The Impact of Enterprise Knowledge Sharing on the Supply Model of Key Core Technology

Baolin Li, Zetao Hu, Shengqiang Huang and Lihua Yang

Abstract—**From the perspective of the innovation value chain and guided by the need to achieve sustained breakthroughs in major science and technology in China, this paper establishes four types of Stackelberg game models dominated by the government or the market and investigates the impact of knowledge sharing of innovative enterprises on the efficiency of supplying key core technologies and the impact of decision-making of each innovative entity on the supplying model. The results obtained show that the sharing of private knowledge by innovative enterprises can increase the benefits of the innovation value chain in the new national system model, while knowledge sharing can impair the benefits of innovative enterprises and increase the benefits of the innovation value chain in the industrial technology alliance model in the three market-dominated models. Meanwhile, innovative enterprises are not willing to share knowledge, and a knowledge compensation mechanism can increase the knowledge sharing willingness of innovative enterprises in scenarios with double-low accuracy in the potential value prediction of technological knowledge and the price of technology introduction. Additionally, the choice of knowledge sharing strategy and academic research institution supply model strategy of innovative enterprises depends on the accuracy of potential value prediction of technological knowledge, the price of technology introduction, and the cost saving of re-research institutions.**

Index Terms—**Key core technologies, knowledge sharing, collaborative innovation, supply model, innovation value chain**

I. Introduction

THE report of the 20th National Congress of the Communist Party of China puts forward that 'We should take the national strategic needs as the guidance, improve the ability of independent innovation, strengthen the capability of original leading scientific and technological research, and win the battle of key core technologies'. Currently, many industries in China have weak basic and sustainable R&D capabilities, and they cannot guarantee the safety of the industrial chain and the technology chain in the face of technological blockades by established developed countries. Key core technologies can effectively enhance the industrial chain, cultivate collaborative innovation ecology, and develop technology applications [1]. However, the key core technology is mainly characterized by high barriers to knowledge structures, high investment of innovation resources, long-term R&D processes, and systematic breakthrough mechanisms [2]. Only by focusing on the coordination of innovation entities such as government, industry, academia and research can we ensure the efficient circulation of technical knowledge in the innovation chain and achieve high-quality breakthroughs in key core technologies [3].

The key core technology is composed of key technology and core technology, where the former emphasizes the importance of industrial technology development, while the latter emphasizes the dominant position of national technology. The academic research on key core technologies mainly focuses on macro issues such as connotation definition [2], measurement identification [4], supply model [5], and breakthrough path [6]. With the improvement of China's basic research and the enhancement of development capabilities, the technology catch-up theory no longer meets the practical needs of key core technology breakthroughs. The key core technology is a highly complex collection of technical knowledge, so it is necessary for the innovation entity to deeply integrate and co-evolve the knowledge [7]. Some researchers have paid attention to innovative entities such as governments, colleges, research institutions, and enterprises [8], and collaborative models such as 'government-industry-university-research' and a new national system have been proposed to enhance the interaction efficiency of complex knowledge to achieve sustainable innovation of key core technologies [9]. At present, research mainly focuses on the contributing factors of knowledge sharing [10] and value realization [11]. There is little investigation on how knowledge sharing affects the decision-making of innovation entities in the process of key core technology research and development from a micro perspective.

This paper introduces the theory of innovation value chain and leverages the flow of value to show the flow of knowledge, thereby demonstrating the R&D process of each entity in the key core technology collaborative innovation model in more detail. Currently, there are four mainstream key core technology innovation models in China [5,9]. Among them,

Manuscript received September 19, 2023. revised March 13, 2024.

This work was supported by the Humanities and Social Sciences Planning Fund of the Ministry of Education of China under Grant 23YJAZH060, the Education Planning Project of Hubei Province under Grant 2023GB111 and Doctoral Research Foundation by Hubei University of Automotive Technology under Grant BK202109.

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the Stackelberg game model can better reflect the strategic response of the leader under the collaborative innovation model and other entities under different models. Considering the complexity of key core technology collaborative innovation and knowledge leakage, a knowledge sharing compensation mechanism is established via a strategic game to change the sharing willingness of enterprises to improve the synergy between innovation entities. The main contributions of this paper include providing a new research perspective on key core technology breakthroughs by taking knowledge sharing as an entry point in response to the real needs of key core technologies in China, and providing guidance for each innovation entity in the innovation value chain to choose the appropriate key core technology supply model while focusing on collaborative innovation.

II. Literature Review and Problem Description

A. Background of Relevant Literature

Currently, the development of key core technologies in high-end manufacturing such as chips, aerospace, and new energy vehicles in China is slow, and there are problems such as low input-output ratio and insufficient utilization of innovative resources [12]. This paper introduces the two-stage innovation value chain theory and systematically investigates how to efficiently integrate innovation elements to achieve breakthroughs in key core technologies. Hansen and Birkinshaw [13] integrated the innovation process with the value chain, established the "innovation value chain model", and proposed the theory of the innovation value chain. Hong [14] believed that the technological innovation chain starts with knowledge innovation and ends with technological industrialization. The total value obtained by technological innovation is the result of the innovation chain. Xu *et al.* [15] considered that enterprise technological innovation is the process of realizing the "innovation value chain", and knowledge transfer can have a significant impact on the innovation value chain. Based on the above analysis, the key to enhancing innovation efficiency lies in factor integration. By systematically investigating the process of factor integration from the perspective of the innovation value chain, the complex environment of collaborative breakthroughs in key core technologies can be effectively simulated.

Knowledge sharing is a process of knowledge transferring involving different entities [10], and knowledge exchange can effectively improve the core competitiveness of the innovation value chain [16]. Still, it requires efficient collaboration among innovation entities. Essentially, collaborative innovation is a process of absorbing and transforming explicit and tacit knowledge [17], and high-level knowledge sharing is usually accompanied by efficient collaborative innovation. From the perspective of industry-university-research interaction, Meng *et al.* [18] pointed out that knowledge absorptive capacity is an important factor for innovation entities to improve collaborative interaction and innovation performance. Through empirical analysis, Shujahat *et al.* [19] found that knowledge workers' knowledge creation and utilization ability significantly affects innovation performance. Keszey [20] considered that the more complex the external environment is, the more dependent the organization is on continuous knowledge sharing to facilitate responsive decision-making. In collaborative innovation, knowledge sharing is mainly manifested in the effective transfer and utilization of information [21], and the key technical information is sorted out to form knowledge [22]. This integrated knowledge can reduce the differences in management and technology among innovation entities and then improve innovation ability [23]. To sum up, the current research mainly focuses on the integration effect of knowledge sharing on innovation elements, and few studies have been conducted on the impact of knowledge sharing on the decision-making of each entity in the innovation value chain.

The previous technology catch-up strategy in China is mainly based on technology introduction, and enterprise capital is mainly based on technology utilization [24]. Zhang *et al.* [25] considered that technology research and development mainly have two paths: independent research and development and technology introduction. The former focuses on long-term interests, while the latter is conducive to short-term achievement transformation. Rosiello and Malek [26] found that the complexity and diversity of the industrial knowledge base increase the industrial access threshold by tracking the energy industry. Long-term technology introduction will weaken the independent innovation ability of the industry, which is not conducive to the formation of core competitiveness [27]. The technical route of technology introduction, absorption, and re-innovation can be adopted to realize the independent research and development of key core technologies [28]. Currently, most of the research investigates the impact of the supply model and R&D path on the breakthrough of key core technologies at the macro level. However, few studies have examined how inter-enterprise knowledge sharing affects innovative enterprises' selection of appropriate key core technology supply modes at the micro level.

