Hindawi
Mathematical Problems in Engineering
Volume 2020, Article ID 8859458, 8 pages
https://doi.org/10.1155/2020/8859458

Research Article

Research on the Internal Financing Mechanism in the Innovation Chain

Huihong Liu, Han Ding, and Xinmiao Zhou

Business School, Ningbo University, Ningbo 131521, Zhejiang, China

Correspondence should be addressed to Xinmiao Zhou; zhouxinmiao@nbu.edu.cn

Received 15 September 2020; Revised 19 November 2020; Accepted 23 November 2020; Published 7 December 2020

Academic Editor: Chonghui Zhang

It is of great significance to build an efficient and cooperative innovation system and support system under the background of China persisting in leading the development with innovation and speeding up the construction of an innovation-oriented country. The collaborative relationship and profit distribution of each innovation subject will be analyzed through the study of the innovation activity in the innovation chain. With consideration of the characteristics of the innovation chain such as high risk, financing difficulty, cooperative partnership and so on and using the internal financing mode of supply chain for reference, the game model of internal financing between members of the innovation chain will be established. The game equilibriums will be solved and analyzed, and the optimal equilibriums will be achieved by designing the contracts to establish the internal financing mechanisms in the innovative chain. For the risk asymmetry at each stage of the innovation chain, the contracts will be optimized to construct the risk sharing mechanism to control the risk of the internal financing in the innovation chain. In order to make innovations, this paper creates the financial support mode of the innovation chain, improves the innovation support system and increases the efficiency of the innovation chain.

1. Introduction

China has entered an era of New Economic Normality, one characteristic of which is the turn from a factors-driven and investment-driven economy to an innovation-driven one. To achieve this goal, China continues to invest heavily in innovation. In 2018, R&D spending as a share of GDP was 2.18%, higher than the average level of OECD countries. However, such investment has not led to a rapid increase of TFP (total factor productivity), which, by contrast, is only half that of OECD countries. This shows that the innovation efficiency of China is still relatively low. The main reason is the lack of synergy of the innovation system, such as the disconnection between the research and development stage and the production and commercialization stage of the technological innovation, which renders many technological innovations really unable to meet the market demand and thus unable to be transformed. In addition, the support system for innovation is not perfect, such as the financial support system. Although the investment of R&D is increased, the investment is unevenly distributed among different industries, different regions and different subjects, and a large number of firms are still facing the constraints of innovation funds. To establish and improve the innovation system and support system is the most important task in the current scientific and technological innovation.

The innovation chain is an important means to realize the innovation-driven economy. The famous economist, Schumpeter, who put forward the concept of the "innovation," thought that in addition to the breakthrough in science and technology and the production of new invention, the innovation should also include their introduction into the firms, so as to improve the productivity of the firms and society [1]. That is, innovation refers not only to the R&D of the new technology but also to the whole process of converting it into the real productivity and the diffusion. It is a complex system process from the source of innovation to the successful transformation of technological achievements. It is difficult for an individual innovation subject to complete the whole process. The innovation chain, an efficient and collaborative innovation system, needs to be constructed by innovation agents in different fields [2]. According to the functions in the innovation chain, the innovation chain can be divided into relatively independent three or five stages [3, 4]. There is no recognized definition of the innovation chain, but it is generally believed that the innovation chain will produce and market the technological innovation results in order to meet the needs of customers and make the technological innovation diffuse among the main members of innovation activities. Innovation subjects can improve innovation by improving the ability of cluster collaborative innovation [5]. This collaborative development relationship has been empirically proved [6–8].

The innovative activities in the innovation chain require financial support. Innovation is a high risk activity with a great risk of loss that can be prohibitive for most of the actors. In addition, the innovation activity needs a lot of financial support, and more capital is needed to transform the scientific research results into the real productivity and then to become a high-tech industry, so a good financial support is the necessary guarantee of the innovation chain. How to deploy the capital chain around the innovation chain, explore the new mechanism of the docking between science and technology and finance, and promote the capitalization and industrialization of scientific and technological achievements are of great value [9]. Scholars design mechanisms with the help of investment loans, project financing, securities issuance and other tools to finance innovative projects and support the operation of innovative science and technology business incubators [10] and build a relational loan model which is closely related to banks to solve the financing problems of innovation subjects in the innovation chain [11]. The innovation chain is often faced with a shortage of innovation fund, and different financial markets, different financial instruments, and different financial arrangements have heterogeneous promotion and support effect on each main body at different stages of the innovation industrialization [12] [13]; therefore, it is necessary to reasonably allocate the innovative funds. To optimize the allocation, the scholars allocate the financial resources in the innovation network according to the resource tree and the technology roadmap [14, 15], and put forward the innovation fund allocation mode in the innovation chain based on the financial service demand of the innovation-driven development and from the perspective of coordination and integration of the innovation chain, the industrial chain, the capital chain and the profit chain [16].

The internal financing mode between members of the innovation chain is a new financial support model to promote an innovation-driven economy by innovation chain. The innovation chain connects the subjects of innovation, forms a certain profit community through the partnership, and better realizes the process of knowledge economy and the optimization goal of innovation system. The internal financing mode between members of the innovation chain can perfect the resource allocation mode in accordance with the law of innovation and provide a new financial support mode for innovation activities. On the one hand, the joint fusion of the innovation chain and the capital chain is realized, which makes the capital chain be used for boosting the innovation chain and the innovation motivation be activated to realize the financing for innovation-driven economy by the innovation chain. On the other hand, the finance-assisting relationship in the innovation chain is established, which strengthens the leading role of the core innovation subject and the relationship between innovative subjects, improves the coordination and cooperation mechanism to strive to maximize the efficiency of scientific and technological innovation activities.

