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TRANSFER PRICING OF INNOVATION CONSIDERING MATCHES BETWEEN INNOVATION AND TECHNOLOGY IN FIRMS

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Abstract. Firms can purchase innovation results to improve their technology. In this context, the key to transfer success is reasonably priced innovation results. Considering the match between innovation results and firm technology, this study analyzes the nonlinear improvement effect of innovation results on technology. The pricing decision is then assessed by a game model of the innovation results transfer and pricing that is based on the entire innovation process, including research and development (R&D) and transfer. Then the method for transfer pricing of innovation results is obtained from the equilibrium of game. The results show that firms tend to evaluate innovation results by matching them with their own technologies, and then make bids based on the R&D costs. Here, innovation results are obtained by firms with high-level matching. After considering the matching, the transfer pricing of innovative results will prosper the transfer market and improve the success rate of transfer. Several factors affect the possibility of transfer of innovation results and their price, including the R&D ability of the institution, the technology levels of firms, and the technological competition between firms. These conclusions were validated using a numerical example.

Keywords: transfer of innovation result, match between innovation and technology, transfer price, influencing factor, bidding game, pricing decision.

JEL Classification: O33, C72, D43.

Introduction

With increasingly fierce competition in science and technology across the globe, firms can establish a competitive advantage by enhancing their technological capabilities. This has influenced leading technological innovators to take initiative in the industrial market. Meanwhile, firms have gradually diversified their modes of seeking innovative technologies. In addition

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to relying on their own development capacities, they can also obtain innovative technologies through purchases. However, only a small number of Chinese firms currently obtain innovative technologies through transfers, which both limits the transfer rate of patents and affects their rate of industrialization (patents are the most common type of innovation results). According to The 2020 China Patent Survey Report issued by the China National Intellectual Property Administration, the transfer rate of effective invention patents was only 6.2%, while the transfer rate of effective patents was 4%; moreover, the transfer success rate was less than 10%, while the industrialization rate of effective invention patents was 34.7% (the rates of firms, universities, and R&D institutions were 44.9%, 3.8%, and 11.3%, respectively). In contrast, developed countries such as the United States, Japan, and Germany have shown transfer rates of patents reaching 20% to 30%, with industrialization rates of approximately 50%. In sum, the patent transfer success rate is very low in China, making the country one of the lowest patent utilizers and restricting technological innovation abilities and effects in Chinese firms.

Still, there is both supply and demand for innovation technology in the Chinese transfer market. In this regard, it is important to determine how to find the right innovation result to bid and whether pricing is reasonable, as these are the keys to successful transfers and industrializations. This highlights the need for continued research aimed at clarifying the nature of technology transfer pricing in the context of innovation management in China.

The remainder of this paper is organized as follows. Section 1 is literature review. Section 2 discusses the methodology to investigate the transfer and pricing of innovation results. Section 3 presents the results including the equilibriums and the method of transfer and pricing. Section 4 provides an extended discuss of the basic study model. Section 5 presents a numerical example. The last part concludes the main results and further ways of research.

1. Literature review

Valuation is necessary to determine whether it is feasible to commercialize innovation technology. Indeed, this is an important issue in technology management. The valuation of innovation results has also remained an important research field in innovation management. Of note, the valuation of innovation results is affected by factors such as innovation costs, R&D risks, and production levels (Bessen, 2009; Hong et al., 2010), including cost-based, market-based, and income-based approaches (Da Cruz et al., 2017; Biagioli, 2019). A cost-based approach determines the relationship between the innovation results and their R&D cost; that is, the actual cost of developing a new technology (Carte, 2005). The market-based approach seeks the real value of a similar innovation result in the market, then makes appropriate price adjustments, which requires reliable accounting data and similar innovation statistics (Baeket al., 2007). The income-based approach estimates the price of innovation results based on the profitability those results can bring to firms and is widely used by scholars (Tsai et al., 2016; Tukoff-Guimarães et al., 2021). From the purchaser's perspective (Yun et al., 2016), the profitability of any technological improvement effectsthat are derived from innovation results predict their valuation (Sakakibara, 2010; Kabulova & Stankevičienė, 2020), while the value of the patent is determined by its ability to generate future revenues for the owner (Wu & Tseng, 2006). Based on the risks and returns associated with technical results, Galai and Ilan (1995) evaluated compensations for patent and technology transfers. Later, Faulkner (1996) applied the option method to study transfer pricing for innovation results. Hsieh (2013) measured and analyzed patent commercial value via factor analysis, with a focus on general management benefits general management risks general offensive interests, cost-related risks. Yagi and Managi (2018) measured and compared the shadow price (marginal cost) and shadow value (total cost) using the Data envelopment analysis (DEA) method. From the perspectives of both buyers and sellers, Smith and Parr (1989) studied the pricing strategy for innovation results using game theory and local equilibrium theory, then discussed the equilibrium price in the game process between the suppliers and demanders of innovation results based on Marshall's local equilibrium theory. Research has shown that the double marginalization problem in the transfer process can be solved using licensing pricing for sales revenue (Lin et al., 2011). Various studies have also confirmed the existence of relationships between patent prices and various influencing factors (Lee et al., 2018; Su et al., 2023; Zeng et al., 2022); the patent transfer price can be predicted through several patent factors (e.g., patent age, universality, originality, technical field, quotation situation) and company factors (e.g., scale, ownership nature) (Sreekumaran Nair et al., 2012; Vimalnath et al., 2017; Thoma, 2020). Machine-learning algorithms, such as Bayesian neural network-based model and deep learning method, are used to predict patent price (Grimaldi & Cricelli, 2020; Liu et al., 2020).