The innovations of this paper are summarized as follows: (1) Taking knowledge sharing as the starting point, from the perspective of the innovation chain, the collaborative relationship of each entity in the key core technology innovation model is simulated, and the interaction of knowledge in the collaborative innovation model is represented by the flow of value. (2) Based on China's mainstream key core technology collaborative innovation model, four Stackelberg game models dominated by government or market are established to investigate the decision-making choices between technological innovation leaders and non-leaders in the context of collaboration. (3) Knowledge sharing is deconstructed into knowledge absorption and transformation, and how the absorption and transformation ability of each innovation entity affects the strategic choice of collaborative innovation of key core technologies is considered.

B. Problem Description

It is assumed that the innovation value chain consists of three parties: academic research institutions (represented as

AR in the following mathematical formulas), innovative enterprises, and downstream enterprises. To break through a key core technology, academic research institutions can adopt not only independent innovation (referred to as self-innovation) but also technology introduction, absorption, and re-innovation (referred to as re-innovation). After the transformation of innovative enterprises, the technological breakthroughs made by academic research institutions will overflow the technological achievements to the downstream enterprises. The existing key core technology cooperation supply models mainly include the new national system with strong government intervention and state-owned innovative enterprises as the pillar, the core enterprise leadership model with the leading enterprises in the industry, the industrial technology alliance with the docking of academic research institutions and enterprise achievements, as well as the non-profit organization leading model with the participation of third-party technology suppliers. Ge and Zheng *et al.* [5, 9] employed a similar analysis method to compare the three market-oriented supply models with the new government-led national system. The above models have been widely used in the research and development of key core technologies in China, such as manned space flight, high-end chips, and other cutting-edge fields with a new national system of strong government intervention. Artificial intelligence, virtual reality and other digital fields usually adopt a market-oriented cooperative research and development model. The relationship between the entities is shown in Fig. 1:

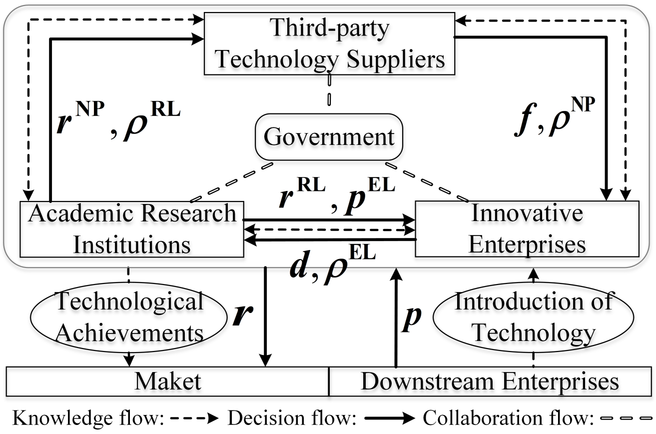

Fig. 1. Four key core technology supply modes.

C. Symbol Definition and Model Assumptions

The main symbols used in this paper and their meanings are listed in TABLE I. Some basic assumptions made for the model are given below:

Assumptions 1: The independent innovation of academic research institutions has a greater cost than re-development. Since the product is the carrier of technology, the R&D cost and expenses in this study refer to the technical cost and expenses apportioned to a single product, and there is no inventory [30]. Let $\Delta = c_1 - c_2$ denote the unit cost saving from re-innovation compared to self-innovation, and $\Delta > r$ (abbreviation for cost-saving).

Assumptions 2: Due to the high barriers of key core technology research and development, multi-industry and multi-domain subjects need to collaborate in research and development, and there is an asymmetric game. In terms of basic ability, academic research institutions are leaders in the innovation value chain, and innovative enterprises and third-party technology suppliers are followers.

TABLE I
DESCRIPTION OF THE SYMBOLS

Symbol	Description
c_1	Self-innovation cost of academic research institution.
c_2	Re-innovation cost of academic research institution.
f	The technology transfer price charged by the innovative enterprise to the downstream enterprise.
Δ	Unit cost of re-innovation saving, $\Delta = c_1 - c_2$.(Cost saving)
d	The technology development price charged by the academic research institution to the innovative enterprises.
$N(f)$	Demand function of technology, $N(f) = a - bf$.
a	Potential demand of market.
b	Sensitivity coefficient of value.
ρ	Proportion of technology introduction.
s	Input cost of technology introduction.
I	Effort cost of technology introduction.
r	The technology introduction price charged by academic research institutions to innovative enterprises or third-party technology suppliers [29].
p	Predictive accuracy of technology value.
E_{ik}^{j}	Profit function of subject *i* under model *j* in scenario *k*.
V_{ik}^{j}	Value function of subject *i* under model *j* in scenario *k*.
$\forall_{i}^{j}$	Value added function of subject *i* under model *j* in scenario *k*.
i	The subscript *i* denotes innovative enterprises, academic research institutions, third-party technology supplier and innovation value chains, $i = \mathrm{IE}, \mathrm{AR}, \mathrm{TS}, \mathrm{IC}$.
j	The superscript *j* denotes the model of technology supply, which are the new national system, core enterprise leadership, industrial technology alliance and non-profit institution, $j = \mathrm{GL}, \mathrm{EL}, \mathrm{RL}, \mathrm{NP}$.
k	The superscript *k* denotes knowledge sharing by innovation enterprise, N denotes no application, and Y denotes application.

Assumptions 3: The forecast information ζ of the potential value of the technical knowledge of the innovative enterprise is its private knowledge, while the market potential value and the remaining information is the common knowledge of each innovative entity. $\zeta = a + \varepsilon$ denotes the predicted potential value of private knowledge, where ε represents the error term with an expectation of 0 and a variance of ψ . The potential value of new technology $a = a_0 + \mu$ is a random variable, which denotes the demand determination part, and the uncertainty factor μ is a random function with an expectation of 0 and a variance of φ. Among them, the random variables μ and ε are independent of each other. Referring to the previous studies of Li [31] and Luan [32], we have:

$$E(a \mid \zeta) = \frac{\varphi}{\varphi + \psi} a_0 + \frac{\varphi}{\varphi + \psi} \zeta \quad (1)$$

$$E((\zeta - a_0)^2) = \varphi + \psi \quad (2)$$

$p = \varphi / (\varphi + \psi)$, $p \in (0,1)$ is used to measure the prediction accuracy of the potential value of technical knowledge (Abbreviation for pre-accuracy). The greater the value, the more accurate the prediction of innovative enterprises, and the stronger the ability to transform information. On the contrary, the smaller the value, the greater the error, and the weaker the transformation ability.

Assumptions 4: Re-innovation requires much capital investment, and the higher the substitution effect of imported technology on new technology, the higher the cost will be [33]. Referring to the research of Savaskan and Van Wassenhove [34], let $\rho = \sqrt{I/s}$, where s denotes the investment cost coefficient of technology introduction, and I denotes the investment cost of technology introduction.

Assumptions 5: Let the knowledge transfer cost of technology importer be ω_1 and the unit cost of technological achievement spillover of innovative enterprises be ω_2, and both are constants. Referring to related research, to simplify the model derivation and ensure the generality of the results, let $\omega_1 = \omega_2 = 0$ (without affecting the derivation results) [34].