Although there is a lack of research on the internal financing of the innovation chain, the development of supply chain finance is mature, which provides a reference for the resource reconfiguration and cost optimization in the chain ecosystem [12, 17]. Considering the characteristics of innovation activities in the innovation chain, we mainly draw lessons from the downstream firms of the supply chain to provide internal financing for suppliers. When the supplier has a fund constraint, one of the main financing modes provided by the downstream firm to the supplier is the prepayment, the most important of which is to determine the payment time, the price discount, the price dependency, the economic order quantity, etc. [18–20], while the selling price, the cost of purchase, the uncertainty of the product, and the type of contract are also the influential factors of the financing [21–23]. The supplier's own funds affect internal financing decisions [24]. The core firms give full play to their coordination and control advantages in the supply chain and use the spare funds of upstream and downstream firms to provide financing for small and medium-sized firms in the chain [25, 26].

The present research is mainly focused on the financing model of a single innovation subject, and the research on the financing mode of the whole innovation chain is, however, inadequate. In fact, the profit of each innovative subject in the innovation chain is correlated, which makes the innovation chain to be a partnership and a benefit community, so the internal financing model of the innovation chain can be set up completely to relieve the financing constraint problem of the innovation chain. Although the internal financing model of the chain provides a reference for internal financing in the chain ecosystem, it is necessary to design the internal financing model of the innovation chain because of the special relationship between innovation subjects and the special operating mechanism of innovation subjects.

The objective of this paper is to contribute to the literature on innovation chains in two ways. First, it is among the first to focus on the quantitative research of the innovation chain. This paper is to construct models of innovation chain to study innovation activity and income distribution by game theory based on the analysis of composition and operation mechanism of innovation chain, solve game equilibrium and carry on optimization analysis to design internal financing mode of innovation chain. That provides quantitative research results for innovation chain research. Second, it provides the theoretical basis and operation guide for the financial support of the innovation chain. This paper is to design the internal financing model between members of the innovation chain and the risk control mechanism based on the relationship and the profit distribution among the innovative subjects in the innovation chain, so as to reduce the financial constraints of innovation subjects and improve the innovation efficiency of the innovation chain.

The remainder of this paper is organized as follows. In Section 2, the operation mode and the profit distribution of the innovation chain are discussed. In Section 3, the internal financing in the innovation chain and the profit distribution mechanism are studied. In Section 4, the risk control mechanism of internal financing in the innovation chain is designed. Section 5 concludes the paper.

2. Operation Mode and Profit Distribution of Innovation Chain

In order to design the internal financing mechanism of the innovation chain, it is necessary to clarify the relationship between the innovative subjects in the innovation chain. In this section, we sort out the innovation process, analyze the relationships of innovation subjects at each stage, build the innovation chain to carry out the collaborative innovation, and make clear the profit distribution among the innovative subjects.

2.1. Innovative Activities and Profits in Noninnovation Chain

2.1.1. Assumptions of Innovative Activities. The innovation process is divided into two stages: research and development; production and commercialization. There is only one the R&D institution at the R&D stage, and there are n firms at the production stage, and n is exogenous and fixed. At the first stage, the R&D institution has its own fund C and invests K in R&D, and innovation result is a function of R&D investment, $X=\sqrt{2K}$.The innovation result is bid in competition by n firms, and firm i bids P_i for the innovation result, and it is only transferred to the highest bid firm k, $P_k=\max_i P_i$. At the second stage, the original marginal production cost of firm i is z_i. If firm k obtains the innovation result, its marginal cost becomes z_k-X; if there is gradual innovation in the innovation chain, that is to say $X(K)<\min_i z_i$. Given marginal cost condition, n firms compete through quantities, which indicates Cournot competitiveness.

2.1.2. Innovation Activities and Profit of Innovation Subjects. For the dynamic problems of innovation process, the reverse solution analysis is adopted. At the second stage, after observing the marginal cost and the transfer result, firm i chooses the quantity q_i to maximize the profit π_i. Suppose the product inverse demand function is $p=1-\sum_{i=1}^n q_i$. The production decision-making problem of firm k, who obtains the innovative result, is as follows:

$$\max_{q_k}\pi_k=\left(1-\sum_{j=1}^n q_j-(z_k-X)\right)q_k. \quad (1)$$

The production decision-making problems of other firms are as follows:

$$\max_{q_i}\pi_i=\left(1-\sum_{j=1}^n q_j-z_i\right)q_i, \quad i\neq k. \quad (2)$$

By solving the optimization problems (1) and (2), the quantity $q_i^E(k)$ and the profit $\pi_i^E(k)$ of each firm can be obtained when the firm k obtains the innovation result, in which the superscript E represents the equilibrium result. The quantities are as follows:

$$q_k^E=\frac{\left(1+\sum_{j=1}^n z_j-(n+1)z_k+nX\right)}{(n+1)},$$
$$q_i^E=\frac{\left(1+\sum_{j=1}^n z_j-(n+1)z_i-X\right)}{(n+1)}, \quad i\neq k. \quad (3)$$

For all firms, the profit of firm i is $\pi_i^E=(q_i^E)^2$.

