

Staged Separation and Asymmetric Reconfiguration of Equity-Control Rights Allocation in Innovation Consortia

Wenping Wang, Jianhong Yuan, Yingmei Zhao*, Ming Li*

(School of Economics and Management, Southeast University, Nanjing 211189, China)

Abstract: Innovation consortia are a key organizational form for overcoming the high investment, long-cycle, and cross-actor coordination challenges associated with critical technology breakthroughs and the commercialization of R&D outcomes, yet they often suffer from unclear property-rights and benefit-sharing rules and misaligned equity-control rights. Using the factor potential contribution rate (FPCR) as the basis for multi-actor value allocation, this study develops a cooperative game model with dynamically evolving equity-control rights among government agencies, research talent teams, and social investors, and employs numerical simulations to trace stage-dependent governance evolution and its value-enhancing effects. The findings are as follows: (1) Governance should evolve across stages—from a government-led one-share-one-vote structure, to a more balanced equity allocation with enhanced control for the research talent team, and ultimately to an asymmetric configuration with enhanced control for social investors and limited control for the research team, supported by an orderly government exit. (2) Increasing the control-right share of either the research talent team or social investors in isolation may induce a dominant-player crowding-out effect. (3) The optimal arrangement is an asymmetric equity – control structure featuring “large equity with limited control” and “small equity with enhanced control,” implying an effective inverse adjustment range between equity and control rights.

Keywords: Innovation consortium; equity-control rights allocation; factor potential contribution rates (*FPCRs*); multi-actor value allocation; cooperative game model

1. Introduction

Against the backdrop of intensifying climate change and a new wave of technological revolution, achieving breakthroughs in critical core technologies has become a central strategic imperative for industrial development. However, such breakthroughs are typically

Correspondence: Yingmei Zhao (zhaoyingmeio@126.com) Ming Li (230258396@seu.edu.cn)

characterized by high investment requirements, long development cycles, and strong cross-disciplinary complementarities, making it difficult for any single actor to accomplish them independently and calling for novel forms of innovation organization. Innovation consortia have emerged in response to this need. They can be understood as cross-organizational innovation communities formed by governments, universities and research institutes, enterprises, and social/financial capital around shared technological objectives, operating under arrangements of joint resource mobilization and shared risk-bearing. Representative practices include the national-level “3C Intelligent Manufacturing Innovation Consortium” led by Xiaomi ¹, Alibaba-Tsinghua jointly established laboratories ², and Siemens Energy’s innovation center in Shenzhen oriented toward green transition ³. Despite their potential to integrate heterogeneous innovation resources, the most salient bottlenecks of innovation consortia remain concentrated in governance and incentive mechanisms: unclear rules for intellectual property ownership and benefit sharing, and misalignment between equity allocation and contribution intensity, which weakens sustained participation incentives across stakeholders and ultimately undermines resource integration efficiency and the effectiveness of technology commercialization.

To maximize the innovation potential of innovation consortia to realize value added and efficient transformation of technological achievements, it is necessary to break the organizational boundaries between the government, universities, research institutes, enterprises, and other subjects, to absorb the financial capital, research capital (including talents and technology), social capital and other innovation resources invested by multiple subjects (i.e., government departments (*GN*), research teams (*RT*) and social investors (*SI*)), then to enhance the contribution rates of diversified innovation resources collaborative interaction to economic output growth of innovation consortium (i.e., factor potential contribution rates (*FPCR*s)) (Gao et al., 2022). Among them, the key is to clarify the ownership attribution and benefit-sharing mechanism for the technological achievement transformation (Gou and Xu, 2020). In addition, the equity-control rights as a regulatory instrument to drive the participation

¹ https://www.beijing.gov.cn/ywdt/yaowen/202208/t20220801_2783597.html?utm_source

² https://www.tsinghua.edu.cn/en/info/1245/5045.htm?utm_source

³ https://www.siemens-energy.com/global/en/home/press-releases/siemens-energy-launches-innovation-center-in-shenzhen.html?utm_source

enthusiasm of multiple subjects, is also a catalyst to enhance the *FPCRs* and realize the economic output growth of innovation consortium. Thus, we analyze the mechanism by which equity-control rights restructuring affects *FPCRs*, to explore the sustainable development path of innovation consortia.

The previous studies on the role of equity-control rights restructuring on the organizational innovation resources allocation and innovation efficiency are inconsistent, varying according to research object types and the characteristics of equity-control rights structure. In terms of equity rights structure, different types of equity rights can provide different innovation resources for enterprises (Suk et al., 2011, 2012). The higher the equity rights diversification, the greater the innovation investment of the state-owned enterprises after mixed ownership reform (Luo et al., 2022), which in turn can significantly improve the innovation performance and abilities (Xia and Zhou, 2022). Recent research further confirms that equity structure exhibits an inverted U-shaped relationship with innovation performance, indicating that both excessively low and high ownership concentration can be detrimental to corporate innovation (Chen et al., 2024). Antón et al. (2025) demonstrated that common ownership can promote corporate innovation through technological spillover effects, particularly when firms share common institutional investors who facilitate knowledge transfer and reduce duplicative R&D investments. Meanwhile, the mutual balances of heterogeneous shareholders in equity rights can avoid the defects in single-shareholder governance and improve governance efficiency (Ruan and Liu, 2021). However, a dominant equity rights structure has a “hollowing out effect” and is not conducive to investment in technological innovation and the recruitment of high intellectual talent (Gao et al., 2022; Marco et al., 2016). Deng et al. (2025) found that stable institutional ownership significantly facilitates firms' exploratory innovation through disciplinary, informational, and resource-provision channels, with institutional ownership concentration strengthening this positive relationship. In addition, the diversification of equity rights can avoid the negative moderating effect of excessive dominance on enterprise performance (Liu et al., 2022).

In contrast, changes in control rights have a greater impact on enterprise innovation behavior than that of equity rights (Claessens et al., 2002). The distribution of control rights can enhance cooperation among heterogeneous shareholders and the enterprise performance

through synergistic effect and balance effect (Luo et al., 2022). However, the private benefits accompanying control rights are also a cause of interest and goal conflicts among shareholders (Feng et al., 2016; Rapaport, 2010), which may inhibit internal and external monitoring mechanisms and intensify principal-agent conflicts, thereby inhibiting the allocation efficiency of technological resources (John et al., 2008). Liu et al. (2024) revealed that mere equity ownership by non-state shareholders has no significant impact on technological innovation in state-owned enterprises; however, the delegation of executives by non-state shareholders substantially enhances innovation performance, underscoring the importance of active governance participation over passive shareholding. Furthermore, several studies analyzed the role of dual-class equity rights structure on enterprise innovation behavior, and have shown that dual-class equity rights structure with a separation of equity and control rights is an effective way to motivate organizations to innovate and improve investment efficiency (Plunkett et al., 2010; Cheng et al., 2020), and the asymmetric allocation of equity and control rights can help to improve governance performance and innovation investment behavior (Dou and Liu, 2011; Luo et al., 2021; Sung et al., 2017). However, the separation of control and control rights may also enhance the opportunistic behavior of management, resulting in over-investment behavior (Beladi et al., 2022).

How to optimize the differentiated allocation structure of equity and control rights becomes the key to improving the innovation resource allocation efficiency and innovation performance. In this regard, several studies have pointed out that under the condition of ownership concentration, inefficient investment behavior of enterprises will be mitigated by increasing the equity ratio of major controlling shareholders or achieving mutual balances among multiple major shareholders (Choi et al., 2011). However, there is a dilemma in equity-control rights allocation between state-owned managers and social capital in enterprises after mixed ownership reform, and there is no absolute optimal ratio due to the continuous evolution of the industry development stage in which the enterprise operates (Santos *et al.*, 2015). In addition, in the reform process of mixed ownership enterprises, reducing the proportion of state-owned equity rights among the top five shareholders can help improve enterprise performance, but increasing the proportion of non-state-owned equity rights excessively will not improve enterprise performance (Liu et al., 2018). Harrison et al. (2024) examined how inventor CEO

involvement affects firm innovation strategies, finding that ownership structure and control rights allocation significantly influence the balance between exploitative and exploratory innovation activities.

Although previous studies have indicated that the equity rights adjustment among heterogeneous shareholders can help improve the resource allocation efficiency, it does not provide an in-depth analysis of how the equity rights structure affects the synergistic allocation of various innovation resources, and which is the optimal allocation structure of equity-control rights to realize the sustainably organization development of innovation consortium. Meanwhile, the impact of equity-control rights structure on resource allocation and innovation performance is essentially the result of negotiations and balance between multi-subjects' benefits (Rajan and Zingales, 1997). Tang et al. (2024) examined common institutional ownership types and their differentiated impacts on corporate innovation, finding that cross-industry common ownership promotes innovation through resource integration and information sharing mechanisms. Relying on this, from the perspective of factors synergistic allocation, this paper applies the FPCRs to measure the impact intensities of innovation resources (such as financial capital, research capital, and social capital) input to the economic output growth of innovation consortium, then selects the equity-control rights as the core incentive tool to analyze the effect of equity-control rights restructuring on FPCRs and interaction relationship among different FPCRs.