III. Model Construction and Solution

A. Model Construction and Discussion

1) Model GL: In the government-led cooperative supply model, innovative enterprises, academic research institutions, and downstream enterprises will formulate technology transfer cost f and introduction ratios ρ under the guidance of the government to maximize the profit of the innovation value chain (in the following mathematical formulas, innovative enterprises, third-party technology suppliers, and innovation value chains are represented as IE, TS, and IC, respectively). The government can make decisions based on the value forecast information of innovative enterprises, and its expected profit decision model is:

$$\max_{f,\rho}(E_{ICY}^{GL} \mid \zeta) = E\left((f - c_1 + \rho\Delta)(a - bp) - s\rho^2 \mid \zeta\right) \quad (3)$$

The optimal values of f and ρ are:

$$f^{GL} = \left((2s - b\Delta^2)((1-p)a_0 + p\zeta) + 2bsc_1\right) \big/ b(4s - b\Delta^2) \quad (4)$$

$$\rho^{GL} = \Delta\left(a_0 - p\left(a_0 - f\right) - bc_1\right) \big/ b\left(4s - b\Delta^2\right) \quad (5)$$

The premise of the second-order condition of the model is $s > b\Delta^2/4$ (the hypothesis is given later), indicating that the cost of technology introduction is not low, which is consistent with reality (the more advanced the introduced technology, the greater the cost). Based on the optimal expected value criterion, the expected profit of innovation value chains is expressed as:

$$E_{ICY}^{GL} = s(s\varphi + (a_0 - bc_1)^2) \big/ b(4s - b\Delta^2) \quad (6)$$

From (5) and (6), it can be seen that in the GL model, the optimal profit of innovation value chains is $s(a_0 - bc_1)^2 \big/ b(4s - b\Delta^2)$, the value of innovative enterprises' prediction information is $V_{IC}^{GL} = sp\varphi \big/ b(4s - b\Delta^2)$, and the higher the prediction accuracy the larger the value.

2) Model EL: In this model, innovative enterprises are responsible for the transformation of results and the decision-making of technology introduction, and academic research institutions are responsible for the re-development. The decision path is: innovative enterprises determine the transfer cost f and the proportion of imported technology ρ, while academic research institutions determine the development cost d. Innovative enterprises can make decisions based on market and value forecast information. In this case, the expected profit decision model is:

$$\max_{f,\rho}\left(E_{IEN}^{EL} \mid \zeta\right) = E\left(\left(f - d + r\rho\right)\left(a - bf\right) - s\rho^2 \mid \zeta\right) \quad (7)$$

When there is no knowledge sharing, academic research institutions make decisions based on past experience and market information, and the expected profit decision model is:

$$\max_{d}\left(E_{ARN}^{EL}\right) = E\left(\left(d - c_1 + (\Delta - r)\rho\right)\left(a - bf\right)\right) \quad (8)$$

When there is knowledge sharing, academic research institutions can make decisions by combining predictive information, and the expected profit decision model is:

$$\max_{d}\left(E_{ARY}^{EL} \mid \zeta\right) = E\left(\left(d - c_1 + (\Delta - r)\rho\right)\left(a - bf\right) \mid \zeta\right) \quad (9)$$

In this case, the potential market value of the technology is given in. (1), and the expected profit decision model for academic research institutions is shown in (7).

3) Model RL: In this model, academic research institutions dominate the research and development work, and innovative enterprises are only responsible for the transformation of results. The decision path is: academic research institutions determine the proportion of imported technology ρ and the development cost d, while innovative enterprises determine the transfer price f. In this case, the expected profit decision model of innovative enterprises is:

$$\max_{f}\left(E_{IEN}^{RL} \mid \zeta\right) = E\left(\left(p - e\right)\left(a - bp\right) \mid \zeta\right) \quad (10)$$

When there is no knowledge sharing, the expected profit decision model of academic research institutions is:

$$\max_{d,\rho}\left(E_{ARN}^{RL}\right) = E\left(\left(d - c_1 + \Delta\rho\right)\left(a - bf\right) - s\rho^2\right) \quad (11)$$

When there is knowledge sharing, the expected profit decision model of academic research institutions is:

$$\max_{d,\rho}\left(E_{ARY}^{RL} \mid \zeta\right) = E\left(\left(d - c_1 + \Delta\rho\right)\left(a - bf\right) - s\rho^2 \mid \zeta\right) \quad (12)$$

4) Model NP: In this model, innovative enterprises are responsible for the transformation of results, academic research institutions are responsible for research and development, and third-party technology suppliers are responsible for technology introduction. The decision path is: third-party technology suppliers select the introduced technology ρ, academic research institutions determine the development cost d, and finally, innovative enterprises determine the technology transfer price f. In this case, the expected profit decision model of innovative enterprises is:

$$\max_{f}\left(E_{IEN}^{NP} \mid \zeta\right) = E\left(\left(f - d\right)\left(a - bf\right) \mid \zeta\right) \quad (13)$$

When there is no knowledge sharing, the decision-making models of third-party technology suppliers and academic research institutions are:

$$\max_{\rho}\left(E_{TSN}^{NP}\right) = E\left(r\rho\left(a - bf\right) - s\rho^2\right) \quad (14)$$

$$\max_{\rho}\left(E_{TSN}^{NP}\right) = E\left(r\rho\left(a - bf\right) - s\rho^2\right) \quad (15)$$

When there is knowledge sharing, the decision-making models of third-party technology suppliers and academic research institutions are:

$$\max_{\rho}\left(E_{TSY}^{NP} \mid \zeta\right) = E\left(r\rho(a - bf) - s\rho^2 \mid \zeta\right) \quad (16)$$

$$\max_{\rho}\left(E_{ARY}^{NP} \mid \zeta\right) = E\left(\left(d - c_1 + \Delta\rho\right)\left(a - bf\right) \mid \zeta\right) \quad (17)$$

By using the backward induction to derive the model, the optimal solution and profit of the model are listed in TABLE II.