As shown above, previous studies have discussed pricing strategies from different perspectives and explored the impacts of the external environment and innovation uncertainty on the pricing of innovation results. However, their conclusions were based on only the innovation technology itself and price innovation technology based on the profit effect resulting from linear improvements in technology innovation. Meanwhile, researchers have ignored whether there is a match between the firm's own technology and the innovation results. In fact, the improvement effects achieved through such innovations are determined by whether the firm's existing technology can absorb and transform the innovation results; this is the key factor in pricing those results. In other words, both the transfer and pricing of innovation results must be determined based on whether there is a match between the innovation results and the firm's technology.

This study contributes to the literature on innovation transfer pricing in two ways. First, regarding transfer pricing, this is among the first studies to consider the match between innovation and technology. A nonlinear improvement effect model was constructed to study the transfer pricing of innovation results and assess how it affects firm technology; this can better simulate and interpret the realistic transfer market and transfer pricing of such results. Second, based on the entire innovation process (consisting of R&D, bidding and transfer, production and commercialization), innovation transfer pricing was investigated through an innovation transfer game model that combined the cost, market, and income. Using the equilibrium solution, the analysis of innovation transfer pricing decisions and the influencing factors can reasonably price and improve both the transfer success rate and industrialization rate of innovation.

2. Methodology

2.1. Assumptions of innovation and transfer

The innovation and transfer process is divided into three stages, including R&D, bidding and transfer, and production and commercialization. There is only one R&D institution in the R&D stage. In the bidding and production stage, there are *n* firms, with *n* being exogenous and fixed. In the first stage, the R&D institution chooses the level of the innovation result X, while the R&D investment is a linear function of the level of the innovation result $K = aX$, where *a* is the R&D cost coefficient, which is negative correlated with R&D capability. Further analysis shows that the linear investment function only affects the income size, and does not therefore affect the innovation transfer and pricing decision. To focus on this, we adopted the linear function. In the second stage, the innovation result is competitively bid on by *n* firms; firm *i* bids P_i for the innovation result, but this is only transferred to firm *k* with the highest bid $P_k = \max_i P_i$. In the third stage, the original marginal production cost of firm *i* is z_i. If firm *k* obtains the innovation result, then its marginal costs decrease $\Delta z_k(X)$ and become $z_k - \Delta z_k$. The marginal production costs of other firms remain unchanged. Given the marginal cost condition, *n* firms compete through quantities, which results in Cournot competition.

2.2. Improvement effect of innovation on technology in consideration of matching

Innovation can improve firm technology and enhance core competitiveness. Most researchers assume that innovation linearly improves technology; that is, the technical improvement effect resulting from a unit innovation result is expected to remain constant. However, this does not align with reality. In fact, the improvement effect of innovation on technology not only depends on the innovation results, but also on both the original technology and transformation ability of the firm. In other words, it is dependent on the match between innovation and technology, as determined by the level of agreement between the innovation results and firm's existing technology.

The improvement effect of the innovation result on the firm's technology can be expressed as the product of the technical knowledge which is available for learning (TK) and the transformation ability of the firm (TA). TK, which is usually denoted as the maximum of zero and the difference between the level of the innovation result and the level of the firm's original technology, is positive correlation with the level of the innovation result. TA is affected by the firm's knowledge accumulation, researchers, learning ability, and other factors. The higher the level of the innovation result, the more beyond the technical level of the firm, the more difficult it is for the firm to transform, as it is limited by the lack of original technology. So TA is a decreasing function with respect to the level of the innovation result and concave down. Of course, $TA \in [0,1]$.

2.2.1. Completely mismatching

When the level of the innovation result is lower than the level of the firm's original technology, it cannot bring about new technical knowledge (i.e. TK = 0). The firm can transform the innovation result, but this does not sufficiently improve the firm's technology. When the level of innovation is higher than the upper limit of the firm's transformation capacity due to limitations in the original technology and transformation capacity, TA = 0 and the firm cannot transform the innovation result, meaning that it cannot improve its technology. Therefore, innovation results those do not match the firm's technology level do not improve the firm's technology.

2.2.2. Matching

When the innovation results match the firm's technology level (i.e., the level of the innovation result is between the original technology level and the upper limit of the transformation ability), the transformation of the innovation results can improve the firm's technology. (1) Lower-level innovation results. When the level of the innovation result increases, TK increases and TA decreases. For the improvement effect, the increase effect of TK is greater than the reduction effect of TA, because $\partial^2 TK / \partial X^2 = 0$ and $\partial^2 TA / \partial X^2 \leq 0$. Therefore, the improvement effect increases monotonically with the innovation level, while the marginal improvement effect decreases. (2) High-level innovation results. Still TK increases and TA decreases when the level of the innovation result increases. But now the reduction effect of TA for the improvement effect is dominant because $\partial^2 TK / \partial X^2 = 0$ and $\partial^2 TA / \partial X^2 \leq 0$. So the improvement effect decreases while the level of innovation result increases, with a continually growing rate of decrease. (3) Therefore, the improvement effect of an innovation result that matches the firm's technology shows an inverted U-shape that reaches a maximum under a full match.