Therefore, this study primarily addresses three questions: first, within the context of multi-actor collaborative innovation in innovation consortia, how can the factor potential contribution rates (FPCRs) of government agencies (GN), research talent teams (RT), and social investors (SI) be constructed and characterized to quantify the relative contributions of heterogeneous innovation inputs to output growth, including the endogenous synergy component; second, through what mechanisms does equity - control rights restructuring affect the FPCRs of the three actors and their synergistic effects, thereby driving benefit growth and value enhancement in innovation consortia; and third, across different development stages, how should the optimal equity - control rights allocation structure evolve dynamically to achieve multi-actor goal alignment and the sustainable development of innovation consortia.

The main innovation contributions are as follow: (i) In terms of research content, we focus

on the role of equity-control rights restructuring on *FPCRs* of multi-subjects in the innovation consortium, which opens the black box of the mechanism of equity-control rights optimal allocation on sustainable development of innovation consortium. (ii) In terms of research perspectives, most of the existing studies on equity-control rights restructuring are focused on the research objects such as mixed state-owned enterprises, family enterprises, and high-tech enterprises, but there is a lack of studies directly on innovation consortia. As a for-profit alliance organization involving multi-subjects, the special characteristics of its internal equity-control rights structure and the multiple interest conflicts between the individual goals of multi-subjects and the organization overall goal are key factors affecting the sustainable development. In this regard, we focus on the innovation consortium to explore the internal mechanism of sustainable development, which can enrich the related research fields. (iii) In terms of research methodology, different from existing studies that mostly use historical data for empirical analysis, we construct a mathematical analysis model for theoretical analysis, and utilize numerical simulation to validate the analysis results, which can help formulate and implement supportive policies to the innovation consortium.

2. Methodology

2.1. Problem Description and Model Assumptions

Innovation consortia integrate various innovation factors, such as financial capital, research capital, and social capital, by gathering multi-subjects, such as *GN*, *RT*, and *SI*, to constitute the multiple functions to scientific and technological innovation and achievement transformation, market-oriented and independent operation, talent gathering, and industry cultivation, etc., and jointly achieve both technological and economic output growth, as shown in figure 1. However, with the continuous evolution of innovation consortium development stages, the key innovation resources relied on in different development stages are also different, accordingly, the role played by multi-subjects will also be different, i.e., different subjects and their innovation resource inputs will form different forms of interactive relationships.

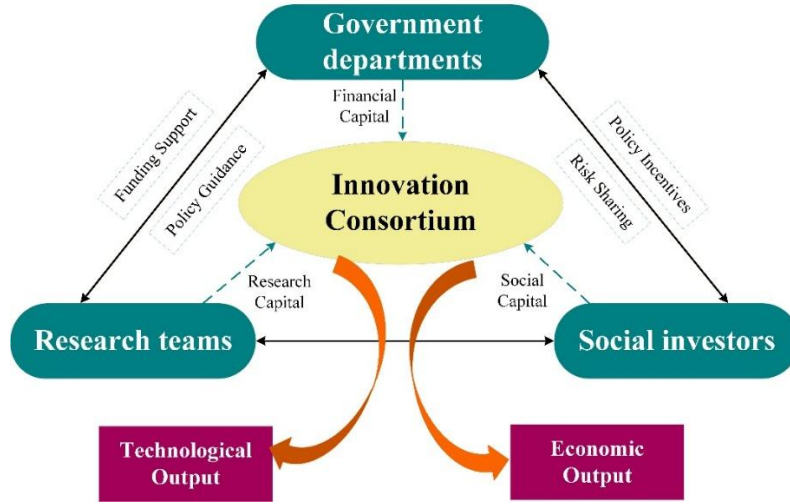


Figure 1. Conceptual Framework of Multi-Actor Resource Inputs and Outputs in Innovation Consortia

Assumption 1: The innovation consortium is jointly participated in and governed by three rational parties: a government department (GN), a research talent team (RT), and social investors (SI), denoted by G , R , and S , respectively. Each party makes rational decisions on innovation inputs and strategic interactions toward technological innovation and the commercialization of R&D outcomes, while the consortium, as a cross-organizational cooperative arrangement, integrates heterogeneous innovation resources to jointly generate technological and economic outputs.

Assumption 2: Governance and investment decisions evolve over discrete nodes $t \in \{0,1,2,3,4\}$. At $t = 0$, the initial equity–control structure is determined. At $t = 1$, given the prevailing governance structure, each party chooses its optimal innovation-resource input. At $t = 2$, the consortium integrates the inputs to generate technological and economic outputs and allocates payoffs; parties observe and compare realized payoffs with their expectations. At $t = 3$, equity shares are renegotiated based on the gap between expected and realized individual payoffs, and control rights can be adjusted through a dual-class (one-share–multiple-votes) mechanism. At $t = 4$, the consortium’s overall optimization objective is achieved (as illustrated in Figure 2).

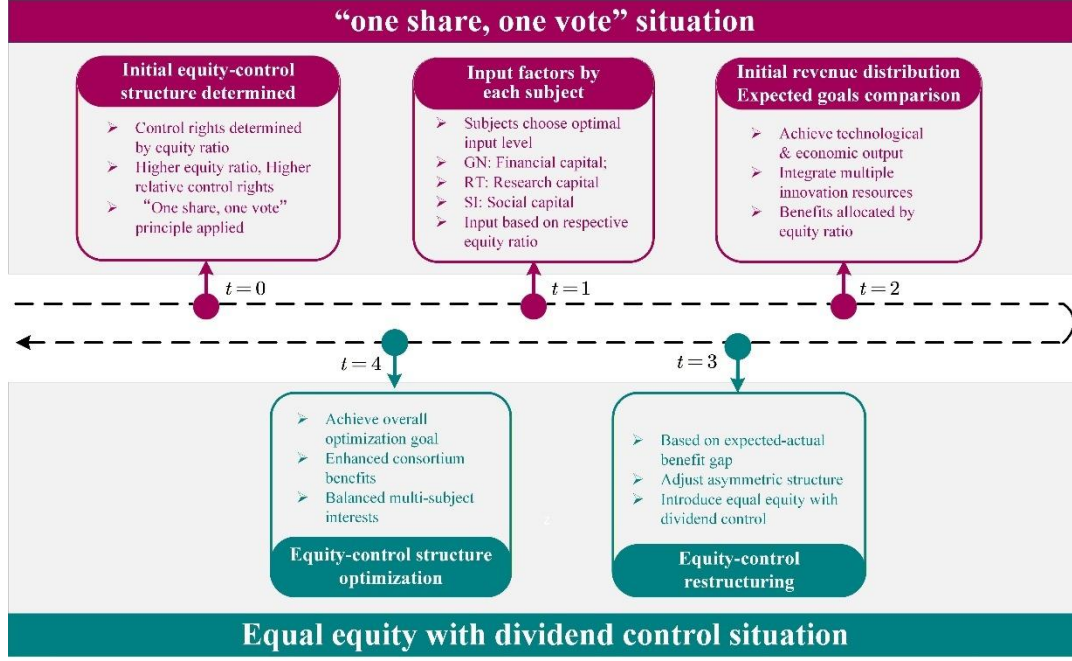


Figure 2. The dynamic optimal allocation process of equity-control rights structure among multi-subjects in an innovation consortium

Assumption 3: At any node t , equity (cash-flow right) shares are denoted by $a_{i,t}$, satisfying $a_{i,t} \geq 0$ and $\sum_{i \in \{G,R,S\}} a_{i,t} = 1$. For notational convenience within the same stage, we denote $a_{G,t}, a_{R,t}, a_{S,t}$ by a, b, c , respectively.

Assumption 4: To capture a one-share–multiple-votes arrangement, each party is assigned a voting multiplier (control intensity) $n_{i,t} > 0$, where the one-share-one-vote benchmark corresponds to $n_{i,t} = 1$. Define the weighted voting total $S_t = \sum_i n_{i,t} a_{i,t}$. The control-right (voting-right) share of party i is $\omega_{i,t} = \frac{n_{i,t} a_{i,t}}{S_t}$, with $\sum_i \omega_{i,t} = 1$. When $n_{i,t}$ is heterogeneous, cash-flow rights and control rights are separated, leading to an asymmetric equity–control structure; in numerical simulations, the upper bound of $n_{i,t}$ is denoted by $\bar{n}$ and is consistent with the simulation design.

For ease of subsequent derivations and numerical simulations, the key notation and parameters, together with their definitions, constraints, and baseline settings, are summarized as Table 1.