Firm i evaluates the innovation result by the difference between the profit when the innovation result is obtained and the one when the innovation result is not obtained. The difference is as follows:

$$v_i=\Delta\pi_i=X\frac{\left(2+2\sum_{j=1}^n z_j-2(n+1)z_i+(n-1)X\right)}{(n+1)}. \quad (4)$$

Therefore, the difference in the evaluation by different firms is $v_i-v_j=2X(z_j-z_i)$, which is entirely dependent on the difference in the original marginal production cost z_i. The less z_i is, the higher the valuation v_i is. Under the condition of complete information, it is clear that the bid of firm i can be $P_i=\max_{j\neq i}\{v_j|v_jt\leq nv_i\}$.

Since the transfer price of innovation result mainly depends on the number of technology leaders but not the number of firms at the production stage, in order to focus on the internal financing of the innovation chain, the production stage is simplified to duopoly, that is, $n=2$.

(1) A Single Leader. Assuming that $z_1<z_2$, then $v_1>v_2$, firm 1 obtains the innovation result at the price $P_1=\max_{i\neq 1} v_i=v_2$. Then the profit of the R&D institution is as follows:

$$\pi_0=P_1-K=v_2-K=\frac{1}{3}X(2+2z_1-4z_2+X)-K. \quad (5)$$

The decision of the R&D institution is as follows:

$$\max_K \pi_0=P_1-K,$$
$$\text{s.t.}\begin{cases}K=\dfrac{X^2}{2},\\ 0\leq K\leq C.\end{cases} \quad (6)$$

The optimization problem (6) is solved to obtain the following:

(i) If $\sqrt{2C}<2(1+z_1-2z_2)$, then the optimal innovation result is $X_1^*=\sqrt{2C}$, the R&D investment is $K_1^E=C$, the profit of the R&D institution, firm 1 and the sum of both respectively are $\pi_{01}^E=3/2(1+z_1-2z_2)\sqrt{2C}-1/3C$, $\pi_{11}^E=1/9(1-2z_1+z_2+$

$2\sqrt{2C})^2$ and $\Pi_1^E = \pi_{01}^E + \pi_{11}^E = 1/9(1-2z_1+z_2)^2 + 2/9(5-z_1-4z_2)\sqrt{2C} + 5/9C$.

(ii) If $\sqrt{2C} \geq 2(1+z_1-2z_2)$, then the optimal innovation result is $X_1^* = 2(1+z_1-2z_2)$, the R&D investment is $K_1{}^E = 2(1+z_1-2z_2)^2$, the profit of the R&D institution, firm 1 and the sum of both respectively are $\pi_{01}^E = 2/3(1+z_1-2z_2)^2$, $\pi_{11}^E = 1/9(5+2z_1-7z_2)^2$ and $\Pi_1^E = \pi_{01}^E + \pi_{11}^E = 10/9z_1^2 + 73/9z_2^2 - 52/9z_1z_2 + 22/9z_1 - 94/9z_2 + 31/9$.

(2) Multiple Leaders. Assuming that $z_1 = z_2$, then $v_1 = v_2$. The two firms have the same bid and the R&D institution randomly selects the trader, so firm 1 obtains the innovation result at the price $P_1 = v_1$ with the probability 1/2. Then the profit of the R&D institution is as follows:

$$\pi_0 = P_1 - K = v_1 - K = \frac{1}{3}X(2-4z_1+2z_2+X) - K. \tag{7}$$

The decision of R&D institution still is optimization problem (6), and the solutions are as follows.

(i) If $\sqrt{2C} < 2(1-z_1)$, then the optimal innovation result is $X_2^* = \sqrt{2C}$, the R&D investment is $K_2^E = C$, the profit of the R&D institution, firm 1 and the sum of both respectively are $\pi_{02}^E = 2/3(1-z_1)\sqrt{2C} - 1/3C$, $\pi_{12}^E = 1/9(1-2z_1+2\sqrt{2C}))^2$ and $\Pi_2^E = \pi_{02}^E + \pi_{12}^E = 1/9(1-2z_1)^2 + 2/9(5-7z_1)\sqrt{2C} + 5/9C$.

(ii) If $\sqrt{2C} \geq 2(1-z_1)$, then the optimal innovation result is $X_2^* = 2(1-z_1)$, the R&D investment is $K_2^E = 2(1-z_1)^2$, the profit of the R&D institution, firm 1 and the sum of both respectively are $\pi_{02}^E = 2/3(1-z_1)^2$, $\pi_{12}^E = 5/9(1-z_1)^2$ and $\Pi_2^E = \pi_{02}^E + \pi_{12}^E = 11/9(1-z_1)^2$.

2.2. Innovative Activities and Profit Distribution in Innovation Chain

2.2.1. Motivation to Set up Innovation Chain. In the case of a single leader, firm 1 obtains the innovative result, resulting in a change in revenue $v_1 - P_1 = v_1 - v_2 > 0$, so firm 1 has the motivation to obtain the innovative result. In the case of multiple leaders, firm 1 obtains the innovative result, resulting in a change in revenue $v_1 - P_1 = v_1 - v_1 = 0$, but the innovation result can make it a single leader and dominance in the follow-up competition, so firm 1 still has the motivation to obtain the innovative result.