TABLE II
OPTIMAL SOLUTIONS AND BENEFITS OF THE THREE MODELS UNDER THE SCENARIOS OF KNOWLEDGE SHARING AND NO SHARING

Optimal	Model EL-N	Model RL-N	Model NP-N	Model EL-Y	Model RL-Y	Model NP-Y
f^*	$\frac{\left(2s-br^2\right)A^*+2bsd_N^{EL}}{b\left(4s-br^2\right)}$	$\frac{bd_N^{RL}+A}{2b}$	$\frac{bd_N^{NP}+A}{2b}$	$\frac{bc_1\left(4s-br^2\right)+AB^*}{2b(4s-br\Delta)}$	$\frac{4bsc_1+A\left(4s-b\Delta^2\right)}{b\left(8s-b\Delta^2\right)}$	$\frac{2bsc_1+A\left(B-2s\right)}{b\left(4s+br^2-br\Delta\right)}$
d^*	$\frac{bc_1\left(4s-br^2\right)+a_0\left(4s+br^2-2br\Delta\right)}{2b(4s-br\Delta)}$	$\frac{4bsc_1+a_0\left(4s-b\Delta^2\right)}{b\left(8s-b\Delta^2\right)}$	$\frac{2bsc_1+a_0\left(B-2s+br\Delta\right)}{b\left(B+br\Delta\right)}$	$\frac{bc_1\left(4s-br^2\right)+AB}{2b\left(4s-br\Delta\right)}$	$\frac{4bsc_1+A\left(4s-b\Delta^2\right)}{b\left(8s-b\Delta^2\right)}$	$\frac{2bsc_1+A\left(B-2s\right)}{b\left(B+br\Delta\right)}$
ρ^*	$\frac{r\left(A-be_{NS}^{EL}\right)}{4s-br^2}$	$\frac{\Delta\left(a_0-bc_r\right)}{8s-b\Delta^2}$	$\frac{r\left(a_0-bd_N^{NP}\right)}{4s}$	$\frac{r\left(A-bd_Y^{EL}\right)}{4s-br^2}$	$\frac{\Delta\left(A-bc_1\right)}{8s-b\Delta^2}$	$\frac{r\left(A-bd_Y^{NP}\right)}{4s}$
E_{IE}^*	$\frac{r\left(A-be_{NS}^{EL}\right)}{4s-br^2}$	$\frac{\Delta\left(a_0-bc_r\right)}{8s-b\Delta^2}$	$\frac{r\left(a_0-bd_N^{NP}\right)}{4s}$	$\frac{s\left(4s-br^2\right)\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{4b(4s-br\Delta)^2}$	$\frac{4s^2\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{b\left(8s-b\Delta^2\right)^2}$	$\frac{s^2\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{b\left(4s-br\Delta+br^2\right)^2}$
E_{AR}^*	$\frac{sp\varphi}{b\left(4s-br^2\right)}+\frac{s\left(4s-br^2\right)\left(a_0-bc_1\right)^2}{4b(4s-br\Delta)^2}$	$\frac{p\varphi}{4b}+\frac{4s^2\left(a_0-bc_1\right)^2}{b\left(8s-b\Delta^2\right)^2}$	$\frac{p\varphi}{4b}+\frac{s^2\left(a_0-bc_1\right)^2}{b\left(4s-br\Delta+br^2\right)^2}$	$\frac{s\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{2b(4s-br\Delta)}$	$\frac{s\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{b\left(8s-b\Delta^2\right)}$	$\frac{s\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{2b\left(4s+br^2-br\Delta\right)}$
E_{TS}^*	$\frac{2rsp\varphi(\Delta-r)}{\left(4s-br^2\right)^2}+\frac{s\left(a_0-bc_1\right)^2}{2b(4s-br\Delta)}$	$\frac{s\left(a_0-bc_1\right)^2}{b\left(8s-b\Delta^2\right)}$	$\frac{s\left(a_0-bc_1\right)^2}{2b\left(4s+br^2-br\Delta\right)}$	N/A	N/A	$\frac{sr^2\left(\left(a_0-bc_1\right)^2+p\varphi\right)}{4\left(4s+br^2-br\Delta\right)^2}$

$Note: A=\left(1-p\right)a_0+p\zeta, B=4s+br^2-2br\Delta$

B. Comparison and Analysis under Different Supply Models

1) The Value Change of Knowledge Sharing: This section will compare the profit changes of innovative enterprises, academic research institutions, innovation value chains, and third-party technology suppliers with and without knowledge sharing under different modes, and obtain the value of knowledge sharing to each innovation entity. Under the GL model, the value of knowledge sharing to innovation value chains is: $V_{IC}^{GL} = kp\varphi / b(4s-b\Delta^2) > 0$.

(1) In the EL model, the value of knowledge sharing to innovative enterprises, academic research institutions and innovation value chains is:

$$V_{IE}^{EL} = \frac{kp\varphi\left(4s+br^2-2br\Delta\right)\left(-12s+br^2+2br\Delta\right)}{4b(4s-br\Delta)^2\left(4s-br^2\right)} < 0 \tag{18}$$

$$V_{AR}^{EL} = \frac{kp\varphi\left(4k+br^2-2br\Delta\right)^2}{2b\left(4s-br\right)^2(4s-br\Delta)} > 0 \tag{19}$$

$$\begin{aligned} &V_{IC}^{EL} = V_{IC}^{EL} = -kp\varphi C\left(4s+br^2-2br\Delta\right), \\ &C = \frac{8s\left(2s-3br^2+2br\Delta\right)+br^2\left(r^2+4r\Delta-4\Delta^2\right)}{4b\left(4s-br\right)^2\left(4s-br\Delta\right)^2} < 0 \end{aligned} \tag{20}$$

(2) In RL model:

$$V_{IE}^{RL} = p\varphi(4s-b\Delta^2)(-12s+b\Delta^2)/4b(8s-b\Delta^2)^2 < 0 \tag{21}$$

$$V_{AR}^{RL} = sp\varphi/b(8s-b\Delta^2) > 0 \tag{22}$$

$$\begin{aligned} &V_{IC}^{RL} = p\varphi\left(16s^2-12bs\Delta^2+b^2\Delta^4\right)/4b\left(8s-b\Delta^2\right)^2 > 0, \\ &b\Delta^2/4 < s < (3+\sqrt{5})b\Delta^2/8 \end{aligned} \tag{23}$$

(3) In NP model:

$$\begin{aligned} &V_{IE}^{NP} = p\varphi H_2/2bH_1^2 < 0, V_{CR}^{NP} = ps\varphi/2bH_1 > 0, \\ &V_{TS}^{NP} = ps\varphi r^2/4H_1^2 > 0, V_{IC}^{NP} = p\varphi H_3/4bH_1^2 < 0 \end{aligned} \tag{24}$$

where V denotes the difference between the expected profit of Y and N, and $V_{IC}=V_{IE}+V_{AR}, H_1=4s-br\Delta+br^2>0, H_2=(2s-br\Delta+br^2)(-6s-br\Delta+br^2)<0, H_3=k(4s+5br^2-6br\Delta)+b^2r^2(\Delta-r^2)^2>0$.

Proposition 1: (1) In the GL model, knowledge sharing will increase the value of innovation value chains. (2) In the EL, RL, and NP models, knowledge sharing will reduce the expected profit of innovative enterprises and increase the expected profit of academic research institutions. (3) In the NP model, knowledge sharing will increase the expected profit of third-party technology suppliers. (4) In the EL and NP models, knowledge sharing will reduce the overall value of innovation value chains. (5) In the RL model, when $s \in (b\Delta^2/4, (3+\sqrt{5}b\Delta^2)/8)$, knowledge sharing will increase the overall value of innovation value chains.

Proof: It is proved by the results of (18)-(24).

The proposition suggests that knowledge sharing by innovative enterprises can undermine their expected profit because other members of the innovation value chain can optimize their R&D decisions based on the information about the potential value of the technology predicted, which in turn puts innovative enterprises at a disadvantage in collaborative innovation. Meanwhile, in the market-driven supply model, the competitive nature of the market amplifies the negative impact of innovative enterprises following decisions. Innovative enterprises will not share knowledge with collaborative members if they are not compensated accordingly. In the new national system model, innovative enterprises are willing to engage in knowledge sharing because technology potential value prediction information improves the overall profit of the innovation value chain. Knowledge sharing reduces the profit of the innovation value chain in the core enterprise leadership and non-profit institution model, but it increases the profitability of the innovation value chain under the industrial innovation alliance model. This is because, under the industrial innovation alliance, academic research institutions are more inclined to increase the proportion of technology introduction, which directly reduces the cost of re-innovation. To sum up, knowledge sharing helps academic research institutions to dominate innovation activities. However, only when the innovative enterprise receives sufficient compensation for knowledge sharing, the profit of all parties can be increased, thus promoting the formation of an industrial technology alliance.

2) Comparison of Expected Profits: It can be seen from $E\left(\rho_k^j\right) \triangleq E\left(\rho_N^j\right) = E\left(\rho_Y^j\right)$ that knowledge sharing does not have a significant effect on the proportion of imported technology ρ . Then, this study will compare the size of ρ under different supply modes:

Proposition 2: The size relationship of ρ under four supply models is given below:

(1) If $b\Delta^2/4 < s < br\Delta^2/8(\Delta - r)$, then $E(\rho^{GL}) > E(\rho^{EL}) > E(\rho^{RL}) > E(\rho^{NP})$.