Table 1. Key parameters and notation

Symbol	Definition	Constraint/Notes
t	Decision/evolution node	$t \in \{0,1,2,3,4\}$

i	Player index	$i \in \{G, R, S\}$
$a_{i,t}$	Equity (cash-flow right) share	$a_{i,t} \geq 0, \sum_i a_{i,t} = 1$
$n_{i,t}$	control intensity	$n_{i,t} > 0$
S_t	Weighted voting total	$S_t = \sum_i n_{i,t} a_{i,t}$
$\omega_{i,t}$	Control-right (voting-right) share	$\omega_{i,t} = \frac{n_{i,t} a_{i,t}}{S_t}, \sum_i \omega_{i,t} = 1$
P_t, I_t, F_t	Financial/research/social capital inputs	$P_t, I_t, F_t > 0$
α, β, γ	Output elasticities	$\alpha, \beta, \gamma > 0$
ρ_G, κ_R, η_S	FPCRs of G, R, S	≥ 0
Y_t	Baseline output	$Y_t > 0$
ψ_i, ϕ_i	Equity/control incentive sensitivities	$\psi_i, \phi_i > 0$
μ_G, μ_R, μ_S	Cost coefficients	$\mu_G, \mu_R, \mu_S > 0$

2.2. Extended C-D Production Function Construction

The impact mechanism of economic output growth of innovation consortium is complex, and achieving endogenous growth driven by the interaction and synergy of innovation resources and technological progress is pivotal, which is different from the exogenous growth brought by the increase in innovation resource investment. Thus, we construct the extended *Cobb-Douglas* (i.e., *C-D*) *production function* to measure the contribution rates of the economic output growth of innovation consortium brought by the innovation resource inputs of multi-subjects. At any time t , the cooperative's economic output is jointly determined by total factor productivity and three categories of factor inputs.

$$V_t = A_t P_t^\alpha I_t^\beta F_t^\gamma, t \in \{0,4\}. \quad (1)$$

Among them, V is the economic output of innovation consortium; P , I and F are the financial capital, research capital, and social capital invested by GN , RT , and SI , respectively; α , β , and γ are the elasticity coefficients of the innovation resource inputs of multi-subjects. The greater the elasticity coefficient is, the higher the relative output efficiency of each resource input relatively. After transforming and differentiating equation (1), equations (2-3) are obtained as follows:

$$\ln V_t = \ln A_t + \alpha \ln P_t + \beta \ln I_t + \gamma \ln F_t \quad (2)$$

$$\frac{dV_t}{V_t} = \frac{dA_t}{A_t} + \alpha \frac{dP_t}{P_t} + \beta \frac{dI_t}{I_t} + \gamma \frac{dF_t}{F_t} \quad (3)$$

In equations (3), $\frac{dV_t}{V_t}$ represents the economic growth rate of innovation consortium, $\frac{dA_t}{A_t}$ represents the growth rate of total factor productivity rate, $\frac{dP_t}{P_t}$, $\frac{dI_t}{I_t}$, and $\frac{dF_t}{F_t}$ represent the input growth rates of financial capital, research capital and social capital, respectively.

The relationship between each resource input and the economic output of innovation consortium can be established as following equation (4):

$$D_P(t) = \frac{\alpha d P_t / P_t}{d V_t / V_t}, D_I(t) = \frac{\beta d I_t / I_t}{d V_t / V_t}, D_F(t) = \frac{\gamma d F_t / F_t}{d V_t / V_t} \quad (4)$$

Furthermore, the average growth rate of total factor productivity rate is further transformed into differential form as shown in equation (5):

$$\Delta \ln A_t = \Delta \ln V_t - \alpha \Delta \ln P_t - \beta \Delta \ln I_t - \gamma \Delta \ln F_t \quad (5)$$

The equation (5) is also the Solow growth rate equation, $\Delta \ln P_t$, $\Delta \ln I_t$, and $\Delta \ln F_t$ are denoted as the average growth rates of the corresponding resources, and $\Delta \ln V_t$ is denoted as the growth rate of economic output of innovation consortium, then, the contribution of total factor productivity rate to the innovation consortium output can be expressed as equation (6):

$$D_A(t) = \frac{\Delta \ln A_t}{\Delta \ln V_t} = 1 - D_P(t) - D_I(t) - D_F(t) \quad (6)$$

According to equation (6), the total factor productivity rate is jointly influenced by the innovation resource inputs of three subjects. Therefore, the contribution of total factor productivity rate to the economic growth of innovation consortium needs to be further decomposed according to the proportion of factor contribution rates of multi-subjects, and then obtain the *FPCRs* of multi-subjects, as shown in equations (7-9):

$$\rho_G(t) = D_P(t) + \frac{D_P(t)}{\Sigma_D(t)} D_A(t) \quad (7)$$

$$\kappa_R(t) = D_I(t) + \frac{D_I(t)}{\Sigma_D(t)} D_A(t) \quad (8)$$

$$\eta_S(t) = D_F(t) + \frac{D_F(t)}{\Sigma_D(t)} D_A(t) \quad (9)$$

In this, $\rho_G(t)$, $\kappa_R(t)$, and $\eta_S(t)$ are *FPCRs* of *GN*, *RT*, and *SI*, $\Sigma_D(t) = D_P(t) + D_I(t) + D_F(t)$. The above equations (7-9) reflect that the economic output growth of innovation consortium includes endogenous growth drivers brought by the interaction and synergy of

innovation resources and technological progress, in addition to the exogenous growth drivers brought by the absolute increase of innovation resource investments. Besides, *FPCRs* can be represented as a measure of the maximum degree of economic output growth of innovation consortium that can be achieved by innovation resource investments of multi-subjects.

2.3. Analysis of the Impact of Equity-Control Rights on *FPCRs*

the innovation consortium is co-governed by three subjects: government (GN, denoted by G), research team (RT, denoted by R), and social investors (SI, denoted by S). At any decision node t , the equity shares are

$$a_{i,t} = (a_{G,t}, a_{R,t}, a_{S,t}), a_{G,t} + a_{R,t} + a_{S,t} = 1 \quad (10)$$

To capture the one share–multiple votes mechanism, we introduce the voting multipliers (control intensities)

$$n_{i,t} = (n_{G,t}, n_{R,t}, n_{S,t}), t \in [0,4] \quad (11)$$

Define the weighted voting total

$$S_t = n_{G,t}a_{G,t} + n_{R,t}a_{R,t} + n_{S,t}a_{S,t} \quad (12)$$

then the control-right share (voting-right share) of subject i is

$$\omega_{i,t} = \frac{n_{i,t}a_{i,t}}{S_t}, i \in \{G, R, S\}, \sum_i \omega_{i,t} = 1 \quad (13)$$

Under the one-share-one-vote principle, ownership rights coincide with voting rights; when $n_{i,t}$ is heterogeneous, a separation between cash-flow (equity) rights and control rights emerges.

For any investment decision time point $t \in \{0,4\}$, the corresponding governance structure is characterized by $(a_{i,t}, n_{i,t})$.

From the above analysis, it is clear that increasing *FPCRs* helps to achieve the economic output growth of innovation consortium, and there is a non-linear interaction between them. To simplify the relationship between *FPCRs* and economic output, the following hypotheses are made as equation (14):

$$Y_{new} = Y_t(1 + V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t})) \quad (14)$$

$$V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t}) = e^{\psi_i a_{i,t}} e^{\phi_i \omega_{i,t}} \rho_G(t)\kappa_R(t)\eta_S(t) \quad (15)$$

Among them, Y_{new} is the final economic output of innovation consortium that can be achieved under the synergistic interaction of *FPCRs*, which is positively related to each *FPCR*,

and also influenced by the initial economic output level (i.e., Y). The larger Y indicates the greater innovation ability and development potential of innovation consortium, and accordingly, the larger Y_{new} .

Further, each subject will incur certain investment cost while input innovation resources, and the investment cost is related to $FPCRs$. So, we assume the investment cost of multi-subject is: $C_{GN} = \frac{1}{2}(\mu_1\rho_G(t))^2$, $C_{TN} = \frac{1}{2}(\mu_2\kappa_R(t))^2$, $C_{SC} = \frac{1}{2}(\mu_3\eta_S(t))^2$, all of which satisfy the assumption that the cost functions are marginal increasing and convex. Among them, μ_1 , μ_2 , and μ_3 are the investment cost coefficients, all of which are constants greater than 0. Besides, the inclusion of $1/2$ in equations is for the convenience of subsequent arithmetic simplification and does not affect the actual functional relationship among the variables.

As a result, the final benefit function of innovation consortium can be derived as shown in equation (16).

$$\begin{aligned} \Pi = Y + Y * V(\rho_G(t)\kappa_R(t)\eta_S(t), a_t, \omega_{i,t}) - \frac{1}{2}(\mu_1\rho_G(t))^2 - \frac{1}{2}(\mu_2\kappa_R(t))^2 \\ - \frac{1}{2}(\mu_3\eta_S(t))^2 \end{aligned} \quad (16)$$

According to section 2.1, GN , RT , and SI will allocate the innovation consortium benefit according to their respective equity-control ratios, and then compare their individual benefits. Since the innovation consortium is initially set up with “one share, one vote”, it is assumed that each subject will allocate the original economic output of the innovation consortium according to their equity ratio, which is also the basic individual benefit of each subject. While for the growth of economic output of innovation consortium brought by the synergistic interaction of $FPCRs$, it will be allocated according to the control ratio of multi-subjects. It also means that the coordinated allocation of equity-control rights among multi-subjects can realize the synergy of $FPCRs$, which in turn stimulates the innovation enthusiasm of RT and attracts SI to participate in the operation, then drives the innovation consortium to achieve market-oriented and independent operation, ultimately achieving economic output growth.