The R&D institution and firm k establish an innovation chain to collaborate on innovation. The firm collects market information and provides it to the R&D institution, which makes the innovation activities of R&D institutions more targeted. At the same time, the R&D institution can arrange personnel to guide the firm to transform the innovation result, so as to enhance the contribution of it. The same innovation result X can improve more of the marginal production cost of firm k. No matter how many leaders, firms have the motivation to obtain the innovation result, so they can establish an innovation chain with the R&D institution. Especially for multiple leaders, the leader has only a probability of $1/m$ to obtain the innovation result (m is the number of neck-and-neck leaders). If the innovation chain is established, the probability of obtaining the innovation result can be improved, which is also one of the motivations to establish an innovation chain.

2.2.2. Innovation Chain Activities and Profit Distribution. The innovation activities in the innovation chain can also be expressed as a two-stage problem. At the first stage, the R&D institution cooperates to innovate with the firm and transfers the innovative result to the firm who pays the innovation result transfer price. At the second stage, the firm works with the R&D institution to transform the innovation result to improve its marginal productivity, compete with other firms, and finally allocate the excess profit of the innovation chain.

The R&D institutions and firm k establish an innovation chain to collaborate on innovation, so as to enhance the contribution of the innovation result. The same innovation result X can make the marginal production cost of firm k become $z_k - \gamma X$, where $\gamma > 1$. Then the production decision of firm k is as follows:

$$\max_{q_k} \pi_k = \left(1 - \sum_{i=1}^{n} q_i - (z_i - \gamma X)\right)q_k. \tag{8}$$

Firms, which fail to obtain the innovative result, still make decisions according to problem (2). The quantities and profits can be obtained by solving optimization problems (8) and (2):

$$q_k^E = \frac{\left(1 + \sum_{j=1}^{n} z_j - (n+1)z_k + n\gamma X\right)}{(n+1)}, \quad \pi_k^E = \left(q_k^E\right)^2. \tag{9}$$

If $n = 2$ and the R&D institution forms the innovative chain with firm 1 (i.e., $k = 1$), then the solution can be simplified to the following:

$$q_1^E = \frac{1}{3}(1 - 2z_1 + z_2 + 2\gamma X), \quad \pi_1^E = \left(q_1^E\right)^2. \tag{10}$$

In order to maximize the profit of the innovation chain, the decision-making problem of the R&D institutions is as follows:

$$\max_K \Pi = \pi_1 - K, \quad \text{s.t.} \begin{cases} K = \dfrac{X^2}{2}, \\ 0 \leq K \leq C, \end{cases} \tag{11}$$

The optimization problem (11) is solved to obtain the following:

(1) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} \geq 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, then the optimal innovation result is $X_3^* = 4\gamma(1-$

$2z_1 + z_2)/(9 - 8\gamma^2)$, the R&D investment is $K_3^E = 8\gamma^2(1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)^2$, and the profit of the innovation chain is $\Pi_3^E = (1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)$. At this time, the R&D institution has sufficient funds and does not need financing.

(2) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} < 4\gamma(1 - 2z_1 + z_2)/(9 - 8\gamma^2)$, then the optimal innovation result is $X_3^* = \sqrt{2C}$, the R&D investment is $K_3^E = C$, the profit of the innovation chain is $\Pi_3^E = 1/9((8\gamma^2 - 9)C + 4(1 - 2z_1 + z_2)\gamma\sqrt{2C} + (1 - 2z_1 + z_2)^2)$. At this time, the R&D institution needs financing for lack of sufficient funds.

(3) If $8\gamma^2 - 9 \geq 0$, then the optimal innovation result is $X_3^* = \sqrt{2C}$, the R&D investment is $K_3^E = C$, the profit of the innovation chain is $\Pi_3^E = 1/9((8\gamma^2 - 9)C + 4(1 - 2z_1 + z_2)\gamma\sqrt{2C} + (1 - 2z_1 + z_2)^2)$. At this time, the R&D institution needs financing for lack of sufficient funds.

The profit of the innovation chain need to distribute among the members of the innovation chain. The profit of the members of the innovation chain (R&D institution and firm (1) consists of two parts: one is the basic profit, that is, the profit in noninnovation chain; the other is the excess profit, that is, the excess profit of the innovation chain distributed according to the contribution of each member. There is only one member of each type in the simple innovation chain, so the excess profit of the innovation chain is distributed equally among the members. The total profit from the innovation chain of R&D institution and firm can be expressed as follows. If s denotes the number of the leaders (i.e., $s = 1$, the case of a single leader; $s = 2$, the case of multiple leaders), then the profits of R&D institution and the firm respectively are $\pi_{03}^E = \pi_{0s}^E + (\Pi_3^E - \Pi_s^E)/2$ and $\pi_{13}^E = \pi_{1s}^E + (\Pi_3^E - \Pi_s^E)/2$.

3. Internal Financing and Profit Distribution Mechanism in Innovation Chain

The R&D institution in the innovation chain need more financing because of their own financial constraints, but since they lack the collateral, the external financing is more difficult, so the financing of the firms in the innovation chain can be considered. On the other hand, the innovation result can bring more profit to firms when the R&D investment of R&D institution increases, so firms also have the motivation to lend funds to the R&D institution. In this paper, we, with reference to the supply chain finance, design the innovation chain internal prepayment financing mode.