(2) If $s > br\Delta^2/8(\Delta - r)$, then $E(\rho^{GL}) > E(\rho^{RL}) > E(\rho^{EL}) > E(\rho^{NP})$.

Proof: It is proved by the subtraction of the optimal value of the technology introduction proportion of each model.

The proposition suggests that, compared to the industrial technology alliance model, the core enterprise leadership model has a higher proportion of technology introduction than for a certain range of technology introduction input, while the industrial technology alliance model has a higher proportion of technology introduction for a larger technology introduction input. This is because academic research institutions are more concerned with the substitution benefits of the introduced technology, while innovative enterprises are more concerned with the direct inputs of the introduced technology. Meanwhile, the proportion of technology introduction is highest in the new national system model and lowest in the non-profit technology institution model, and the key lies in the degree of innovation coordination among members of the innovation value chain.

Corollary 1: In EL and RL models, when $2\Delta/3 < r < \Delta$, ρ of EL model has a larger value than that of the RL model. When $0 < r < 2\Delta/3$, ρ of RL model has a larger value than that of the EL model.

The corollary suggests that the proportion of technology introduction in the industrial technology alliance model increases with the technology introduction price r. When the innovative enterprise gains more than $2\Delta/3$ from technology introduction, the industrial technology alliance model is willing to introduce technologies with stronger substitution effects. This indicates that the increase in technology introduction price in academic research institutions can make innovative enterprises introduce technologies with stronger substitution effects, which in turn reduces the cost of re-innovation and the pressure of research and development.

Proposition 3: Comparing the expected profits of innovative enterprises and academic research institutions in the EL, RL, and NP models, we have:

(1) When there is no knowledge sharing, the expected profit relationship of innovative enterprises and academic research institutions in different models is as follows:

$$\begin{cases} E_{IEN}^{EL} > E_{IEN}^{RL} > E_{IEN}^{NP}, p > p_1 \\ E_{IEN}^{RL} > E_{IEN}^{EL} > E_{IEN}^{NP}, p < p_1 \end{cases}, \begin{cases} E_{ARN}^{EL} > E_{ARN}^{RL} > E_{ARN}^{NP}, p > p_2 \\ E_{ARN}^{RL} > E_{ARN}^{EL} > E_{ARN}^{NP}, p < p_2 \end{cases}$$

(2) When there is knowledge sharing:

$$E_{IEY}^{RL} > E_{IEY}^{EL} > E_{IEY}^{NP}, \begin{cases} E_{ARY}^{EL} > E_{ARY}^{RL} > E_{ARY}^{NP}, r > \Delta/2 \\ E_{ARY}^{RL} > E_{ARY}^{EL} > E_{ARY}^{NP}, r < \Delta/2 \end{cases}$$

where the expressions of p_1 and p_2 are given in (26) and (27).

Proof: (1) By comparing the expected profit of innovative enterprises in the EL and RL models, we have:

$$E_{IEN}^{EL} - E_{IEN}^{RL} = \frac{s\begin{pmatrix} 4p\varphi(8s - b\Delta^2)(4s - br\Delta)^2 \\ -(4s - br^2)(a_0 - bc_1)^2 H_4 \end{pmatrix}}{4b(4s - br\Delta)^2(4s - br^2)(8s - b\Delta^2)} \quad (25)$$

where $s > b\Delta^2/4$ and $H_4 = 32s^2 + 4bs(\Delta^2 - 8r\Delta + 2r^2) + 3b^2r^2\Delta^2 > 0$. From (25), let:

$$p_1 = (4s - br^2)(a_0 - bc_1)^2 H_5 \big/ 4\varphi(4s - br\Delta)^2(8s - b\Delta^2) \quad (26)$$

It can be seen that when there is no knowledge sharing, if $p > p_1$, the expected profit of innovative enterprises in the EL model is greater than that of the RL model, and if $p < p_1$, the result is the opposite. Comparing RL and NP, NP and EL respectively, it is found that the expected profit of innovative enterprises in the RL and EL models is greater than that in the NP model.

(2) The same can be proven. We have:

$$p_2 = \frac{\Delta(\Delta - 2r)(a_0 - bc_1)^2(4s - br^2)^2}{4\varphi r(\Delta - r)(8s - b\Delta^2)(4s - br\Delta)} \quad (27)$$

The proposition suggests that without knowledge sharing, if the forecasting accuracy is higher $(p > p_1, p_2)$, the innovative enterprise and academic research institution have greater expected profits under the core enterprise leadership model than the industrial technology alliance model. This result indicates that, when the pre-accuracy is high, innovative enterprises can gain more profits by adopting the core enterprise leadership model; when the pre-accuracy is low, the larger information error will cause the decision of innovative enterprises to deviate from the established goal, leading to the opposite result. When knowledge is shared, the innovative enterprise favors the industrial technology alliance model. If the price of introducing technology is too high $(r > \Delta/2)$, innovative enterprises will prefer the core enterprise leadership model. To sum up, the pre-accuracy of innovative enterprises and the price of technology introduction can affect the supply model decision of innovative enterprises and academic research institutions.

Corollary 2: (1) Without knowledge sharing, when $0 < r < \Delta/(2+\sqrt{2})$, $p_1 < p_2$. In this case, we have:

$$E_{ICN}^{EL} > E_{ICN}^{RL} > E_{ICN}^{NP}$$

(2) When there is no knowledge sharing and there is a r^* such that $0 < r < \Delta/(2+\sqrt{2})$, when $r > r^*$, $p_1 > p_2$. When $p < p_2$:

$$E_{ICN}^{RL} > E_{ICN}^{EL} > E_{ICN}^{NP}$$

(3) When there is knowledge sharing and $r < \Delta/2$:

$$E_{ICY}^{RL} > E_{ICY}^{EL} > E_{ICY}^{NP}$$

Proof: The size relationship between p_1 and p_2 is the key to Corollary 2, and $p_1 - p_2$ is simplified to:

$$p_1 - p_2 = \frac{(4s - br^2)(a_0 - bc_1)^2(4s + br^2 - 2br\Delta)H_5}{r\varphi(\Delta - r)(4s - br\Delta)^2(8s - b\Delta^2)}, \quad (28)$$

$$H_5 = 4s(\Delta^2 - 4s\Delta + 2s) + b\Delta^2 s^2$$

$\Delta^2 - 4r\Delta + 2r^2 > 0$, i.e., when $r < \Delta/(2+\sqrt{2})$, there is $p_1 < p_2, H_5 > 0$. When $r = \Delta/(2+\sqrt{2})$, we have $H_5 > 0$, and when $r = \Delta$, we have $H_5 < 0$. This is because H_5 is a decreasing function of r, so there exists $\Delta/(2+\sqrt{2}) < r^*$ $< \Delta$ such that $p_1 > p_2$. Then, it is proven by the relationship between the three expected profits.

The corollary suggests that when there is no shared knowledge, if the pre-accuracy is sufficiently high ($p > p_2$), the expected profit of the innovation value chain under the core enterprise leadership model is the highest, and the expected profit of the innovation value chain under the non-profit institution model is the smallest. When the pre-accuracy is small ($p < p_2$), the expected profit of the innovation value chain under the industrial technology alliance model is the highest, and the expected profit of the innovation value chain under the non-profit institution model is still the smallest. For knowledge sharing, if the price of technology introduction is low ($r < \Delta/2$), the expected profit of the innovation value chain under the industrial technology alliance model is the highest. To sum up, the price of technology introduction can affect the innovation value chain's choice of key core technology supply model, while the pre-accuracy of innovative enterprises only affects the innovation value chain's choice of key core technology supply model in the context of no knowledge sharing.