Therefore, the payoff function of subjects is given by.

$$\Pi_{G,t} = a_{G,t}Y_t + \omega_{G,t}Y_t V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t}) - \frac{1}{2}(\mu_1\rho_G(t))^2 \quad (17)$$

$$\Pi_{R,t} = a_{R,t}Y_t + \omega_{R,t}Y_t V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t}) - \frac{1}{2}(\mu_2\kappa_R(t))^2 \quad (18)$$

$$\Pi_{S,t} = a_{S,t}Y_t + \omega_{S,t}Y_t V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t}) - \frac{1}{2}(\mu_3\eta_S(t))^2 \quad (19)$$

3. Equilibrium Analysis

Lemma 1. For any investment decision time $t \in \{0,4\}$, given the governance structure $(a_{i,t}, n_{i,t})$, and assuming $Y_t > 0$, $\omega_{i,t} > 0$, and $\mu_i > 0$ for all $i \in \{G, R, S\}$, there exists a unique interior optimum, given by :

$$\rho_G^*(t) = \frac{\sqrt{\mu_R\mu_S}}{Y_t\Lambda_t\sqrt{\omega_{R,t}\omega_{S,t}}}, \kappa_R^*(t) = \frac{\sqrt{\mu_G\mu_S}}{Y_t\Lambda_t\sqrt{\omega_{G,t}\omega_{S,t}}}, \eta_S^*(t) = \frac{\sqrt{\mu_G\mu_R}}{Y_t\Lambda_t\sqrt{\omega_{G,t}\omega_{R,t}}}.$$

Where $\omega_{i,t} = \frac{n_{i,t}a_{i,t}}{s_t}$.

This lemma highlights a central incentive mechanism in the context of innovation consortia. The consortium's economic output growth hinges on the complementary interaction among government financial support, the research team's R&D capability, and social investors' market-oriented operational resources. The effectiveness of any single party's effort therefore depends on the simultaneous engagement of the other two parties, generating strong complementarity under the governance framework. Meanwhile, the convexity of investment costs implies that each party chooses a stable and identifiable optimal effort level by balancing marginal benefits against marginal costs, which provides a micro-foundation for a well-defined and stable allocation of resources within the consortium. More importantly, the control-rights arrangement not only determines how returns are distributed, but also reshapes each party's expected payoff from the incremental gains generated by synergy—thereby institutionally regulating incentives to participate in collaborative innovation.

Proposition 1. Under the conditions of Lemma 1, the relative intensities of the three parties' equilibrium efforts satisfy,

$$\frac{\rho_G^*(t)}{\kappa_R^*(t)} = \sqrt{\frac{\mu_R}{\mu_G}} \sqrt{\frac{\omega_{G,t}}{\omega_{R,t}}}, \frac{\rho_G^*(t)}{\eta_S^*(t)} = \sqrt{\frac{\mu_S}{\mu_G}} \sqrt{\frac{\omega_{G,t}}{\omega_{S,t}}}, \frac{\kappa_R^*(t)}{\eta_S^*(t)} = \sqrt{\frac{\mu_S}{\mu_R}} \sqrt{\frac{\omega_{R,t}}{\omega_{S,t}}}.$$

This proposition explains “who exerts more effort” as the outcome of two countervailing forces: (i) the relative magnitude of investment costs (a higher μ weakens incentives to invest), and (ii) the distributional weight of synergistic incremental gains induced by control rights (a

higher ω strengthens incentives). Hence, in the consortium's growth and maturity stages, if policymakers aim to increase the research team's relative effort, they may do so not only by alleviating its R&D constraints (reducing effective costs), but also by reallocating control rights to enhance the research team's access to incremental synergistic returns — thereby institutionalizing a sustainable innovation commitment.

We assume that the differences in different stages can be reflected by the relative importance of various *FPCRs* and their subject. The greater one of *FPCRs*, the greater the role of innovation resource in the growth of innovation consortium benefit, reflecting the innovation consortium is accordingly in the development stage dominated by the subject of this resource. Then, by comparing the *FPCRs* of each factor, we can analyze the interaction relationship between equity-control rights structure and development stages of innovation consortium (see Figure 3).

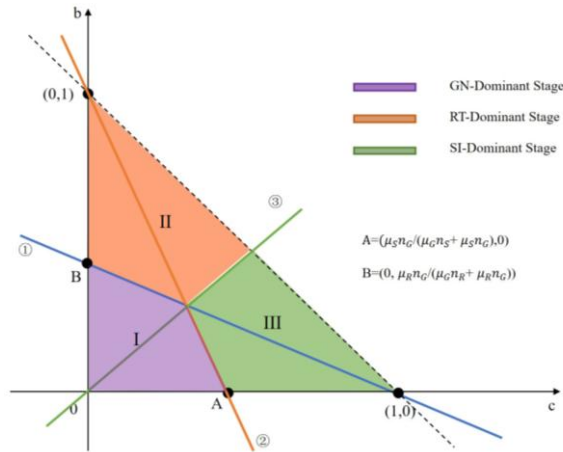


Figure 3. Relationship between the equity-control rights structure and innovation consortium development stages

As shown in Figure 3, the development process of innovation consortium can be divided into the following three stages, corresponding to section 2.1: In Stage I, the financial capital of *GN* contributes most to the growth of innovation consortium benefit, which is the initial construction development stage. In Stage II, research capital of *RT* is the most important resource of benefit growth. This is the operation growth stage. In Stage III, the social capital of *SI* is the most resource, and it is the operation maturity stage.

Proposition 2. For any $t \in \{0,4\}$, given equity shares $a_{i,t}$, consider a dual-class adjustment that changes the voting multiplier of a single party $k \in \{G, R, S\}$, denoted by $n_{k,t}$, while keeping the others $n_{-k,t}$ unchanged. Then:

(i) The equilibrium payoff of party k , $\Pi_{k,t}^*$, is strictly increasing in its own voting multiplier: $\frac{\partial \Pi_{k,t}^*}{\partial n_{k,t}} > 0$.

(ii) For any $j \neq k$, the direction of change in $\Pi_{j,t}^*$ with respect to $n_{k,t}$ is determined by whether $\omega_{k,t}$ exceeds $1/2$: $\text{sgn} \left(\frac{\partial \Pi_{j,t}^*}{\partial n_{k,t}} \right) = \text{sgn} (2\omega_{k,t} - 1)$.

That is, if $\omega_{k,t} < \frac{1}{2}$, increasing $n_{k,t}$ reduces the other parties' equilibrium payoffs; if $\omega_{k,t} > \frac{1}{2}$, it instead increases them; and $\omega_{k,t} = \frac{1}{2}$ is the knife-edge case.

This proposition captures a key payoff-externality logic in dual-class governance design. Raising one party's voting multiplier necessarily strengthens its institutional claim on the synergistic incremental surplus, thereby increasing its equilibrium payoff. For the other parties, however, changing $n_{k,t}$ generates two competing forces: a control-right dilution effect and a total-vote expansion effect. The net effect produces a threshold at $\omega_{k,t} = 1/2$: when the adjusted party is not yet dominant in control rights, the dilution effect dominates; when it is already dominant, the expansion effect can dominate and improve others' payoffs via an enlarged effective synergy. This result is particularly useful for stage-wise governance design, implying that reallocations should avoid excessive concentration in control rights.

Corollary 1. Under the conditions of Lemma 1, the equilibrium efforts satisfy an input-substitution property: increasing the research team's or social investors' control-right share reduces the government's equilibrium effort. $\frac{\partial \rho_G^*(t)}{\partial \omega_{R,t}} < 0$, $\frac{\partial \rho_G^*(t)}{\partial \omega_{S,t}} < 0$. Similarly, increasing the government's control-right share reduces the equilibrium efforts of the research team and social investors. $\frac{\partial \kappa_R^*(t)}{\partial \omega_{G,t}} < 0$, $\frac{\partial \eta_S^*(t)}{\partial \omega_{G,t}} < 0$.

This corollary accords with the governance logic in the consortium's transition from the construction phase to a more market-oriented stage. As control rights are gradually tilted toward the research team (strengthening long-term R&D commitment and commercialization efficiency) or toward social investors (enhancing market-based governance and resource integration), their marginal returns from the consortium's synergistic incremental gains increase. This strengthens their incentives to exert effort and partially substitutes for the government's

continuous input, thereby facilitating a phased withdrawal of government support without undermining the consortium's growth momentum.

Corollary 2. Suppose that at $t = 0$ the consortium adopts one-share-one-vote, $\omega_{i,0} = a_{i,0}$, and that at $t = 4$ a dual-class arrangement results in $\omega_{R,4}\omega_{S,4} > \omega_{R,0}\omega_{S,0}$, $Y_4\Lambda_4 \geq Y_0\Lambda_0$, the government's equilibrium effort satisfies $\rho_G^*(4) < \rho_G^*(0)$.

This corollary aligns with the paper's stage-evolution narrative. When the governance structure is dynamically reconfigured—such as strengthening the research team's control rights to sustain long-term R&D commitment, and enhancing social investors' control rights to improve market-oriented governance and resource integration—an increase in the synergy-bearing capacity of the research–capital side allows the consortium to sustain synergistic incremental gains with a lower level of governmental effort. This facilitates the transition from a construction stage to a market-oriented, autonomous, and sustainable operating stage.

4. Simulation Analysis

To further explore the characteristics of optimal equity-control rights allocation structure to enhance multiple *FPCRs* at different development stages, we analyze the influence of the equity-control ratio among multi-subjects on the innovation consortium benefit, the individual benefits and *FPCRs* by adjusting the equity-control ratios separately. As the importance of *RT* and *SI* will rise by the development of innovation consortium, and *GN*, as a supporting subject, will eventually withdraw from the innovation consortium, we will focus on *RT* and *SI* to analyze.