3.1. Prepayment Financing Activities in Innovation Chain. For the insufficient capital of the R&D institution, the constraint in the optimization problem (11) is a tight constraint, that is, $K^E = C$. At this time, increased R&D investment can boost the profits of the R&D institution and the firm, so the firm can pay the transfer price of the innovation result in advance, and increase the R&D investment for R&D institution financing. The purchase prices of production input elements(such as the innovative production of the upstream subject) influence the profit of the firm in the innovation chain, but the quality of the upstream subject's innovative product impacts more significantly the profit. Therefore when the firm in innovation chain pays the innovation result transfer price to the R&D institution in advance, it is more desirable for the R&D institution to deliver high-quality innovation, rather than hope to get a price discount. Considering cost control and risk control, the firm only pays part of the transfer price in advance.

The financing activities of prepayment in the innovation chain can be divided into three stages. At the first stage, the R&D institution finances B from the firm. At the second stage, the R&D institution invests K in R&D, obtains the innovation result X and then transfers it to the firm, which in turn transfers the remaining cost, $P_1 - B$, to the R&D institution. The R&D institution obtains the first part of the profit, that is, noninnovation chain profit P_1. At the third stage, the firm converts the innovation result into the productive force, competes with other firms to get the profit, and finally distributes the excess profit of the innovation chain.

3.2. Prepayment Financing Mechanism and Member Profit in Innovation Chain. The third stage problem is the same as that in section 2.2.2, so the optimization problems (8) and (2) are used to describe the problem, and the quantity and profit of the firm are $q_1^E = 1/3(1 - 2z_1 + z_2 + 2\gamma X)$and $\pi_1^E = (q_1^E)^2$.

The second stage problem is similar to that in section 2.2.2, which can be expressed as follows:

$$\max_K \Pi = \pi_1 - K,$$
$$\text{s.t.} \begin{cases} K = X^2/2, \\ 0 \leq K \leq C + B, \end{cases} \tag{12}$$

By changing C in the optimization problem (11) to $C + B$, we obtain the solution of the optimization problem (12) as follows:

(1) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} \geq 4\gamma(1 - 2z_1 + z_2)/(9 - 8\gamma^2)$, then the optimal innovation result is $X_4^* = 4\gamma(1 - 2z_1 + z_2)/(9 - 8\gamma^2)$, the R&D investment is $K_4^E = 8\gamma^2(1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)^2$, the profit of the innovation chain is $\Pi_4^E = (1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)$. At this time, the R&D institution has sufficient funds and does not need financing.

(2) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} < 4\gamma(1 - 2z_1 + z_2)/(9 - 8\gamma^2) \leq \sqrt{2(C + B)}$, then the optimal innovation result is $X_4^* = 4\gamma(1 - 2z_1 + z_2)/(9 - 8\gamma^2)$, the R&D investment is $K_4^E = 8\gamma^2(1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)^2$, the profit of the innovation chain is $\Pi_4^E = (1 - 2z_1 + z_2)^2/(9 - 8\gamma^2)$. At this time, R&D

institution has insufficient funds of their own, but after financing, there will be a surplus of funds.

(3) If $8\gamma^2 - 9 < 0$ and $\sqrt{2(C+B)} < 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, then the optimal innovation result is $X_4^* = \sqrt{2(C+B)}$, the R&D investment is $K_4^E = C+B$, the profit of the innovation chain is $\Pi_4^E = 1/9((8\gamma^2-9)(C+B) + 4(1-2z_1+z_2)\gamma\sqrt{2(C+B)} + (1-2z_1+z_2)^2)$. At this time, R&D institution has insufficient funds of their own, but after financing, there will still be a shortage of funds.

(4) If $8\gamma^2 - 9 \geq 0$, then the optimal innovation result is $X_4^* = \sqrt{2(C+B)}$, the R&D investment is $K_4^E = C+B$, the profit of the innovation chain is $\Pi_4^E = 1/9((8\gamma^2-9)(C+B) + 4(1-2z_1+z_2)\gamma\sqrt{2(C+B)} + (1-2z_1+z_2)^2)$. At this time, R&D institution has its insufficient own funds, and there is still a shortage of funds after financing.

At the first stage, the R&D institution in the innovation chain finances B from the firm. With consideration of the capital cost of the firm, the innovation chain makes financing B as small as possible while maximizing the overall profit in order to realize the internal financing of the innovation chain. The problem can be expressed as follows:

$$\max_{B} \ (w\Pi - B), \quad \text{s.t. } B \leq MB, \tag{13}$$

where w is a sufficiently large positive number, indicating that the target level of maximizing total profit is much higher than the goal of minimizing financing, and MB indicates the maximum amount of financing that the firm can provide. The solution is as follows:

(1) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} \geq 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, then the optimal financing is $B^* = 0$, the innovation result is $X_4^* = 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, and the profit of the innovation chain is $\Pi_4^E = (1-2z_1+z_2)^2/(9-8\gamma^2)$.

(2) If $8\gamma^2 - 9 < 0$ and $\sqrt{2C} < 4\gamma(1-2z_1+z_2)/(9-8\gamma^2) \leq \sqrt{2(C+\text{MB})}$, then the optimal financing is $B^* = 8\gamma^2(1-2z_1+z_2)^2/(9-8\gamma^2)^2 - C$, the innovation result is $X_4^* = 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, and the profit of the innovation chain is $\Pi_4^E = (1-2z_1+z_2)^2/(9-8\gamma^2)$.