Generally, a firm's ability to transform innovation results is affected by its knowledge accumulation, researchers, learning ability, and other factors. Thus, the transformation ability is positively related to the firm's technology level, which can be used to measure its transformation ability.

The marginal production cost was used to represent the firm's technology level, while its degree of reduction was used to measure the improvement effects on the firm's technology. For the positive correlation between the ability to transform the innovation results and technology level, different functions of marginal cost were used to represent the upper limit and optima of the transformation capacity. When the marginal cost is $z_k, 0 < z_k < 1$, it is supposed that the technology level of the firm is $\alpha_1(1 - z_k)$, the optimal transformation capacity is $\alpha_2(1 - z_k)$, and the upper limit of the transformation capacity is $\alpha_3(1 - z_k)$, where $\alpha_1 < \alpha_2 < \alpha_3$. The value of α_i is depend on the industry characteristics, enterprise characteristics and other factors. In order to focus on the transfer pricing method of innovation results, it is supposed that $\alpha_1 = 1$, $\alpha_2 = 2$ and $\alpha_3 = 3$, which will simplify the calculation and results of the model, but will not affect the transfer pricing methods and conclusions. According to the analysis of the improvement effect of innovation on technology, when $(1 - z_k) < X < 3(1 - z_k)$, the improvement effect can be expressed as:

$$\Delta z_k = \frac{b(-(X - (1 - z_k))^2 + 2(1 - z_k)(X - (1 - z_k)))}{(1 - z_k)^2}. \tag{1}$$

Otherwise $\Delta z_k = 0$ where b is the transformation coefficient, which depends on industry characteristics, innovation environment characteristics, and other external factors. Assuming that there are only incremental innovations, i.e. $\Delta z_k < z_k$.

2.3. Modeling for the transfer pricing of innovation results

In the first stage, the income of the R&D institution is P, which is the transfer price of the innovation result; it chooses the level of the innovation results to maximize its own profit, which is the difference between the transfer price and R&D cost. When the innovation result is zero, the profit of the R&D institution is also zero; thus, zero is the guaranteed profit that it can generate. Therefore, the R&D models of R&D institutions are as follows:

$$\max_{X} P(X)-K(X)$$
$$s.t.\begin{cases} P(X)-K(X)\geq 0 \\ P(X)=P_k=\max_{i} P_i \\ X\geq 0 \end{cases}. \quad (2)$$

In the second stage, n firms bid for innovation. Since zero is the guaranteed profit of an R&D institution, the price cannot be lower than the R&D cost. The bidding mechanism with the highest price shows that a firm that bids lower than any other firms cannot obtain the innovation result. Moreover, the firm's bid will not be higher than its valuation of the innovation result v. The binary decision variables D_{i1} and D_{i2} were introduced for firm i. If $P_i \geq K$, then D_{i1} = 1; otherwise, D_{i1} = 0. If $P_i \geq \max_{j\neq i} P_j$, then $D_{i2}=1$; otherwise, $D_{i2}=0$. Then, the firm's bidding model is as follows:

$$\max_{P_i} D_{i1}D_{i2}(v_i(X)-P_i(X))$$
$$s.t.\begin{cases} v_i(X)-P_i(X)\geq 0 \\ P_i(X)\geq 0, D_{i1}, D_{i2}\in\{0,1\} \end{cases}. \quad (3)$$

In the third stage, observed the marginal costs of all firms and the transfer of the innovation result, firm i chooses the output q_i to maximize the income π_i, which means Cournot competition. The inverse demand function was assumed to be $p=1-\sum_{i=1}^{n} q_i$. The production model of the firm that obtains the innovation results was as follows:

$$\max_{q_k} \pi_k = (1-\sum_{j=1}^{n} q_j-(z_k-\Delta z_k))q_k. \quad (4)$$

Meanwhile, the production models of other firms were as follows:

$$\max_{q_i} \pi_i = (1-\sum_{j=1}^{n} q_j - z_i)q_i. \quad (5)$$

Firm i evaluates the innovation result based on the related income increase $v_i=\pi_i^E-\pi_{i0}^E$, where π_{i0}^E is the income of firm i when the innovation result is not in the market.

The three stages of transfer and pricing of the innovation result influence each other. To assess the improvement effects of innovation results in consideration of matching, this study adopted a reverse solution analysis to study this dynamic problem.

3. Results

3.1. Equilibrium of the production and commercialization stage

3.1.1. Equilibrium of the production game

To investigate the production and commercialization stage, a system of equations was constructed from the optimal first-order conditions of models (4) and (5), from which the output of each firm can be obtained as $q_i^E(k)$, where the superscript E represents the equilibrium result. The equilibrium outputs were as follows:

$$q_k^E = (1+\sum_{j=1}^{n} z_j - (n+1)z_k + nb\Delta z_k)) \Big/ (n+1)\,; \tag{6}$$

$$q_i^E = (1+\sum_{j=1}^{n} z_j - (n+1)z_i - b\Delta z_k) \Big/ (n+1)\,,\ i \neq k\,. \tag{7}$$

For all firms, the equilibrium income of firm i is $\pi_i^E = (q_i^E)^2$. Obviously, when the innovation result is not in the market, the equilibrium of Cournot competition is as follows:

$$q_{i0}^E = (1+\sum_{j=1}^{n} z_j - (n+1)z_i) \Big/ (n+1)\,,\ \pi_{i0}^E = (q_{i0}^E)^2\,. \tag{8}$$