4.1. Parameter Design

The new R&D institutions is selected as the particular form of innovation consortia. Nanjing, Jiangsu Province is one of the cities where the construction of new R&D institutions has been carried out earlier and been of representative. So, we choose the new R&D institutions in Nanjing, Jiangsu Province in 2020 as the data source. Specifically, the initial values of simulation parameters are shown in Table 2. For notational convenience, within the same stage

we denote $a_{G,t}, a_{R,t}, a_{S,t}$ by a, b , and c , respectively. Besides, as all the new R&D institutions selected are “one share, one vote”, it is assumed that the control ratio of each subject corresponds to the respective equity ratio.

Table 2. Default Parameter Value

Y	aY	bY	cY	a	b	c	μ_i	ψ_i	ϕ_i
1057	106	634	317	8%	61%	31%	0.5	0.5	0.5

4.2. The Impact of Equity Allocation on Innovation Consortia

When the innovation consortium adopts “one share, one vote” ($n_1 = n_2 = n_3 = 1$), the larger the equity ratio of a certain subject, the stronger the control rights of that subject. Comparing the changing trends of FPCRs under equity-control rights restructuring, we can see that the difference in the equity ratio of each subject is consistent with the distribution of FPCRs. When a certain subject has absolute control rights, its FPCR will be much higher than that of other subjects, becoming the main contributor to the growth of innovation consortium benefit.

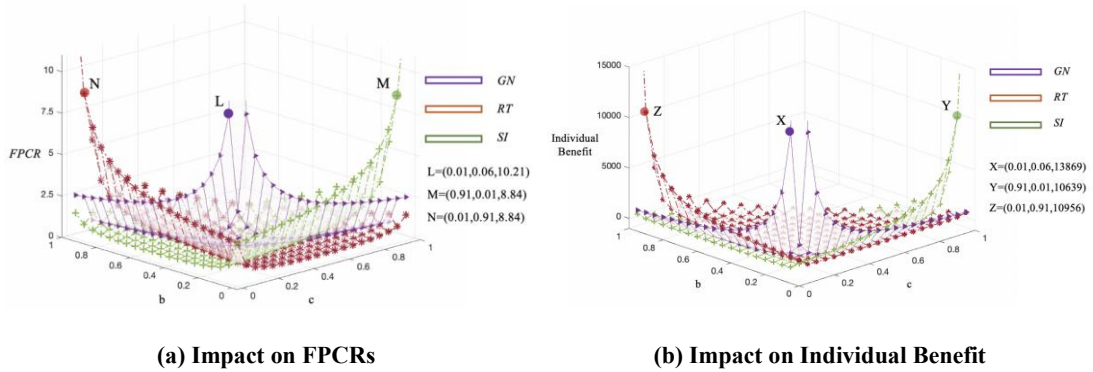


Figure 4. The impact of equity allocation on innovation consortia under “one share, one vote” situation

Meanwhile, as in Figure 4, it can be found that the changing trends of $FPCR$ s are consistent with that of individual benefits, i.e., the increase of each $FPCR$ is conducive to improving the value creation and distribution ability of each subject. Specifically, in “one share, one vote”, the individual benefits show the relationship of “ $RT > GN > SI$ ” in most cases, and only when GN or SI account for 90% equity ratios can they obtain the largest individual benefit. This also reflects that it is difficult to attract SI with relatively small equity ratio under “one share, one vote” situation, which reflects that the situation of “one share, one vote” is suitable for the initial construction development stage of innovation consortium dominated by GN .

4.3. The Impact of Control-Rights Allocation on Innovation Consortia

In this part, we focus on two scenarios to analyze: equity- B held by RT or equity- B held by SI , the results are shown in Table 3.

Table 3. Impact of equity-control rights restructuring on the innovation consortium

Control rights structure	Innovation consortium benefit	$FPCR-GN$	$FPCR-RT$	$FPCR-SI$
$n_1 = 1, n_2 = 1, n_3 = 1$	15836(A)	10.21(A)	2.59(A)	1.06(A)
	12400(B)	2.62(B)	0.93(B)	8.84(B)
	12400(C)	2.78(C)	8.84(C)	0.93(C)
	1603(D)	0.57(D)	1.59(D)	1.13(D)
$n_1 = 1, n_2 = 2, n_3 = 1$	9870(A)	7.65(A)	2.75(A)	0.79(A)
	6900(B)	1.87(B)	0.94(B)	6.31(B)
	40576(C)	3.54(C)	16.88(C)	1.25(C)
	2196(D)	0.65(D)	2.56(D)	1.29(D)
$n_1 = 1, n_2 = 3, n_3 = 1$	7987(A)	6.60(A)	2.90(A)	0.68(A)
	5069(B)	1.54(B)	0.95(B)	5.21(B)
	85850(C)	4.27(C)	24.93(C)	1.51(C)
	3048(D)	0.74(D)	3.52(D)	1.45(D)
$n_1 = 1, n_2 = 1, n_3 = 2$	8618(A)	7.29(A)	1.85(A)	1.07(A)
	40576(B)	3.54(B)	1.25(B)	16.88(B)
	6900(C)	1.87(C)	6.31(C)	0.94(C)
	1671(D)	0.53(D)	1.47(D)	1.48(D)
$n_1 = 1, n_2 = 1, n_3 = 3$	6292(A)	6.01(A)	1.53(A)	1.08(A)
	85850(B)	4.27(B)	1.51(B)	24.93(B)
	5069(C)	1.54(C)	5.21(C)	0.95(C)
	1831(D)	0.54(D)	1.49(D)	1.83(D)

Notes: The equity rights structure of Vertex A is “ $a=93\%$, $b=6\%$, $c=1\%$ ”, vertex B is “ $a=8\%$, $b=1\%$, $c=91\%$ ”, vertex C is “ $a=8\%$, $b=91\%$, $c=1\%$ ”, and vertex D is “ $a=8\%$, $b=61\%$, $c=31\%$ ”. The control rights structure “ $n_1=1, n_2=1, n_3=1$ ” is under the situation of “one share, one vote”, others are under the situation of “equal equity with dividend control rights”. Additionally, the black font represents the results under the situation of “one share, one vote”, the green font represents the values have fallen compared with the previous equity-control rights structure, while, the red font represents the values have risen compared with the previous ones, and the circled values are only to visualize the differentiation between various values.

When the equity rights structure is in an extreme situation (as at vertex A, B, and C), the subject in control only contributes to its own $FPCR$. However, when the equity rights structure is in a non-extreme situation (different from vertex A, B, and C), the situation of “large equity and multiple control held by RT ” and “large equity for RT with multiple control for SI ” can all contributes to the increase of each $FPCR$ and innovation consortium benefit, but in the situation of “large equity for RT with multiple control for SI ”, the control rights ratio of SI need to be

greater than a certain range to play the synergistic role (like $n_3 > 2$ in this simulation). Besides, the situation of “large equity for *RT* with multiple control for *SI*” has a marginal increasing effect on innovation consortium benefit (like the value at vertex D will increase from 1603 to 1671 and 1831 when n_3 is increasing), reflecting that *SI* can offset the negative impact on *FPCR*s of *GN* and *RT* through a significant increase in its own *FPCR*, then promoting the increase in innovation consortium benefit.

Further analysis is conducted by letting n_2 and n_3 take integer values from 1 to 11, respectively. We then examine, under different control-right configurations, the equity structure and the corresponding terminal values that maximize value in each stage. The resulting evolutionary patterns are illustrated in Figures 5

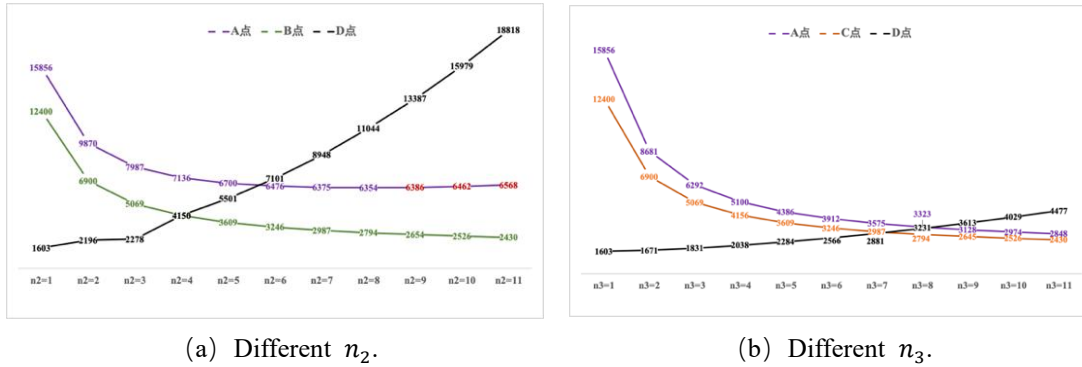


Figure 5. Effects of Control-Rights Allocation on Innovation Consortium Benefits

A comparison of Figures 5 indicates that, as the control rights of a given actor gradually increase, the stage-wise maximum value of the innovation consortium under stages dominated by the other actors generally exhibits a declining trend. In other words, increasing the control rights of the dominant actor in a given developmental stage helps enhance value creation in that stage, but it may hinder value realization by the remaining actors and impede stage transitions within the consortium. Notably, points A and D display heterogeneous responses to changes in actors' control rights.