C. Strategy Game and Knowledge Compensation Mechanism

1) Supply Model and Knowledge Sharing Strategy: The driving force of innovation comes from the basic R&D capability, and academic research institutions support the decision-making of the supply model in innovation value chains. It is assumed that the two carry out a strategic game.

Proposition 4: In the strategic game between innovative enterprises and academic research institutions, the strategy space of academic research institutions and innovative enterprises is $\{\mathrm{EL}, \mathrm{RL}, \mathrm{NP}\}$ and $\{\mathrm{N}, \mathrm{Y}\}$, respectively. When $p_1 > p_2$, the pure strategy Nash equilibrium is $\{\mathrm{EL}, \mathrm{N}\}$, and when $p_1 < p_2$, the equilibrium is $\{\mathrm{RL}, \mathrm{N}\}$.

The proposition suggests that no knowledge sharing is an equilibrium strategy for innovative enterprises. This is because the technology potential prediction information is private knowledge, and the sharing of private knowledge will reduce the core competitiveness of the enterprise. For the academic research institution, the value prediction accuracy of the innovative enterprise affects the selection of the key core technology supply model of the academic research institution. When $p_1 = p_2$, the pure-strategy Nash equilibrium is not unique, so the theory of mixed-strategy game will be introduced. From the description in the previous section, the academic research institution has the lowest expected profit under the non-profit institution model, and the innovative enterprise has no willingness to share knowledge. Therefore, the probability of the academic research institution choosing the non-profit institution model and the innovative enterprise choosing the knowledge sharing strategy is 0. The probability of the academic research institution choosing the core enterprise leadership model is β, and the probability of the academic research institution choosing the industrial technology alliance model is $1-\beta$.

Proposition 5: In the mixed strategic game where innovative enterprises and academic research institutions participate, the strategy space of academic research institutions and innovative enterprises is $\{\mathrm{EL}, \mathrm{RL}, \mathrm{NP}\}$ and $\{\mathrm{N}, \mathrm{Y}\}$, respectively. When $p_1 = p_2$, the mixed strategy Nash equilibrium is $P = \{(\beta^*, 1-\beta^*, 0), (1, 0)\}$, and we have:

$$\beta^* = \frac{p_2\varphi + 16s^2 \beta_1 / \beta_2}{s_2\varphi\beta_5 / \beta_3 + s\beta_1\left(16s / \beta_2 + \beta_3 / \beta_4\right)} \tag{29}$$

where $\beta_1 = (a_0 - bc_1)^2, \beta_2 = (8s - b\Delta^2)^2, \beta_3 = 4s - br^2, \beta_4 = 4s - br\Delta$, $\beta_5 = 8s - br^2$, and p_2 is given in (27).

The proposition states that the probability that the academic research institution chooses the core enterprise leadership model is β^*, while the probability that it chooses the industrial technology alliance model is $1-\beta^*$. Considering the complexity of the expression of β^*, the cost of savings Δ and the effect cost of technology introduction efforts k on the probability β^* will be analyzed separately below.

2) Knowledge Sharing Compensation Mechanism: It can be seen from Proposition 1 that innovative enterprises are unwilling to share knowledge. To improve innovative enterprises' willingness to share knowledge and increase the overall value of innovation value chains, a knowledge sharing compensation mechanism should be adopted. In EL, RL, and NP models, only the RL model increases the profit of innovation value chains when the benefit of innovative enterprises is damaged, so the knowledge sharing compensation mechanism is established based on the RL model. The compensation mechanism must satisfy: (1) E_{IEY}^{RL} increases and is greater than E_{IEN}^{RL}. (2) E_{ARY}^{RL} is not smaller than E_{ARN}^{RL}. (3) The compensation mechanism can effectively increase the expected returns of academic research institutions and innovation value chains. With the assistance of the bargaining model, the construction logic of the compensation mechanism is to re-divide the added value $\forall_{IC}^{RL}$ of innovation value chains. Let the profits of innovative enterprises and academic research institutions be $\forall_{IE}^{RL}$ and $\forall_{AR}^{RL}$ respectively and the compensation of academic research institutions to innovative enterprises be $\forall_{IE}^{RL}$. The utility functions of innovative enterprises and academic research institutions are $\delta_1 = (\forall_{IE}^{RL})^{\eta_1}$ and $\delta_2 = (\forall_{AR}^{RL})^{\eta_2}$, respectively, where η_E and η_R denote the degree of risk aversion of the two, and the greater the value, the greater the degree of risk aversion. The model is represented as:

$$\begin{aligned} &\max_{\forall_{IE}^{RL}, \forall_{AR}^{RL}} u = \delta_1\delta_2 = (\forall_{IE}^{RL})^{\eta_1} (\forall_{AR}^{RL})^{\eta_2} \\ &s.t.\ \forall_{IE}^{RL} + \forall_{AR}^{RL} = \forall_{IC}^{RL}, \forall_{IE}^{RL}, \forall_{AR}^{RL} > 0 \end{aligned} \tag{30}$$

We have $\forall_{IE}^{RL} = \eta_1/(\eta_1+\eta_2)\forall_{IC}^{RL}$ and $\forall_{AR}^{RL} = \eta_2/(\eta_1+\eta_2)\forall_{IC}^{RL}$.

When determining the values of η_{IE}^{RL} and η_{AR}^{RL}, innovative enterprises and academic research institutions will share the added value of innovation value chains, and the share of their allocation is determined by the degree of risk aversion of both parties. Under this mechanism, the profits of innovative enterprises and academic research institutions become $E_{IEY}^{RL} + \forall_{IE}^{RL}$ and $E_{ARY}^{RL} - \forall_{IE}^{RL}$, respectively.

Proposition 6: Let innovative enterprises and academic research institutions have the same value of η, that is, $\eta_1 = \eta_2$. When the compensation mechanism is running, if $b\Delta^2/4 < s < b\Delta^2(11+\sqrt{37})/56$, then in the RL model, the expected profits of innovative enterprises and academic research institutions under knowledge sharing are higher than those without knowledge sharing.

proof: When $\eta_1 = \eta_2$, we have $\forall_{IE}^{RL} = \forall_{AR}^{RL} = V_{IC}^{RL} / 2$ and $V_{IC}^{RL} < V_{IE}^{RL}$, and then:

$$E_{ARY}^{RL} - \forall_{IE}^{RL} = E_{ARN}^{RL} + V_{AR}^{RL} - \forall_{IE}^{RL} > E_{ARN}^{RL} \tag{31}$$

$$E_{ARY}^{RL} + \forall_{IE}^{RL} = \frac{p\varphi(-112s^2 + 44b\Delta^2 - 3b^2\Delta^4)}{8b(8s - b\Delta^2)} \tag{32}$$

Let $(-112s^2 + 44b\Delta^2 - 3b^2\Delta^4) = 0$. Then, $E_{IEY}^{RL} + \forall_{IE}^{RL} > 0$ when $b\Delta^2/4 < s < b\Delta^2(11+\sqrt{37})/56$. $s \in (b\Delta^2/4, (3+\sqrt{5}b\Delta^2)/8)$ satisfies the premise of the RL model, so the proposition is true.

This proposition indicates that the knowledge sharing compensation mechanism can increase the expected profit of innovative enterprises and academic research institutions and improve the knowledge sharing willingness of innovative enterprises. Then, the impact of the compensation mechanism on knowledge sharing and supply model strategies will be analyzed.