3.1.2. Firm's valuation of the innovation result and the dividing point

Firm i uses incremental income resulting from the innovation result to evaluate it, as follows:

$$\begin{aligned} v_i &= \pi_i^E - \pi_{i0}^E \\ &= nb\Delta z_i (2+2\sum_{j=1}^{n} z_j - 2(n+1)z_i + nb\Delta z_i) \Big/ (n+1)^2 \end{aligned}. \tag{9}$$

The valuations of the innovation result by any two firms were chosen for comparison. Suppose that firms 1 and 2 were selected for comparison, and $z_1 < z_2$. Let $w = v_1 - v_2$. Firm 1 has an advantage in bidding for the innovation result when $w > 0$, while firm 2 has an advantage in bidding for the innovation result when $w < 0$. And the two firms are of well-matched strength in bidding for the innovation result, the R&D institution chooses the firm with the best match for the transaction when $w = 0$. Therefore, $w = 0$ is the dividing point. The innovation result corresponding to that point is expressed as X_c.

The existence of X_c is motivated as follows. When $X = 1 - z_1$, $3(1-z_2) > X = 1 - z_1 > 1 - z_2$ because $z_1 < z_2$. It is easy to obtain $v_1 = 0$ and $v_2 > 0$ from the definitions of Δz_i and v_i. So, $w = v_1 - v_2 < 0$. When $X = 3(1-z_2)$, $3(1-z_1) > X = 3(1-z_2) > 1 - z_2$ for $z_1 < z_2$. $v_1 > 0$ and $v_2 = 0$ can be obtained from the definitions of Δz_i and v_i. So, $w = v_1 - v_2 > 0$. Moreover, w is a continuous function when $3(1-z_2) > 1 - z_1$. Therefore, according to the median theorem, there is a unique solution called X_c for $w = 0$ on the interval $(1-z_1, 3(1-z_2))$.

The value of X_c can get from model (9). The following equation can be obtained from model (9):

$$X_c^3 + X_c M - N = 0\,,$$

where $\begin{cases} M = \dfrac{16(1-z_1)^2(1-z_2)^2(z_1-z_2)}{(1-z_1)^2+(1-z_2)^2} \\ -\dfrac{(1-z_1)^2(1-z_2)^2(z_1-z_2)^2}{((1-z_1)^2+(1-z_2)^2)(2-z_2-z_1)} \\ N = \dfrac{10(1-z_1)^3(1-z_2)^3}{(1-z_1)^2+(1-z_2)^2} \end{cases}$.

The equation is solved via the Shengjin formula to obtain X_c, as follows:

$$X_c = \sqrt[3]{-\frac{M}{2}+\sqrt{(\frac{M}{2})^2+(\frac{N}{3})^3}} + \sqrt[3]{-\frac{M}{2}-\sqrt{(\frac{M}{2})^2+(\frac{N}{3})^3}}. \quad (10)$$

3.2. Equilibrium of the bidding and transfer stage

3.2.1. Bidding strategies of firms for the innovation result

Firms bid under the condition of complete information; that is, each firm knows the valuations that all other firms have placed on the innovation result, the R&D costs and requirements of the R&D institution for the transfer price $P_i \geq K(X)$. Firm *i* bids P_i to maximize bidding income $v_i - P_i$. Because the bidding income when the firm exits is zero, it obtains the guaranteed bidding income of zero and requires $P_i \leq v_i$.

Firms with $v_i < K(X)$ cannot meet the requirements of the price of the R&D institution and itself at the same time, so they will exit bidding.

Any firm with a valuation that satisfies $v_i \geq K(X)$ first strives to bid not only to obtain the innovation result (that is, to ensure that its bid is the highest of all firms), but also to meet the requirements of the R&D institution $P_i \geq K(X)$. This is because it has the chance to obtain bidding income only when it obtains the innovation result; otherwise, its bidding income is zero. Second, the firm should strive for maximum bidding income; that is, to make its bid as low as possible. Given that no firm can bid higher than its valuation, firm *i* bids $P_i = \max_{j \neq i}\{v_j \mid v_j \leq v_i\}$ to compete with the other firms. Considering the requirement of the R&D institution for the transfer price, the bid for firm *i* is $P_i = \max\{K(X), \max_{j \neq i}\{v_j \mid v_j \leq v_i\}\}$. In particular, when many firms with the highest valuation that meets the requirements, all bid the highest valuation.

The R&D institution transfers the innovation result to firm *k* with the highest bid $P_k = \max_i \{P_i \mid P_i \geq K(X)\}$, which meets its price requirement.

3.2.2. Equilibrium of bidding for the innovation result

For any number *n* of firms at the production stage, the firm who obtains the innovation result and the transfer price can be determined through a pairwise comparison of firms. Given a match between their own technology and the innovation result, two firms bid; then, the firm that bids higher is chosen for comparison with other firms. The highest bid can be obtained through gradual pairwise comparisons; here, the R&D institution transfers the innovation result to the firm with the highest bid. To discuss the bidding process, two firms are compared (i.e., the production stage is reduced to a double oligopoly). The winner is then compared with the third firm (still a double oligarchy competition).

Because the valuation of the innovation result is a higher-order polynomial function, it is difficult to obtain an analytical formula for the bidding equilibrium. In this section, the descriptive geometry solution is therefore used to explain the bidding equilibrium of the two firms, which is not difficult to generalize for the bidding of *n* firms.