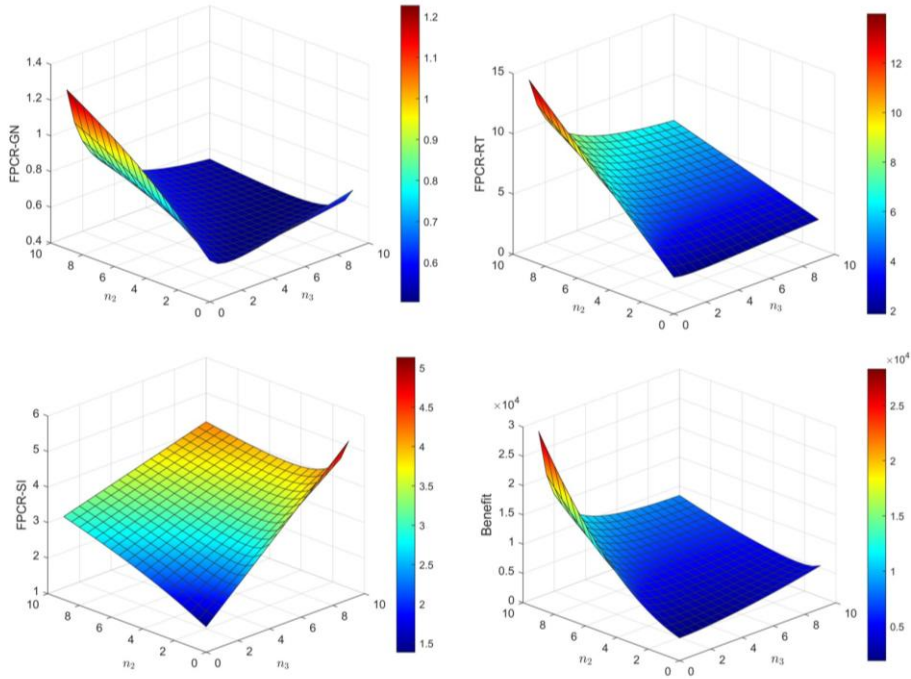
For point A, as n_2 increases, the value extremum of the consortium in Stage I first decreases and then increases. This suggests that when the scientific research talent team holds absolute control, adjusting the equity structure (e.g., increasing the equity share of the government sector) toward the extremum at point A can still improve value to some extent.

For point D ($a = 8\%$, $b = 61\%$, $c = 31\%$), its value increases with larger n_2 and n_3 , and the marginal value-enhancing effect of increasing n_2 is stronger. This result implies that the

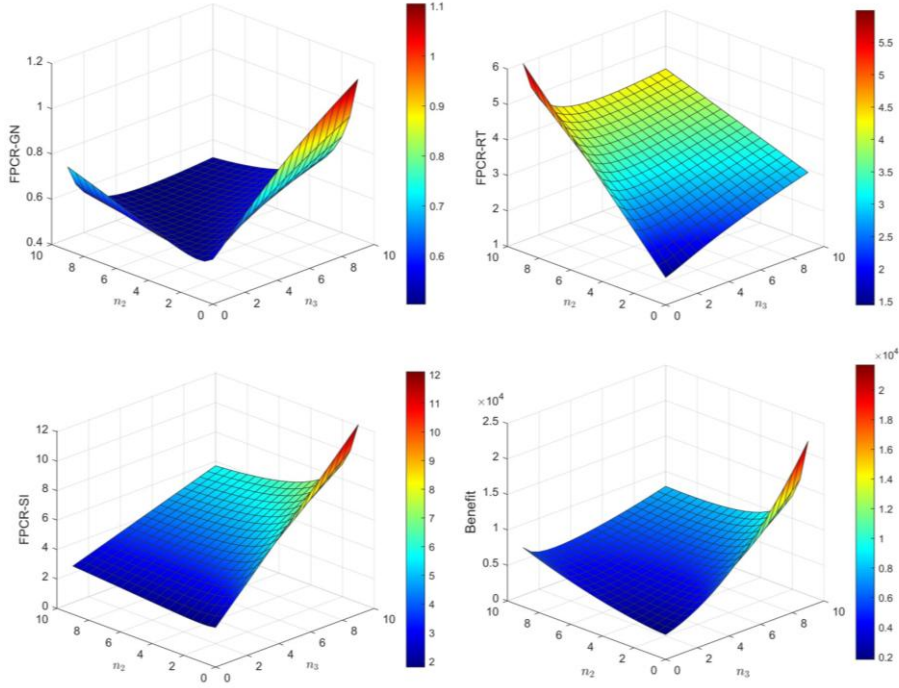
equity structure at point D ($a = 8\%$, $b = 61\%$, $c = 31\%$) is particularly suitable for scenarios in which the scientific research talent team holds control rights. Overall, these findings also provide indirect evidence for the existence of stage-specific optimal, differentiated configurations of equity and control rights across different phases of the innovation consortium's development.

4.4. The Impact of Control-Rights Allocation on Innovation Consortia under Different Development Stages.

Based on the above analysis, changes in the control-rights structure are shaped by the underlying equity structure. That is, different development stages call for distinct control-rights allocation mechanisms. Accordingly, we further examine the optimal control-rights configurations under RT-dominant and SI-dominant regimes, and the results are presented in Figure 6.



(a) Stage of RT-dominant ($b = 65\%$, $c = 30\%$)



(b) Stage of SI-dominant ($b = 35\%$, $c = 60\%$)

Figure 6. Control-Rights Allocation Across Different Development Stages.

Restructuring the control rights of RT and SI exerts heterogeneous effects on FPCRs and the overall benefit of the innovation consortium. For GN, except in the corner case $n_2 = 10$ and $n_3 = 10$, holding one of n_2 or n_3 fixed leads GN's FPCR to exhibit a U-shaped pattern as the other actor's control-rights ratio increases. For RT and SI, their FPCRs also display U-shaped responses to increases in the counterpart's control-rights ratio, while rising monotonically with increases in their own control-rights ratio. Moreover, as a given actor's control-rights ratio and equity share increase jointly, the consortium's total benefit can exhibit a discrete jump once that actor achieves absolute dominance.

A relative disparity equity rights structure can amplify the impact of the control right on the FPCRs. For example, for the FPCR of GN, the smaller the difference in the equity ratio between RT and SI, the smaller the maximum value of the FPCR of GN. For RT and SI, the smaller the equity ratio of GN, the maximum value of FPCR of RT and SI will achieve varying degrees of growth, and the acquisition of residual equity rights by SI has a greater impact on benefit growth of innovation consortium than GN.

5. Conclusions and Management Implications

5.1. Conclusions

In summary, we focus on the effect of equity-control rights restructuring on each *FPCR* and the interaction relationship between *FPCRs*, to explore the optimal equity-control rights allocation structure for achieving innovation synergy among multi-subjects within the innovation consortium. The main findings are shown below.

(1) The trends in individual benefits and innovation consortium benefit under different equity-control rights allocation structures are a reflection of the abilities of each subject to capture and allocate the collaboration surplus value according to specific equity-control rights allocation structure. The changing trend in each *FPCR* coincides with each individual benefit. Moreover, the change in innovation consortium benefit is a reflection of innovation efficiency synergy among multi-subjects.

(2) There are differences in the impact of equity rights and control rights restructuring on each *FPCR*, as equity rights are a direct regulatory tool, while control rights will positively regulate under a reasonable equity rights structure. Specifically, adjusting the equity ratio of one subject can directly increase its *FPCR*. A relative disparity equity rights structure has a stronger effect on increasing *FPCRs*, and can amplify the impact of control rights restructuring on *FPCRs*. However, if the equity rights structure remains unchanged, increasing the control ratio of one subject alone is likely to produce a crowding-out effect on the other *FPCRs*.

(3) The asymmetrical allocation structure of “large equity for *RT* with multiple control for *SP*” can contribute to maximizing the innovation potential of *SI* and accelerate the growth of innovation consortium benefit, which is helpful to realize the independent operation and sustainable development. And a reduction in equity ratio of *GN* will help to increasing the *FPCRs* of *RT* and *SI*.

5.2. Management Implications

To further stimulate the efficiency of scientific and technological innovation of innovation consortia, the suggestions are proposed as follow:

(1) Improve equity-control rights allocation and incentive mechanisms. To encourage social capital and other market-based resources to enter the innovation consortium, it is necessary to ①explore a practical equity-control rights separation mechanism to optimize the

asymmetric allocation structure of equity and control rights, to broaden the input sources of operating capital and market-based resources in the innovation consortium; ②improve the benefit distribution and talent incentive mechanism among multiple innovation subjects, to regulate the trade-off relationships between the individual benefits of different subjects and between individual benefit and organization benefit, and guide multiple innovation subjects to collaborate in innovation and enhance both individual and organization benefits.