Proposition 7: Under a knowledge sharing compensation mechanism, innovative enterprises and academic research institutions participate in the game. When $p > max\{p_1, p_2\}$, the pure strategy equilibrium is. $\{\mathrm{EL}, \mathrm{N}\}$

When $p < min\{p_1, p_2\}$ and $r < \Delta/2$, there exists s^*. When $s > s^*$, the pure strategy equilibrium is $\{\mathrm{RL}, \mathrm{Y}\}$.

proof: When $p < min\{p_1, p_2\}$, academic research institutions select the EL model, and innovative enterprises select strategy N. If academic research institutions select the RL model, then innovative enterprises select Y. If innovative enterprises select N, then academic research institutions select the RL model. If innovative enterprises select Y, when $E_{ARY}^{RL} - \forall_{IE}^{RL} > E_{ARY}^{EL}$, academic research institutions will select the RL model. This can be simplified to:

$$E_{ARY}^{RL} - \forall_{IE}^{RL} - E_{ARY}^{EL} = \frac{4bs\Delta(\Delta - 2r)(8s - b\Delta^2)(a_0{}^2 - bc_1)^2 - H_6}{8b(8s - b\Delta^2)^2(4s - br\Delta)}, \tag{33}$$

$$H_6 = 64s^3 - 16\Delta(5br + b\Delta)s^2 + b^2\Delta^3 r(20s - b\Delta^2)$$

There exists a s^* such that $H_6 > 0$ when $s > s^*$ and $r < \Delta/2$. Therefore, when $p < min\{p_1, p_2\}$, $r < \Delta/2$ and $s > s^*$, if innovative enterprises choose strategy Y, then academic research institutions will choose the RL model. Thus, the pure strategy Nash equilibrium $\{\mathrm{RL}, \mathrm{Y}\}$ can be obtained. Similarly, when $p > max\{p_1, p_2\}$, the Nash equilibrium is $\{\mathrm{EL}, \mathrm{N}\}$.

The proposition states that when the compensation mechanism operates, if the pre-accuracy is high $(p > max\{p_1, p_2\})$, the optimal strategy of the academic research institution is the core enterprise leadership model. When the pre-accuracy is low $(p < min\{p_1, p_2\})$, if the price of introducing the technology is small $(r < \Delta / 2)$ and the cost of introduction is high $(s > s^*)$ in academic research institutions, the pure strategy of Nash equilibrium is $\{\mathrm{RL}, \mathrm{Y}\}$. This is because when the knowledge sharing compensation mechanism operates, the academic research institution demands more prediction accuracy from the innovative enterprise, while the innovative enterprise is more reluctant to share high-value knowledge. This suggests that the knowledge compensation mechanism can change the strategy choice of knowledge sharing and supply model only when the value prediction accuracy of innovative enterprises is low.

IV. Numerical Analysis

To further verify the accuracy of the proposition and observe the change rule of the model more intuitively, Python is used for numerical simulation. Under the premise of satisfying the model assumptions, this section will investigate the impact of pre-accuracy p, technology introduction effort cost s, technology introduction price r, and cost-saving Δ on the expected profit E_{ICY}^{j} of each innovation entity and the RL model probability $1-\beta^*$ of the selection of academic research institutions. Only the results under knowledge sharing are displayed because they are similar. The basic parameters including the market potential value of R&D technology, the R&D cost of self-innovation technology, the value sensitivity coefficient, the pre-accuracy, the cost saving and the prediction deviation are set as follows: $a_0 = 10, c_1 = 5, b = 0.7, p = 0.7, \Delta = 0.7, \varphi = 1$.

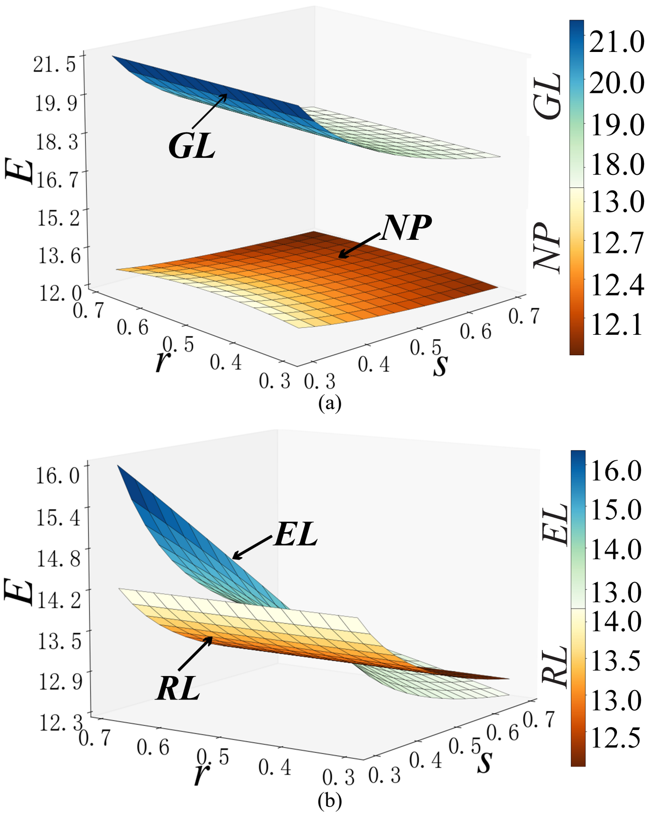

Fig. 2. The impact of r and s on the profit of each model of innovation value chain.

It can be seen from Fig. 2(a) and 2(b) that the new national system model obtains the highest expected profit and the non-profit institution model obtains the smallest expected profit, regardless of the changes in the effort cost of technology introduction s and the price of technology introduction r. This is because the members of the government-led innovation value chain can quickly harmonize their interests, which improves the efficiency of knowledge integration. From Fig. 2(b), it can be observed that the effort cost of technology introduction s is inversely proportional to the expected profit. Meanwhile, the technology introduction cost r is inversely proportional to the expected profit of the core enterprise leadership model and positively proportional to the expected profit of the industrial technology alliance model. It is noteworthy that the effect of technology introduction price r on the expected profit of the core enterprise leadership model is significantly stronger than that on the industrial technology alliance model. The analysis indicates that the interaction effect of the technology introduction cost parameters r and s can change the relationship between the expected profit of the core enterprise leadership model and the industrial technology alliance model, which confirms the validity of the theoretically derived results.

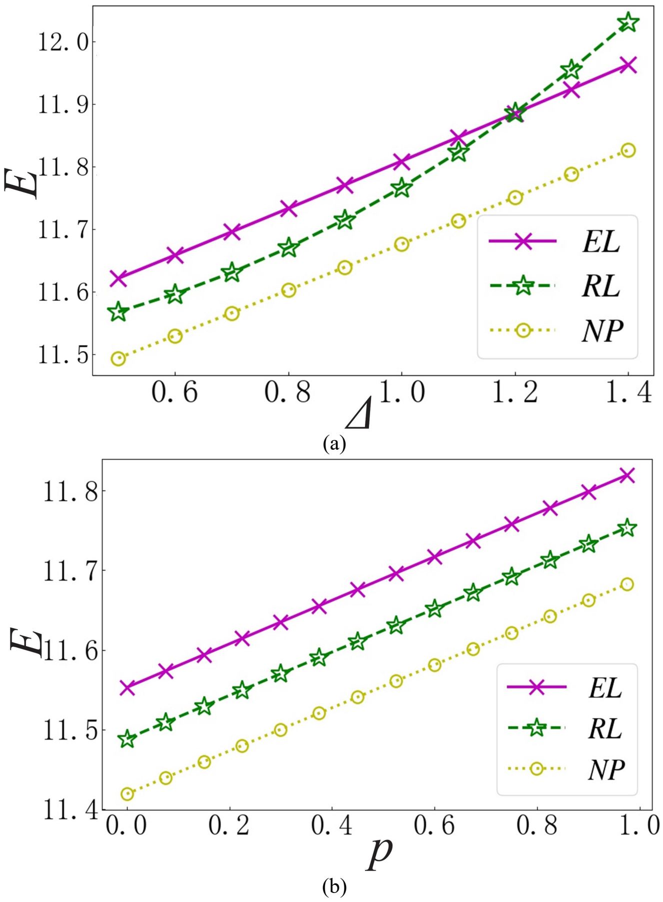

Fig. 3. The impact of Δ and p on the profit of innovation value chains in market-led models.