(1) Large technical gap between firms.

Given $3(1-z_2) \le 1-z_1$, there is a large technical gap between the two firms. According to the previous analysis, the valuation curve of firm *i*, v_i, is a unimodal curve in the effective interval, and there is no intersection between the valuation curves v_1 and v_2. Let the slope of the tangent line of v_i, passing through the origin, be denoted as a_i. It can be obtained as from Eq. (9). If the point, $((\tilde{v}_i, \tilde{X}))$, is satisfied both Eq. (9) and $\partial v_i / \partial X \,|\, (\tilde{v}_i, \tilde{X}) = \tilde{v}_i / \tilde{X}$, then $a_i = \tilde{v}_i / \tilde{X}$. With the R&D cost function of the R&D institution $K = aX$ for the innovation result X, the bidding equilibrium can be obtained by the bidding strategies of the firms in the bidding game.

Case 1.1. As in $a > \max\{a_1, a_2\}$, then $v_1 < K(X)$ and $v_2 < K(X)$. There is no price that meets the requirements of both the R&D institutions and firms. According to the bidding strategies of firms, both firm 1 and firm 2 exit bidding, meaning the bidding fails.

Case 1.2. As $\min\{a_1, a_2\} < a \le \max\{a_1, a_2\}$, suppose that $a_1 < a_2$, from Eq. (9) and the R&D cost function, the intersections X_3 and X_4 between the R&D cost function and the valuation curve of firm 2 can be obtained, and $X_3 \le X_4$. At this time, if $X_3 \le X \le X_4$, then $v_1 < K(X)$ and $v_2 > K(X)$. According to the bidding strategies of firms, firm 1 exits bidding, but firm 2 bids, so the R&D institution transfers the innovation result to firm 2 at the price $K(X)$; otherwise, $v_1 < K(X)$ and $v_2 < K(X)$, then the bidding fails. This is shown on the left side of Figure 1. Similarly for $a_1 > a_2$, the intersections X_1 and X_2 between the R&D cost function and the valuation curve of firm 1 can be obtained, and $X_1 \le X_2$. If $X_1 \le X \le X_2$ at this time, then $v_1 > K(X)$ and $v2 < K(X)$. According to the bidding strategies of firms, firm 1bids, but firm 2 exits bidding, so the R&D institution transfers the innovation result to firm 1 at the price $K(X)$; otherwise, $v_1 < K(X)$ and $v_2 < K(X)$, then the bidding fails.

Case 1.3. For $a \le \min\{a_1, a_2\}$, the intersections of the R&D cost function and the firms' valuation curves can be obtained and denoted as per the previous symbols. If $X_3 \le X \le X_4$, then the innovation result is transferred to firm 2 at price $K(X)$ .If $X_1 \le X \le X_2$, then the innovation result is transferred to firm 2 at price $K(X)$. In other cases, the bidding fails. This is shown on the right side of Figure 1.

(2) Medium technical gap between firms.

For $3(1-z_2) > 1-z_1$ and $X_c > 2(1-z_2)$, there is a medium technical gap between the two firms. The intersection of the two valuation curves is referred to as X_c. Let a_3 denote the slope of the ray connecting this intersection and the origin, which is obviously

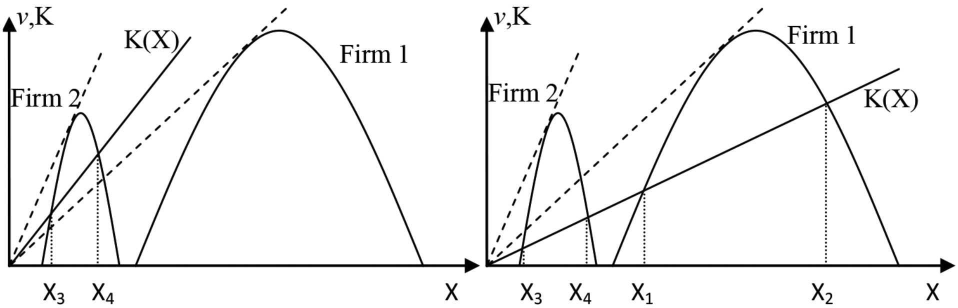

Figure 1. Equilibrium of bidding with large technical gap

$\min\{a_1,a_2\} > a_3$. Each symbol has the same meaning. Similarly, the bidding equilibrium can be obtained.

Case 2.1. As $a \quad \max\{a_1,a_2\}$, there is no price that meets the requirements of both the R&D institution and firms, meaning the bidding fails.

Case 2.2. As $\min\{a_1,a_2\} < a \le \max\{a_1,a_2\}$, the equilibrium is as follows. When $a_1 < a_2$, firm 2 obtains the innovation result from the R&D institution at the price $K(X)$ if $X_3 \le X \le X_4$; otherwise, the bidding fails. When $a_1 > a_2$, if $X_1 \le X \le X_2$, firm 1 obtains the innovation result at price $K(X)$; otherwise, the bidding fails.

Case 2.3. As $a \le \min\{a_1,a_2\}$, the bidding equilibrium is as follows:

If $a \ge a_3$, at the price $K(X)$, the R&D institution transfers the innovation result to firm 2 with $X_3 \le X \le X_4$ and to firm 1 with $X_1 \le X \le X_2$. In other cases, the bidding fails. This is shown on the left side of Figure 2.