(2) Establishing a sound market-based profit-making mechanism and an orderly exit mechanism for *GN*. As for the market-oriented profit mechanism, on the one hand, it is necessary to actively explore the establishment of a profit model that is assisted by financial funds, led by enterprise and project funds and technical service revenue, and supplemented by investment income, to realize the transition from government "blood transfusion" to industrial "blood creation". On the other hand, the innovation consortium technology transfer methods should be broadened. In addition to the innovation achievement transformation, technology services and transactions, and the valuation of patented technology as a means of equity investment, it should support independent entrepreneurship of scientific researchers, promote the free flow of personnel, technology, and funds between universities, research institutes, and the innovation consortium, to realize the full integration and utilization of various innovation factors.

(3) Actively exploring the clustering of advantageous innovation factors and diversified financing mechanisms in the innovation consortium. For the innovation factor clustering mechanism, on the one hand, cross-regional cooperation alliances can be established with technology transfer institutions, entrepreneurship incubation institutions, and other technological innovation platforms to leverage the advantages of cross-regional linkage between different *GNs*, achieve cross-park and cross-cluster innovation cooperation and achievement transfer and transformation, to achieve the agglomeration of advantageous innovation resources within and outside the innovation consortium. On the other hand, by establishing the mechanism for information sharing among different innovation subjects and building a corresponding information disclosure platform, cooperation and communication can be strengthened among *GN*, enterprises, new R&D institutions, universities and institutes, industry associations, and other internal and external subjects of the innovation consortium, to

enhance the efficiency of the innovation consortium in accessing and utilizing key innovation resources.

(4) For the diversified financing mechanism, on the one hand, angel funds and venture capital funds can be established through the joint investment involving GN , investment institutions, and leading enterprises to support the construction and operation of the innovation consortium, thus forming a diversified financing system with the joint participation of social capital and state-owned capital under market orientation. On the other hand, the promotion of financing support policies can also be further enhanced by leveraging the role of GN as a bridge among debt institutions, equity financing institutions, and innovation consortium. In addition, the guidance for the participation of social capital and the support for the construction and operation of an innovation consortium can be enhanced through the establishment of an innovative consortium financing guarantee platform and the improvement of access assessment and credit risk assessment mechanisms for innovative consortium financing.

Appendix

(1) Proof of Lemma 1

Then the government's payoff as a function of $\rho_G(t)$ can be written as

$$\begin{aligned}\Pi_{G,t}(\rho_G(t)) &= a_{G,t}Y_t + \omega_{G,t}Y_t V(\rho_G(t)\kappa_R(t)\eta_S(t), a_{i,t}, \omega_{i,t}) - \frac{1}{2}(\mu_1\rho_G(t))^2 \\ &= a_{G,t}Y_t + (\omega_{G,t}Y_t\Lambda_t\kappa_R(t)\eta_S(t))\rho_G(t) - \frac{1}{2}\mu_G\rho_G(t)^2\end{aligned}\tag{A.1}$$

where, $\Lambda_t = e^{\psi_i a_{i,t}} e^{\phi_i \omega_{i,t}}$, Hence, $\frac{\partial \Pi_{G,t}}{\partial \rho_G(t)} = \omega_{G,t}Y_t\Lambda_t\kappa_R(t)\eta_S(t) - \mu_G\rho_G(t)$, $\frac{\partial^2 \Pi_{G,t}}{\partial \rho_G(t)^2} = -\mu_G < 0$.

Therefore, $\Pi_{G,t}$ is strictly concave in $\rho_G(t)$, implying a unique best response for G given

$(\kappa_R(t), \eta_S(t))$. Analogously, $\frac{\partial^2 \Pi_{R,t}}{\partial \kappa_R(t)^2} = -\mu_R < 0$, $\frac{\partial^2 \Pi_{S,t}}{\partial \eta_S(t)^2} = -\mu_S < 0$

So the best responses of R and S are also unique.

The first-order conditions yield the following best-response equations:

$$\begin{aligned}\omega_{G,t}Y_t\Lambda_t\kappa_R(t)\eta_S(t) - \mu_G\rho_G(t) &= 0 \Rightarrow \rho_G(t) = A_{G,t}\kappa_R(t)\eta_S(t), \\ \omega_{R,t}Y_t\Lambda_t\rho_G(t)\eta_S(t) - \mu_R\kappa_R(t) &= 0 \Rightarrow \kappa_R(t) = A_{R,t}\rho_G(t)\eta_S(t), \\ \omega_{S,t}Y_t\Lambda_t\rho_G(t)\kappa_R(t) - \mu_S\eta_S(t) &= 0 \Rightarrow \eta_S(t) = A_{S,t}\rho_G(t)\kappa_R(t),\end{aligned}\tag{A.2}$$

Where, $A_{i,t} \equiv \frac{\omega_{i,t}Y_t\Lambda_t}{\mu_i} > 0, i \in \{G, R, S\}$. Multiplying the three reaction equations gives

$$\begin{aligned}
\rho_G(t)\kappa_R(t)\eta_S(t) &= (A_{G,t}\kappa_R(t)\eta_S(t))(A_{R,t}\rho_G(t)\eta_S(t))(A_{S,t}\rho_G(t)\kappa_R(t)) \\
&= (A_{G,t}A_{R,t}A_{S,t})(\rho_G(t)\kappa_R(t)\eta_S(t))^2
\end{aligned} \tag{A.3}$$

For an interior positive solution, $\rho_G(t)\kappa_R(t)\eta_S(t) > 0$, so dividing both sides by $\rho_G(t)\kappa_R(t)\eta_S(t)$ yields $\rho_G(t)\kappa_R(t)\eta_S(t) = \frac{1}{A_{G,t}A_{R,t}A_{S,t}}$.

Using $\rho_G(t) = A_{G,t}\kappa_R(t)\eta_S(t)$ and the identity $\kappa_R(t)\eta_S(t) = \frac{\rho_G(t)\kappa_R(t)\eta_S(t)}{\rho_G(t)}$, we obtain $\rho_G(t) = A_{G,t} \frac{\rho_G(t)\kappa_R(t)\eta_S(t)}{\rho_G(t)}$, therefore,

$$\rho_G(t)^2 = A_{G,t}(\rho_G(t)\kappa_R(t)\eta_S(t)) = A_{G,t} \cdot \frac{1}{A_{G,t}A_{R,t}A_{S,t}} = \frac{1}{A_{R,t}A_{S,t}} \tag{A.4}$$

Taking the positive root (since we focus on the interior positive equilibrium) yields $\rho_G^*(t) = \frac{1}{\sqrt{A_{R,t}A_{S,t}}}$.

By symmetry of the argument, $\kappa_R^*(t) = \frac{1}{\sqrt{A_{G,t}A_{S,t}}}$, $\eta_S^*(t) = \frac{1}{\sqrt{A_{G,t}A_{R,t}}}$.

Because $A_{i,t} > 0$, these equilibrium effort levels are strictly positive, establishing existence of a positive interior equilibrium.

Any interior positive equilibrium must satisfy

$$\rho_G(t)^2 = \frac{1}{A_{R,t}A_{S,t}}, \kappa_R(t)^2 = \frac{1}{A_{G,t}A_{S,t}}, \eta_S(t)^2 = \frac{1}{A_{G,t}A_{R,t}} \tag{A.5}$$

Since the right-hand sides depend only on the primitives $\{A_{G,t}, A_{R,t}, A_{S,t}\}$, all interior equilibria share the same squared values. Imposing positivity uniquely pins down $\rho_G^*(t)$, $\kappa_R^*(t)$, and $\eta_S^*(t)$. Hence, the interior equilibrium is unique.

Using $\omega_{i,t} = \frac{n_{i,t}a_{i,t}}{S_t}$ and $A_{i,t} = \frac{\omega_{i,t}Y_t\Lambda_t}{\mu_i}$, we can write

$$A_{i,t} = \frac{Y_t\Lambda_t}{\mu_i} \cdot \frac{n_{i,t}a_{i,t}}{S_t} \tag{A.6}$$

Substituting into $\rho_G^*(t) = 1/\sqrt{A_{R,t}A_{S,t}}$ (and analogously for $\kappa_R^*(t)$ and $\eta_S^*(t)$) and simplifying yields the fully expanded closed-form expressions stated in Lemma 1:

$$\begin{aligned}
\rho_G^*(t) &= \frac{\sqrt{\mu_R\mu_S}}{Y_t\Lambda_t} \cdot \frac{S_t}{\sqrt{(n_{R,t}a_{R,t})(n_{S,t}a_{S,t})}}, \\
\kappa_R^*(t) &= \frac{\sqrt{\mu_G\mu_S}}{Y_t\Lambda_t} \cdot \frac{S_t}{\sqrt{(n_{G,t}a_{G,t})(n_{S,t}a_{S,t})}}, \\
\eta_S^*(t) &= \frac{\sqrt{\mu_G\mu_R}}{Y_t\Lambda_t} \cdot \frac{S_t}{\sqrt{(n_{G,t}a_{G,t})(n_{R,t}a_{R,t})}}
\end{aligned} \tag{A.7}$$

This completes the proof.