(3) If $8\gamma^2 - 9 < 0$ and $\sqrt{2(C+\text{MB})} < 4\gamma(1-2z_1+z_2)/(9-8\gamma^2)$, then the optimal financing is $B^* = \text{MB}$, the innovation result is $X_4^* = \sqrt{2(C+\text{MB})}$, and the profit of the innovation chain is $\Pi_4^E = 1/9((8\gamma^2-9)(C+\text{MB}) + 4(1-2z_1+z_2)\gamma\sqrt{2(C+\text{MB})} + (1-2z_1+z_2)^2)$.

(4) If $8\gamma^2 - 9 \geq 0$, then the optimal financing is $B^* = MB$, the innovation result is $X_4{}^* = \sqrt{2(C+\text{MB})}$, and the profit of the innovation chain is $\Pi_4^E = 1/9((8\gamma^2-9)(C+\text{MB}) + 4(1-2z_1+z_2)\gamma\sqrt{2(C+\text{MB})} + (1-2z_1+z_2)^2)$.

In the case (1), the R&D institution itself has sufficient funds and does not need financing. In the case (2), the R&D institution needs financing, the firm's capital is abundant, and the internal financing of the innovation chain can reach the optimal innovation and production level. In the case (3), the R&D institution needs financing, but the firm's capital is not sufficient, the innovation chain financing does not reach the optimal level, so the innovation chain needs external financing. In case (4), the more R&D investment in the innovation chain, the better, and both the R&D institution and the firm fully invest in R&D and seek external financing. However, in view of the assumption of gradual innovation $\gamma X < z_1$, case (4) is rare and needs to be discussed in the context of disruptive innovation. So it will not be investigated in this paper.

Finally, the total profit of the R&D institution and the firm obtained from the innovation chain can be expressed as follows. If s denotes the number of the leaders, then the profits of the R&D institution and the firm respectively are $\pi_{04}^E = \pi_{0s}^E + (\Pi_4^E - \Pi_s^E)/2$ and $\pi_{14}^E = \pi_{1s}^E + (\Pi_4^E - \Pi_s^E)/2$.

Under the same circumstances, $\Pi_4^E \geq \Pi_3^E \geq \Pi_1^E \geq \Pi_2^E$, $\pi_{04}^E \geq \pi_{03}^E \geq \pi_{01}^E \geq \pi_{02}^E$ and $\pi_{14}^E \geq \pi_{13}^E \geq \pi_{11}^E \geq \pi_{12}^E$. It means that cooperation of innovation and production in the innovation chain can bring the excess profit to the members (R&D institution and firm) and the internal financing of the innovation chain can improve the excess profit.

4. Risk Control Mechanism of Internal Financing in Innovation Chain

4.1. Risk Control Principles of Internal Financing in Innovation Chain. The risk of the internal financing of innovation chain is derived from the risk of the R&D stage and the risk of the production stage. The main operation subject in the R&D stage is the R&D institution, and the main operation subject in the production stage is the firm. Due to the particularity of R&D activities, the risk of the R&D stage is much greater, and the risks of the two stages are seriously asymmetric. So if the risk is to be shared among the members of innovation chain, it may not be possible to attract the firm in the production stage to join the innovation chain. In order to construct the innovation chain and control the risk of the internal financing in innovation chain, it is necessary to let each member bear the risk of its own main activity stage, reduce the risk of each stage and control the chain contagion of the risk of the innovation chain so that the risk of the main subject in the internal financing of the innovation chain does not exceed the risk of the noninnovation chain. The risk control of the internal financing in innovation chain can be realized through the reasonable risk sharing mechanism.

In the internal financing mode of innovation chain, there are three capital transfers between the R&D institution and the firm. The first one is for the firm to finance R&D institution; the second one is for the firm to pay the remaining cost to the R&D institution when transferring innovation result, and the third one is for firm to pay the excess profit of innovation chain to R&D institution at the end of production. The first capital transfer is the realization of the internal financing in innovation chain, and the risk of the internal financing in innovation chain is curbed by controlling the second and third capital transfers.

4.2. Risk Sharing Mechanism at the R&D Stage. The R&D institution shall bear the risk of R&D stage and reduce its transmission to production stage, namely, to ensure the profit of the firm. When the innovation result is transferred, the firm shall pay the remaining part of the price according to the value of the actual innovation result $\widehat{X}$, and determine the excess profit to be paid to the R&D institution.

4.2.1. Superquality Innovation Result. When the innovation result exceeds the plan, the transfer price remains unchanged, and the excess profit of the R&D institution is calculated according to the actual result. Therefore, if $\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) \geq 0$, the firm pays $P_1(C) - B$, and the excess profit of the R&D institution is $1/2(\pi_{14}(\widehat{X}) - \pi_{1s}(\widehat{X}))$, where s denotes the number of the leaders. Then they will wait for the third capital transfer.

4.2.2. Lower-Quality Innovation Result. When the innovation result is lower than the plan, the total profit of the innovation chain is lost, and the loss is borne by the R&D institution. Firstly, the remaining cost is used to compensate for the loss. Secondly, the excess profit of the R&D institution is used to compensate. Finally, the amount of financing is used to compensate. The remaining loss is borne by the firm. We let $s = 1$ to denote the case of a single leader and $s = 2$ to denote the case of multiple leaders:

(1) If $\pi_{1s}(X_4^*) - \pi_{1s}(\widehat{X}) - 2(P_1 - B) < \pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) < 0$, the R&D institution compensates the loss of the firm by repaying from the remaining cost, so the firm pays $(P_1 - B) - 1/2(\pi_{14}(X_4^*) - \pi_{14}(\widehat{X}) + \pi_{1s}(X_4^*) - \pi_{1s}(\widehat{X}))$, but the expected excess profit remains unchanged, which is still $1/2(\pi_{14}(\widehat{X}) - \pi_{1s}(\widehat{X}))$, and then they will wait for the third transfer of funds.

