P. Peer pressure and partnerships. Journal of Political Economy, 1992, 100(4):801–817.
[20]Winter E. Transparency and incentives among peers. RAND Journal of Economics, 2010, 41(3):504–523.
[21]Georgiadis G. Projects and team dynamics. Review of Economic Studies, 2015, 82(1):187–218.
[22]Li Baizhou, Yin Shi, Zeng Jingwei, Luo Xiaofang. Cooperative innovation mechanisms and dynamic evolution in integrated supply chains based on SEM and B–Z reaction. China Management Science, 2020, 28(2):166–177.
[23]Li Dan, Yang Jianjun. Relationship states, trust, innovation modes and cooperative innovation performance. Science Research Management, 2018, 39(6):103–111.
[24]Cheng Xinsheng, Zhao Yang. Professionalism of authoritative directors, executive incentives and innovation activity. Journal of Management Science, 2019, 22(3):40–52.
[25]Mansfield E, et al. Social and private rates of return from industrial innovations. Quarterly Journal of Economics, 1977, 91(2):221–240.
[26]An Tongliang, Qian Huixiong. R&D subsidy strategies of Chinese firms: Subsidy thresholds, optimal scale and mode selection. Economic Research Journal, 2021, 56(1):122–137.
[27]Li Wanfu, Du Jing. Tax incentives, adjustment costs and R&D investment. Accounting Research, 2016, (12):58–63+96.
[28]Shi Junguo, Lu Ziqun, Chen Bin. Government subsidies, market power and firm innovation. Soft Science, 2019, (11):53–58.
[29]Gass V, Schmidt J, Schmid E. Analysis of alternative policy instruments to promote electric vehicles in Austria. Renewable Energy, 2014, 61:96–101.
[30]Zheng Guihua, Li Heli, Pan Bo. Effects of fiscal subsidies and tax incentives on R&D investment in the new energy vehicle industry. Finance and Economics Theory and Practice, 2019, 40(4):101–106.
[31]Wang Xu, Wang Fei. No ingredients or insufficient incentives? Government subsidies, corporate green innovation and executive incentive strategy choice. Science Research Management, 2019, 40(7):131–138.
[32]Xing Lebin, Wang Xu. Evolutionary game analysis of opportunistic behavior based on cooperative spillovers. Journal of Management Engineering, 2011, 25(3):68–72.
[33]Wang Minghai, Li Xiaojing. Government intervention, external investment and firms' independent innovation: A signaling perspective. Shanghai Economic Review, 2017, (2):9–16.
[34]Li Wenjian, Dai Liangping, Guo Benhai, Wu Siyuan. Cooperative innovation game between upstream and downstream new energy vehicle firms under a composite traction mechanism in the post-subsidy era.

Soft Science, 2021, 35(1):81–88.

[35]Wallsten S J. The effects of government–industry R&D programs on private R&D: The case of the Small Business Innovation Research program. RAND Journal of Economics, 2000, 31(1):82–100.

[36]Yi J, Murphree M, Meng S, et al. The more the merrier? Chinese government R&D subsidies, dependence and firm innovation performance. Journal of Product Innovation Management, 2021, 38(2):289–310.

[37]Wu Jiapei, Xie Kang, et al. Information Economics (2nd ed.). Beijing: Higher Education Press, 2007.

[38]Alchian A A, Demsetz H. Production, information costs and economic organization. IEEE Engineering Management Review, 1972, 62(2):777–795.

[39]Xie Xuemei, Sun Kejie. Long-term cooperation mechanisms in industrial technology innovation strategic alliances: Evidence from 144 alliances. Journal of Systems & Management, 2018, 27(3):401–413.

[40]Cooper R, Ross T. Product warranties and double moral hazard. RAND Journal of Economics, 1985, 16(3):103–113.

[41]Bhattacharyya S, Lafontaine F. Double-sided moral hazard and the nature of share contracts. RAND Journal of Economics, 1995, 26(4):761–781.

[42]Zhou Shanshan, Sun Yuejia. Government subsidies and the evolution of sustained adaptive innovation in high-tech industries. Science Research Management, 2019, (10):72–87.

[43]Cao Yu, Zhou Mouting, Hu Hanli. Two-level supply chain optimization considering government subsidies and corporate social responsibility. China Management Science, 2020, 28(5):101–111.