(2) Proof of Proposition 1

Using the ω -based closed-form solutions in Lemma 1,

$$\rho_G^*(t) = \frac{\sqrt{\mu_R \mu_S}}{Y_t \Lambda_t \sqrt{\omega_{R,t} \omega_{S,t}}}, \kappa_R^*(t) = \frac{\sqrt{\mu_G \mu_S}}{Y_t \Lambda_t \sqrt{\omega_{G,t} \omega_{S,t}}} \quad (\text{A.8})$$

Taking their ratio gives

$$\frac{\rho_G^*(t)}{\kappa_R^*(t)} = \sqrt{\frac{\mu_R}{\mu_G}} \sqrt{\frac{\omega_{G,t}}{\omega_{R,t}}} \quad (\text{A.9})$$

The other two ratios follow immediately by dividing the corresponding closed-form expressions.

(3) Proof of Proposition 2

Let $S_t = \sum_{i \in \{G, R, S\}} n_{i,t} a_{i,t} \omega_{i,t} = \frac{n_{i,t} a_{i,t}}{S_t}$.

Using the closed-form equilibrium payoffs in Proposition 1 (equivalently, substituting the ω -based expressions together with the definition of ω), take the research team R as an example:

Starting from

$$\Pi_{R,t} = a_{R,t} Y_t + (\omega_{R,t} Y_t \Lambda_t \rho_G(t) \eta_S(t)) \kappa_R(t) - \frac{1}{2} \mu_R \kappa_R(t)^2 \quad (\text{A.10})$$

we take the derivative with respect to $\kappa_R(t)$:

$$\frac{\partial \Pi_{R,t}}{\partial \kappa_R(t)} = \omega_{R,t} Y_t \Lambda_t \rho_G(t) \eta_S(t) - \mu_R \kappa_R(t) \quad (\text{A.11})$$

Setting it equal to zero yields, we have,

$$\mu_R \kappa_R(t) = \omega_{R,t} Y_t \Lambda_t \rho_G(t) \eta_S(t) \quad (\text{A.12})$$

Multiplying both sides by $\kappa_R(t)$, we obtain

$$\mu_R \kappa_R(t)^2 = \omega_{R,t} Y_t \Lambda_t \rho_G(t) \kappa_R(t) \eta_S(t) \quad (\text{A.13})$$

Note that $\Lambda_t \rho_G(t) \kappa_R(t) \eta_S(t)$ is exactly V_t . Hence, $\mu_R \kappa_R(t)^2 = \omega_{R,t} Y_t V_t$.

Therefore,

$$\begin{aligned} \Pi_{R,t}^* &= a_{R,t} Y_t + \omega_{R,t} Y_t V_t^* - \frac{1}{2} (\omega_{R,t} Y_t V_t^*) = a_{R,t} Y_t + \frac{1}{2} \omega_{R,t} Y_t V_t^* \\ &= a_{R,t} Y_t + \frac{1}{2} \cdot \frac{\mu_G \mu_R \mu_S}{Y_t^2 \Lambda_t^2} \cdot \frac{1}{\omega_{G,t} \omega_{S,t}} \end{aligned} \quad (\text{A.14})$$

Note that

$$\omega_{G,t} \omega_{S,t} = \frac{(n_{G,t} a_{G,t})(n_{S,t} a_{S,t})}{S_t^2} \Rightarrow \frac{1}{\omega_{G,t} \omega_{S,t}} = \frac{S_t^2}{(n_{G,t} a_{G,t})(n_{S,t} a_{S,t})} \quad (\text{A.15})$$

Hence,

$$\Pi_{R,t}^* = a_{R,t} Y_t + \frac{1}{2} \cdot \frac{\mu_G \mu_R \mu_S}{Y_t^2 \Lambda_t^2} \cdot \frac{S_t^2}{(n_{G,t} a_{G,t})(n_{S,t} a_{S,t})} \quad (\text{A.16})$$

Given $a_{i,t}$ and $n_{G,t}, n_{S,t}$, increasing $n_{R,t}$ affects the second term only through S_t , and $\frac{\partial S_t}{\partial n_{R,t}} = a_{R,t} >$

0. Therefore,

$$\frac{\partial \Pi_{R,t}^*}{\partial n_{R,t}} = \frac{1}{2} \cdot \frac{\mu_G \mu_R \mu_S}{Y_t^2 \Lambda_t^2} \cdot \frac{2S_t}{(n_{G,t} a_{G,t})(n_{S,t} a_{S,t})} \cdot a_{R,t} > 0 \quad (\text{A.17})$$

This establishes self-interested monotonicity for $k = R$. The cases $k = G$ and $k = S$ follow analogously.

Consider $k = R$ affecting the government's equilibrium payoff. By Proposition 1,

$$\Pi_{G,t}^* = a_{G,t} Y_t + \frac{1}{2} \cdot \frac{\mu_G \mu_R \mu_S}{Y_t^2 \Lambda_t^2} \cdot \frac{1}{\omega_{R,t} \omega_{S,t}} \quad (\text{A.18})$$

Similarly, $\frac{1}{\omega_{R,t} \omega_{S,t}} = \frac{S_t^2}{(n_{R,t} a_{R,t})(n_{S,t} a_{S,t})}$. Define a positive constant $K_t = \frac{1}{2} \cdot \frac{\mu_G \mu_R \mu_S}{Y_t^2 \Lambda_t^2} \cdot \frac{1}{(n_{S,t} a_{S,t})} > 0$. So that

$$\Pi_{G,t}^* = a_{G,t} Y_t + K_t \cdot \frac{S_t^2}{n_{R,t} a_{R,t}} \quad (\text{A.19})$$

Taking the log-derivative with respect to $n_{R,t}$,

$$\frac{\partial \ln (S_t^2 / n_{R,t})}{\partial \ln n_{R,t}} = 2 \frac{\partial \ln S_t}{\partial \ln n_{R,t}} - 1 \quad (\text{A.20})$$

Now $\frac{\partial \ln S_t}{\partial \ln n_{R,t}} = \frac{n_{R,t}}{S_t} \cdot \frac{\partial S_t}{\partial n_{R,t}} = \frac{n_{R,t}}{S_t} \cdot a_{R,t} = \frac{n_{R,t} a_{R,t}}{S_t} = \omega_{R,t}$.

Hence, $\text{sgn} \left(\frac{\partial \Pi_{G,t}^*}{\partial n_{R,t}} \right) = \text{sgn} (2\omega_{R,t} - 1)$. Applying the same argument to $\Pi_{S,t}^*$ (its relevant term also contains $n_{R,t}$ in the denominator and S_t in the numerator, with the same $\partial S_t / \partial n_{R,t}$) yields the identical threshold-sign conclusion. Replacing R by an arbitrary k gives the general statement: $\text{sgn} \left(\frac{\partial \Pi_{j,t}^*}{\partial n_{k,t}} \right) = \text{sgn} (2\omega_{k,t} - 1), j \neq k$.

This completes the proof.

(4) Proof of Proposition 3

From Lemma 1, the closed-form equilibrium for the government's effort can be written as $\rho_G^*(t) =$

$\frac{\sqrt{\mu_R \mu_S}}{Y_t \Lambda_t \sqrt{\omega_{R,t} \omega_{S,t}}}$. Differentiating with respect to $\omega_{R,t}$ yields $\frac{\partial \rho_G^*(t)}{\partial \omega_{R,t}} = -\frac{1}{2} \cdot \frac{\sqrt{\mu_R \mu_S}}{Y_t \Lambda_t} \cdot \frac{1}{\omega_{R,t}^{3/2} \sqrt{\omega_{S,t}}} < 0$, and the

derivative with respect to $\omega_{S,t}$ is also negative by symmetry. The remaining inequalities follow analogously by differentiating the corresponding closed-form expressions in Lemma 1.

(5) Proof of Corollary 1

By Lemma 1 (in the ω -based closed form), for any $t \in \{0, 4\}$, $\rho_G^*(t) = \frac{\sqrt{\mu_R \mu_S}}{Y_t \Lambda_t \sqrt{\omega_{R,t} \omega_{S,t}}}$. Hence, the ratio

of equilibrium government efforts across the two stages is

$$\frac{\rho_G^*(4)}{\rho_G^*(0)} = \frac{\sqrt{\mu_R \mu_S}}{Y_4 \Lambda_4 \sqrt{\omega_{R,4} \omega_{S,4}}} / \frac{\sqrt{\mu_R \mu_S}}{Y_0 \Lambda_0 \sqrt{\omega_{R,0} \omega_{S,0}}} = \frac{Y_0 \Lambda_0}{Y_4 \Lambda_4} \cdot \sqrt{\frac{\omega_{R,0} \omega_{S,0}}{\omega_{R,4} \omega_{S,4}}} \quad (\text{A.21})$$

Because $\omega_{R,4}\omega_{S,4} > \omega_{R,0}\omega_{S,0}$, we have $\sqrt{\frac{\omega_{R,0}\omega_{S,0}}{\omega_{R,4}\omega_{S,4}}} < 1$. Under the comparability condition $Y_4\Lambda_4 \geq Y_0\Lambda_0$, it follows that $\frac{Y_0\Lambda_0}{Y_4\Lambda_4} \leq 1$. Combining the two inequalities yields $\frac{\rho_G^*(4)}{\rho_G^*(0)} = \frac{Y_0\Lambda_0}{Y_4\Lambda_4} \cdot \sqrt{\frac{\omega_{R,0}\omega_{S,0}}{\omega_{R,4}\omega_{S,4}}} < 1$, and therefore $\rho_G^*(4) < \rho_G^*(0)$. This completes the proof.

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