(2) If $1/2(\pi_{1s}(X_4^*) - \pi_{14}(X_4^*)) - (P_1 - B) < \pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) < \pi_{1s}(X_4^*) - \pi_{1s}(\widehat{X}) - 2(P_1 - B)$, the R&D institution compensates the loss of the firm with the full remaining cost and part of the expected excess profit. The firm pays 0, the excess profit of the R&D institution is $1/2(2\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*)) + (P_1 - B)$, and they will wait for the third capital transfer.

(3) If $1/2(\pi_{1s}(X_4^*) - \pi_{14}(X_4^*)) - P_1 < \pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) < 1/2(\pi_{1s}(X_4^*) - \pi_{14}(X_4^*)) - (P_1 - B)$, the R&D institution repays the firm $B - P_1 - 1/2(2\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*))$. The R&D institution cancels the remaining cost and the expected excess profit to compensate for the loss of the firm and at the same time repays part of the financing.

(4) If $\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) < 1/2(\pi_{1s}(X_4^*) - \pi_{14}(X_4^*)) - P_1$, the R&D institution repays the firm B. The R&D institution cancels the remaining cost and the expected excess profit, and repays the financing to compensate, but the firm still has to bear the remaining loss.

4.3. Risk Sharing Mechanism at the Production Stage. The firm shall bear the risk of production stage and reduce its transmission to R&D stage, that is, to ensure the profit of the R&D institution. At the end of the production, the firm should pay the actual excess profit to the R&D institution according to the actual profit $\widehat{\pi}$.

4.3.1. Pay Total Excess Profit. In the case of superquality innovation result or in the first case of lower-quality innovation result, the firm pays a total excess profit to the R&D institution. If $\widehat{\pi} \geq \pi_{14}(\widehat{X})$, the firm pays the excess profit $1/2(\widehat{\pi} - t\pi_{1s}n(\widehat{X}))$ to the R&D institution, if $1/2(\pi_{14}(\widehat{X}) - \pi_{1s}(\widehat{X})) \leq \widehat{\pi} \leq \pi_{14}(\widehat{X})$, the firm pays $1/2(\pi_{14}(\widehat{X}) - \pi_{1s}(\widehat{X}))$, if $0 \leq \widehat{\pi} \leq 1/2(\pi_{14}(\widehat{X}) - \pi_{1s}(\widehat{X}))$, the firm pays $\widehat{\pi}$, where s denotes the number of the leaders.

4.3.2. Pay Part of Excess Profit. In the second case of lower-quality innovation result, the firm pays part of the excess profit. If $\widehat{\pi} \geq \pi_{14}(\widehat{X})$, the firm pays $1/2(2\widehat{\pi} - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*)) + (P_1 - B)$, if $1/2(2\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*)) + (P_1 - B) \leq \widehat{\pi} \leq \pi_{14}(\widehat{X})$, the firm pays $1/2(2\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*)) + (P_1 - B)$, if $0 \leq \widehat{\pi} \leq 1/2(2\pi_{14}(\widehat{X}) - \pi_{14}(X_4^*) - \pi_{1s}(X_4^*)) + (P_1 - B)$, the firm pays $\widehat{\pi}$, where s denotes the number of the leaders.

4.3.3. Pay No Excess Profit. In the third or fourth case of lower-quality innovation result, the firm pays no excess profit to the R&D institution.

5. Conclusion

Through the research-development stage and production-commercialization stage, we analyze the innovation activities and profits and find that the innovation chain which is established by the R&D institution and the firm can bring the excess profit. Based on the cooperative partnership between the R&D institution and the firm and the characteristics of innovation activities in the innovation chain, the internal financing mechanism between members of the innovation chain is constructed, in which the firm finances funds for the R&D institution. The optimal financing strategy is given to alleviate the constraints of innovation funds and improve the excess profit of the innovation chain. Finally, considering the risk property of the innovation activities, we set up the risk sharing mechanism of each stage to control the risk of the internal financing between members of the innovation chain, which ensures the operation of the internal financing mechanism.

In addition, the internal financing mechanism between members of the innovation chain establishes the mutual finance-assisting relationship of the innovation subject in the innovation chain, which strengthens the leading role of the core innovation subject. If the R&D institution is the core, it can influence the firm through innovation results and its transfer. And if the firm is at the core, it can influence the R&D institution through financing. In a word, it could strengthen the relationship between innovation subjects and improve the coordination and cooperation mechanism, so that it would improve the efficiency of scientific and technological innovation activities.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors gratefully acknowledge the financial support of the General Program of Natural Science Foundation of Zhejiang Province (LY20G030007), Humanities and Social Sciences Research Project of the Ministry of Education of China (20YJA790097), Major Supporting Project of Philosophy and Social Sciences in Zhejiang Province (20XXJC03ZD), Major Supporting Project of Academy of Longyuan Construction Financial Research Ningbo University (LYZDA2003), and Zhejiang Provincial Collaborative Innovation Center of Port Economy.