Assuming $r = 0.5$, Fig. 3(a) shows that the cost saving of re-innovation is proportional to the expected profit of the innovation value chain, but the increase in profit varies in different models. When the cost saving $\Delta > 1.18$, the expected profit of the non-profit institution model is still the lowest, and the expected profit of the industrial technology alliance model will be higher. This suggests that the higher the benefits that the innovation value chain gains from re-innovation after the introduction of technology, the more appropriate it is to adopt the industrial technology alliance model, and otherwise, the more appropriate it is to adopt the enterprise leadership model, thus validating the theoretical derivation. Fig. 3(b) shows that the pre-accuracy is proportional to the expected profit of the innovation value chain. The core enterprise leadership model has the highest expected profit, and the non-profit institution model has the lowest expected profit. This shows that under the knowledge sharing scenario, the level of pre-accuracy will not change the innovation value chain's choice of key core technology supply model, which confirms the validity of the theoretically derived results.

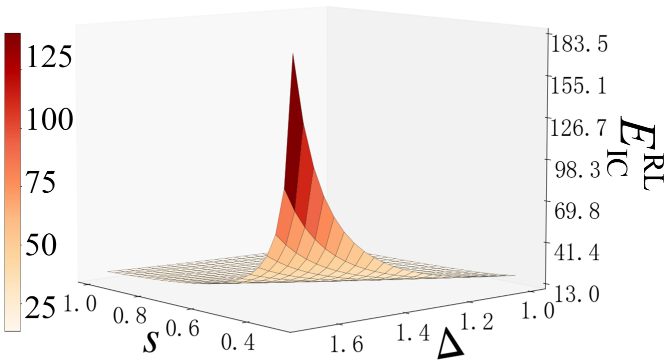

Fig. 4. The impact of Δ and s on the profit of innovation value chains in RL model.

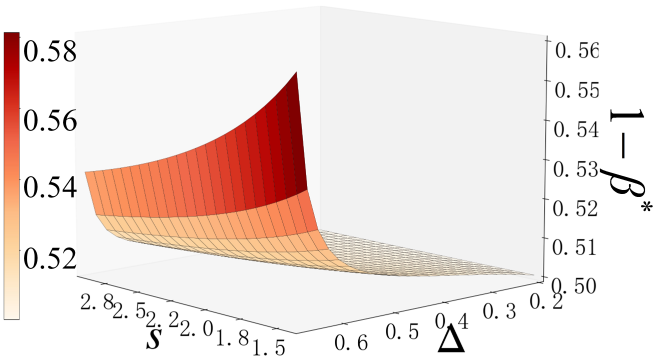

Fig. 5. The impact of Δ and s on the probability of RL model selection by academic and research organizations.

Assuming that $r = 0.5$, it can be seen from Fig. 4 that a higher effort cost of technology introduction ($s > 0.4$) or lower cost of savings ($\Delta < 1.5$) will result in a rapid decrease in the expected profits of the industrial technology alliance model. This suggests that both the expectations of innovation value chain members about the value of technology and the difficulty in technology introduction are foundations for implementing the knowledge compensation mechanism. Also, it is shown in Fig. 5 that, as the effort cost of technology introduction decreases and the cost of saving increases, the probability of the innovation value chain adopting an industrial technology alliance becomes greater, which verifies the theoretical derivation.

V. CONCLUSION

VI. In this paper, from the perspective of the innovation value chain, four types of key core technology supply decision models, are constructed, and the value of knowledge sharing under different supply models as well as the change of the expected profit of each innovation main body are compared and analyzed. Then, the impact of knowledge sharing of innovation enterprises on the efficiency of supplying key core technology and the model choice of innovation value chain members are investigated; also, the pure strategy and mixed strategy Nash equilibrium of knowledge sharing in innovation enterprises and the supply model choice of academic research institutions are obtained. Also, the knowledge sharing compensation mechanism is designed, and the impact of the compensation mechanism on the knowledge sharing of innovative enterprises and the supply model choice of academic research institutions is studied. This study has three main conclusions that enrich research in related fields and have significant reference values.

VII. First, among the four technology supply models, the profit of the innovation value chain and the proportion of technology introduction are always the highest under the new national system model. Meanwhile, among the three market-led models, the profit of the innovation value chain and the proportion of technology introduction are always the lowest under the non-profit institution model. Moreover, when there is no knowledge sharing, the relationship between the innovation value chain profit under the core enterprise leadership and industrial technology alliance model is related to the prediction accuracy of technology value. Additionally, when there is knowledge sharing, the relationship is related to the effort cost and price of technology introduction. It is noteworthy that the effort cost of technology introduction reduces the willingness of innovative enterprises to introduce technology, while academic research institutions can increase the price of technology introduction to motivate innovative enterprises to introduce more appropriate technology.

VIII. Second, the comparison of the three market-led models indicates that knowledge sharing can change the choice strategy of the supply model of innovative enterprises and academic research institutions. Without knowledge sharing, when the prediction accuracy of technology value is high, both innovative enterprises and academic research institutions prefer the core enterprise leadership model. However, when the prediction accuracy is low, both favor the industrial technology alliance model. Under knowledge sharing, if the technology introduction price is too high ($r > \Delta/2$), innovative enterprises still choose the industrial technology alliance model, while academic research institutions tend to choose the core enterprise leadership model, and the two decisions diverge. Additionally, the sharing of private knowledge by innovative enterprises improves the profit of the innovation value chain under the new national system and industrial technology alliance models, although it harms their interests.

IX. Finally, the knowledge compensation mechanism can effectively increase the willingness of innovative enterprises to share knowledge in a double-low scenario. The equilibrium decision of innovative enterprises is not to share knowledge, while academic research institutions can choose the two strategies of core enterprise leadership or industrial technology alliance model, and there is a mixed strategy game. Meanwhile, after the operation of the knowledge compensation mechanism, when both the prediction accuracy of technology value and the price of technology introduction are too low ($p < min\{t_1, t_2\}, r < \Delta/2$), if the effort cost of technology introduction exceeds the threshold $s > s^*$, the innovative enterprise will share the knowledge, and the academic research institution chooses the core enterprise leadership model. Unlike Wang *et al*. [11], who preferred 'punitive' measures to improve innovation collaboration, we believe 'compensatory' measures are more conducive to maintaining the sustainability of innovation and collaborative initiative of each entity.

X. The above findings complement the relevant research of Zhang *et al*. [21] and further reveal that knowledge sharing is an important factor in forming win-win effects and high-value technology supply in open innovation collaboration models, which has certain theoretical value and practical significance. However, the research in this paper has some limitations. First, it only considers the generation of innovations and the transformation of achievements in the innovation value chain but does not consider the spillover effect of key core technology. Secondly, it only considers the knowledge sharing behavior of innovative enterprises at the center of the innovation value chain but does not consider the possible knowledge sharing behavior of academic research institutions.

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