If $a < a_3$, at the price $K(X)$, the R&D institution transfers the innovation result to firm 2 with $X_3 \le X \le X_1$ and to firm 1 with $X_4 \le X \le X_2$. With $X_1 \le X \le X_c$, it is easy to find $v_2 > v_1 > K(X)$. According to the bidding strategies of firms, both firm 1 and firm 2 bid, but $P_2 = v_1 > K(X) = P_1$, so the R&D institution transfers the innovation result to firm 2 at the price $\hat{P} = v$. With $X_c \le X \le X_4$, it is not difficult to get $v_1 > v_2 > K(X)$. According to the bidding strategies of firms, both firm 1 and firm 2 bid, but $P_1 = v_2 > K(X) = P_2$, so the R&D institution transfers the innovation result to firm 2 at the price $\hat{P} = v_2$. In other cases, the bidding fails. This is shown on the right side of Figure 2. The price $\hat{P}$ can be summarized as follows:

$$\hat{P} = \begin{cases} \dfrac{nb\Delta z_2}{(n+1)^2}(2 + 2\sum_{j=1}^{n} z_j & X_1 < X \le X_c \\ -2(n+1)z_2 + nb\Delta z_2), & \\ \dfrac{nb\Delta z_2}{(n+1)^2}(2 + 2\sum_{j=1}^{n} z_j & X_c < X \le X_4 \\ -2(n+1)z_1 + nb\Delta z_1), & \end{cases}. \tag{11}$$

(3) Small technical gap between firms.

When $3(1 - z_2) > 1 - z_1$ and $X_c < 2(1 - z_2)$ are used, there is a small technical gap be-

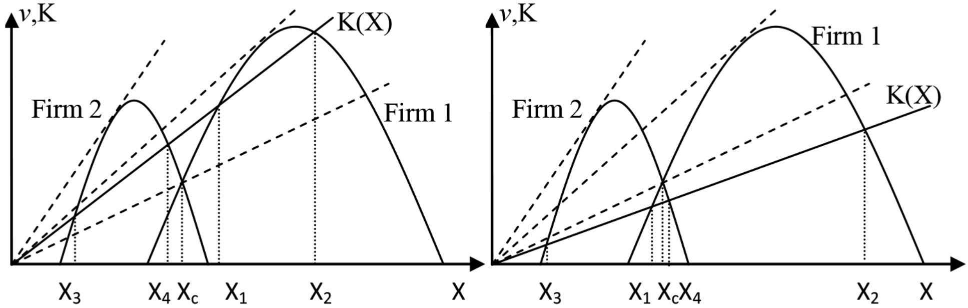

Figure 2. Equilibrium of bidding with medium technical gap

tween the two firms. The meaning of each symbol is consistent. Similarly, the bidding equilibrium can be obtained.

Case 3.1. As $a > \max\{a_1, a_2\}$, there is no price that meets the requirements of both the R&D institution and firms, meaning the bidding fails.

Case 3.2. As $\min\{a_1, a_2\} < a \le \max\{a_1, a_2\}$, the equilibrium is as follows. When $a_1 < a_2$, firm 2 obtains the innovation result at the price $K(X)$ if $X_3 \le X \le X_4$; otherwise, the bidding fails. When $a_1 > a_2$, if $X_1 \le X \le X_2$, then firm 1 obtains the innovation result at price $K(X)$; otherwise, the bidding fails.

Case 3.3. As $a \le \min\{a_1, a_2\}$, the bidding equilibrium is as follows:

(i) If $a \ge a_3$, then the R&D institution transfers the innovation result to firm1 with $X_1 \le X \le X_2$. The transfer price is $K(X)$ when $X_1 \le X \le X_3$ or $X_4 \le X \le X_2$, but is $\hat{P}$ when $X_3 \le X \le X_4$. In other cases, the bidding fails. This is shown on the left-hand-side of Figure 3.

(ii) If $a < a_3$, then the R&D institution transfers the innovation result to firm 2 with $X_3 \le X \le X_c$. The transfer price is $K(X)$ when $X_3 \le X \le X_1$, but is $\hat{P}$ when $X_1 \le X \le X_c$. The R&D institution transfers the innovation-result to firm 1 with $X_c \le X \le X_2$. The transfer price is $K(X)$ when $X_4 \le X \le X_2$, but is $\hat{P}$ when $X_c \le X \le X$. The bidding fails in other cases. This is shown on the right side of Figure 3.

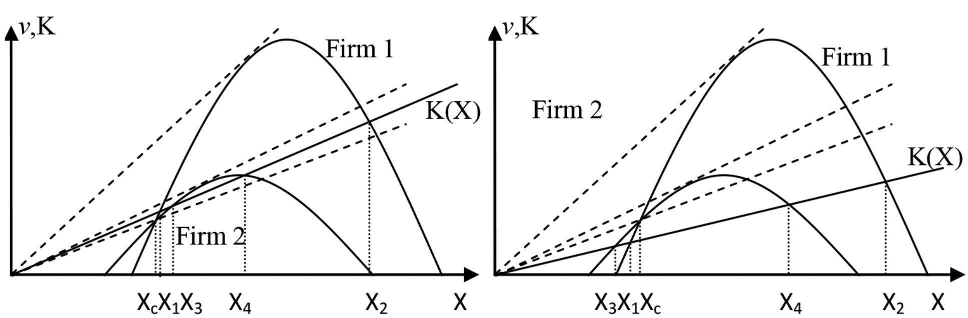

Figure 3. Equilibrium of bidding with small technical gap

3.2.3. Method for the transfer pricing of innovation results

Summarized the equilibrium of bidding and transfer, we get the method for the transfer pricing of innovation results.