References

[1] J. Schumpeter, *Capitalism, Socialism and Democracy*, Harper, New York, NY, USA, 3rd edition, 1950.
[2] M. T. Hansen and J. Birkinshaw, “The innovation value chain,” *Harvard Business Review*, vol. 85, no. 6, pp. 121–135, 2007.
[3] N. Sen, “Innovation chain and CSIR,” *Current Science*, vol. 85, no. 5, pp. 570–574, 2003.
[4] P. Bamfield, *The Innovation Chain, Research and Development Management in the Chemical and Pharmaceutical Industry*, WILrY VCH, Weinheim, Germany, 2nd edition, 2004.
[5] X. Lin, J. B. Liu, and X. Chen, “Industrial upgrading based on global innovation chains: a case study of Huawei technologies Co., Ltd. Shenzhen,” *International Journal of Innovation Studies*, vol. 2, no. 3, pp. 81–90, 2018.
[6] R. Stephen, D. Jun, and H. L. James, “Modelling the innovation value chain,” *Research Policy*, vol. 37, no. 6, pp. 961–977, 2008.
[7] G. Panagiotis and H. L. James, “The innovation value chain in new technology-based firms: evidence from the U.K.” *Journal of Product Innovation Management*, vol. 29, no. 5, pp. 839–860, 2012.
[8] E. L. Olson, “Perspective: the green innovation value chain: a tool for evaluating the diffusion prospects of green products,” *Journal of Product Innovation Management*, vol. 30, no. 4, pp. 782–793, 2013.
[9] L. Lai-Xin and Y. He, “The study on the cycle of technological innovation chain,” in *Proceedings of the International Conference on Wireless Communications*, IEEE, Dalian, China, March 2008.
[10] K. C. Ekaterina, E. K. Ekaterina, D. K. Anna, and S. P. Julia, “Research of instruments for financing of innovation and investment construction projects,” *Procedia Engineering*, vol. 153, pp. 112–117, 2016.
[11] B. Emanuele, “Innovation financing and the role of relationship lending for SMEs,” *Small Business Economics*, vol. 44, no. 2, pp. 449–473, 2015.
[12] H. C. Pfohl and M. Gomm, “Supply chain finance: optimizing financial flows in supply chains,” *Logistics Research*, vol. 1, no. 3-4, pp. 149–161, 2009.
[13] P.-H. Hsu, “development and innovation: cross-country evidence,” *Journal of Financial Economics*, vol. 112, no. 1, pp. 116–135, 2014.
[14] J. F. Tu, “Construction of die and mould technology innovation chain based on resource tree,” *Applied Mechanics and Materials*, vol. 201-202, pp. 1025–1028, 2012.
[15] L. Knut, M. S. Gordon, S. Jorg, and W. Arnold, “Financing innovations in uncertain networks-filling in roadmap gaps in the semiconductor industry,” *Research Policy*, vol. 42, no. 3, pp. 647–661, 2013.
[16] H. Byun and J. Lee, “The study on the technology finance policy for technology development on the value chain based innovation system,” in *Proceedings of the Portland International Center for Management of Engineering & Technology*, IEEE, Portland, Oregon, August 2007.
[17] L. M. Gelsomino, R. Mangiaracina, A. Perego et al., “Supply chain finance: a literature review,” *International Journal of Physical Distribution & Logistics Management*, vol. 46, no. 4, pp. 348–366, 2016.
[18] A. K. Maiti, M. K. Maiti, and M. Maiti, “Inventory model with stochastic lead-time and price dependent demand incorporating advance payment,” *Applied Mathematical Modelling*, vol. 33, no. 5, pp. 2433–2443, 2009.
[19] A. Thangam, “Optimal price discounting and lot-sizing policies for perishable items in a supply chain under advance payment scheme and two-echelon trade credits,” *International Journal of Production Economics*, vol. 139, no. 2, pp. 459–472, 2012.
[20] A. A. Taleizadeh, “Lot-sizing model with advance payment pricing and disruption in supply under planned partial backordering,” *International Transactions in Operational Research*, vol. 24, no. 4, pp. 783–800, 2017.
[21] G. P. Cachon, “The allocation of inventory risk in a supply chain: push, pull, and advance-purchase discount contracts,” *Management Science*, vol. 50, no. 2, pp. 222–238, 2004.
[22] B. Zhang, D. Wu, L. Liang, and D. L. Olson, “Supply chain loss averse newsboy model with capital constraint,” *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 46, no. 5, pp. 646–658, 2016.
[23] A. Diabat, A. A. Taleizadeh, and M. Lashgari, “A lot sizing model with partial downstream delayed payment, partial upstream advance payment, and partial backordering for deteriorating items,” *Journal of Manufacturing Systems*, vol. 45, pp. 322–342, 2017.
[24] M. Wandfluh, E. Hofmann, and P. Schoensleben, “Financing buyer-supplier dyads: an empirical analysis on financial collaboration in the supply chain,” *International Journal of Logistics Research and Applications*, vol. 19, pp. 1–18, 2015.
[25] M. Oliveira, M. Kadapakkam, and M. Beyhaghi, “Effects of customer financial distress on supplier capital structure,” *Journal of Corporate Finance*, vol. 42, pp. 131–149, 2017.
[26] H. Görg and E. Kersting, “Vertical integration and supplier finance,” *Canadian Journal of Economics/Revue Canadienne D’économique*, vol. 50, no. 1, pp. 273–305, 2017.