Step 1: Collect the value of parameter a, b and z_i .

Step 2: z_i is Substituted into Eq. (10) to calculate X_c , in order to judge the degree of technical gap between firms.

Step 3: Use b, z_i and Eq. (9) to obtain the firm's evaluation function of the innovation results v_i , then calculate the slope of its tangent line passing through the origin, a_i . The R&D cost coefficient a is compared with a_i to determine by which case to solve the price.

Step 4: Calculate the intersections of the R&D cost function, $K = aX$, with the firm's evaluation function, X_{i1} and X_{i2} , if they exist. X_{i1} , X_{i2} and X_c are used to divide the feasible domain of X into several intervals.

Step 5: For the innovative results X provided by the R&D institution, judge which interval it belongs to and then determine to whom it is transferred and the transfer price K or $\hat{P}$, which is calculated through the R&D cost function or Eq. (11).

3.3. Impact of considering the matching on the transfer market

Firms can evaluate the profit brought by innovation results. Due to the consideration of matching, firms have higher valuations of innovation results with high matching with their own technical levels, and have more advantages in bidding on them, so it is easier to obtain the high matching results. At the same time, firms are not willing to bid for innovation results with low matching with their own technical level, which would avoid vicious market competition. Therefore, in the transfer of innovation results considering the matching, firms will bid for innovation results according to their own technical level, rather than blindly pursue high-level innovation results or monopolize all innovation results. At the same time, that firms choose the matching innovation results can also avoid the vicious competition, so the transfer price is more reasonable. This makes the transfer market and price of innovation results more rational, and the success rate of transfer can also be improved. Firms pursue matching innovation results so the transformation of innovation results is easier to achieve, which naturally makes the industrialization rate of innovation results also improved.

Considering matching, firms with different technological levels require different levels innovation results. In the face of diverse market demand, R&D institutions can choose the right innovation according to their own conditions for research. Staggered the research of R&D institutions can reduce the competition between each other and make more R&D institutions can research. So they will provide a variety of levels of innovation results that makes the market prosper and improves the success rate of transfer.

4. Discussion

4.1. Factors influencing the equilibrium transfer price

The R&D capacity of the R&D institution (R&D cost coefficient, a) determines both the R&D cost function and its slope, which determines the innovation result. This obviously affects the potential for a successful innovation transfer and its price. Given weak R&D capacity (i.e., the R&D cost coefficient a is large), a higher R&D cost is required to achieve a certain innovation result; this decreases the possibility that the R&D cost is lower than the valuations made by firms and limits the potential for successful transfers. If the cost is only less than one firm's valuation upon completion of the innovation transfer, then the transfer price is the cost and the profit of the R&D institution is zero; this dampens its R&D enthusiasm. However, if the R&D cost is lower than the valuations of multiple firms, then the transfer price is the second-highest valuation, which is higher than the cost. Here, the R&D institution obtains a profit, thus driving more research. In sum, an R&D institution's capacity is positively related to both the possibility of a successful innovation transfer and the potential earnings of the R&D institution. Meanwhile, this also affects the transfer price.

The firm's technology level, as measured by z, determines its valuation of the innovation result and both the location and peak of its valuation curve. When the firm's valuation curve is closer to the origin (i.e., $1-z$ becomes smaller), the corresponding tangent slope is greater. This lowers the level of innovation required to meet the firm's needs and reduces the R&D cost. As such, there is a greater possibility that the innovation result will be successful upon transfer even though the transfer price is lower. By contrast, the lower the peak of the firm's valuation curve (i.e., the smaller $1-z$ becomes), the lower the possibility that the valuation will exceed the R&D cost. Here, both the possibility of success and transfer price are lower.

Transformation coefficient b also affects the peak of the firm's valuation curve. If b is large when z decreases, then the increment in the peak of the curve is greater than the increment in its distance from the origin. If b is small, when z decreases, then the increment in its peak is lower than the increment in its distance. If b is medium, the two increments are nearly equal.

Based on the combined effects of both factors, the following can therefore be predicted: when b is large, the peak effect dominates, meaning that the potential for a successful innovation result transfer increases with the improvement of firm technology. When b is small, the position effect is dominant, meaning that the potential for a successful innovation result transfer decreases with improvement of firm technology. When b is medium and the firm has low technology levels, the potential for a successful innovation result transfer is high due to the dominant position effect. High technology levels also result in high potential due to the dominant peak effect, but the potential remains low with medium technology because neither of the effects is significant. Regardless, as long as the transfer can be completed, the transfer price is positively related to the firm's technology level (that is, negatively related to z), but the profit changes of both the R&D institution and firm are uncertain.

The level of technical competition between firms depends on both the number of firms and the degree of technical gap between them. The number of firms (n) determines the area covered by at least one valuation curve and the possibility of at least one positive intersection between the valuation curves. As n increases, the area covered by the valuation curve also increases. Since the firm only bids in the valuation curve area, the possibility of transfer increases with the area of the valuation curve. An increase in n also improves the possibility of a positive intersection between the valuation curves; that is, there is a higher possibility that there are multiple positive valuations of the innovation result. Only an innovation result with multiple positive valuations may be transferred at a price that is higher than the R&D cost; therefore, an increase in n could improve the probability of the transfer price being higher than the R&D cost of the innovation result.

This study assumed that there was only one R&D institution. Thus, an increase in the number of firms would intensify the degree of short supply and enhance competition between firms, which would obviously benefit the R&D institution. This also increases the possibility of transferring the innovation result and enhances the possible transfer price.

The degree of the technology gap between firms also reflects the level of technical competition. When the technical gap is large, the probability of a positive intersection between the valuation curves is small, meaning there is a low probability of both a transfer and the transfer price will be higher than the cost. When the technical gap is small, the probability of the positive intersection between the valuation curves is high. Here, the range of the innovation result with multiple positive valuations increases, thus increasing the possibility of transfer and enhancing the possibility that the transfer price will be higher than the cost. When the technical gap is medium, there is an intermediate chance of both a corresponding transaction possibility and possibility that the price will be higher than the cost.

Therefore, an increase in the degree of technology gaps between firms entails a weakened degree of technical competition between them. This is unfavorable to the R&D institution and reduces the transaction possibility and possibility that the price will be higher than the cost.

4.2. Equilibrium of the research and development stage

During the R&D stage in the innovation process, the R&D institution makes decision according to its own R&D ability (which determines the R&D cost line) and the technology levels of firms (on which the valuation curve depends). Based on the equilibrium bidding price $P(X)$ and R&D costs $K(X)$, the R&D institution chooses the innovation result level X to maximize its income $P(X)-K(X)$. The R&D institution first deletes the case of bidding failure to choose the innovation result that can be traded, then chooses the innovation result with an equilibrium bidding price of $\hat{P}$. Finally, it chooses the innovation result that satisfies $X=\arg\max(P(X)-K(X))$.

This study primarily focused on the transfer pricing of innovation results. However, there were two reasons for discussing the R&D stage. The first was to build a complete transfer pricing process for the innovation result, while the second was to consider how R&D costs impact transfer pricing. This was fully demonstrated in the previous analysis. As we focused on clarifying the transfer pricing of innovation results, this study does not deeply discuss the process of selecting an optimal innovation result for the R&D institution, which will be the subject of research in a future article.

4.3. Nonlinear R&D cost function

Most previous studies have assumed that the R&D cost function is a quadratic polynomial; namely, $K=aX^2/2$. This cost function curve can run tangent to or intersect with the single-peak valuation curve. However, the cost function curve cannot simultaneously run tangent to and intersect a valuation curve; rather, the cost curve that intersects the valuation curve is at the lower right of the cost curve, which is tangent to the same valuation curve. As such, the adoption of a quadratic function curve will not affect this study's findings. In fact, any findings should be similar given that the cost function satisfies $\partial K/\partial X>0$ and $\partial^2 K/\partial X^2 \le 0$.

5. Numerical example

Suppose two firms are bidding for the same innovation result and the transformation coefficient is $b = 1$. In the case of medium ($z_1 = 0.3, z_2 = 0.6$) and small ($z_1 = 0.5, z_2 = 0.6$) technical gaps, there are two innovation results to bid for, including the lower ($X_1 = 0.69$) and higher ($X_2 = 0.96$). This example was designed with different R&D capabilities of the R&D institution (a is 0.5 or 0.2, respectively). We adopted the method described in previous sections to solve the corresponding transfer price. The calculation results are shown in Table 1. The results of transfer in column 1 and 2 are obtained by case 2.3 but the left subfigure of Figure 2. The results in column 3 and 4 are obtained by case 2.3 but the right subfigure. All results in column 5–8are obtained from case 3.3 and the right subfigure of Figure 3.

Table 1. Transfer and price of innovation results

z	$z_1 = 0.3$, $z_2 = 0.6$				$z_1 = 0.5$, $z_2 = 0.6$			
X	$X_1 = 0.69$		$X_2 = 0.96$		$X_1 = 0.69$		$X_2 = 0.96$	
a	$a_1 = 0.5$	$a_2 = 0.2$	$a_1 = 0.5$	$a_2 = 0.2$	$a_1 = 0.5$	$a_2 = 0.2$	$a_1 = 0.5$	$a_2 = 0.2$
K	0.345	0.138	0.480	0.192	0.345	0.138	0.480	0.192
v_1	0	0	0.432	0.432	0.333	0.333	0.704	0.704
P_1	–	–	–	0.351(v_2)	–	0.333(v_1)	0.480(K)	0.426(v_2)
v_2	0.4208	0.421	0.351	0.351	0.503	0.503	0.426	0.426
P_2	0.345(K)	0.138(K)	–	0.351(v_2)	0.345(K)	0.333(v_1)	–	0.426(v_2)
P	0.345(P_2)	0.138(P_2)	–	0.351(P_1)	0.345(P_2)	0.333(P_2)	0.480(P_1)	0.426(P_1)

A low innovation result ($X_1 = 0.69$) is obtained by firm 2 with low technology, while a high result ($X_2 = 0.96$) is obtained by firm 1 with high technology. After considering the level of matching between the innovation result and the firm's technology, firms are not blindly pursuing high innovation results, but will choose appropriate ones based on their own technology levels and transformation abilities. This allows buyers to find different levels of innovation results. Meanwhile, firms with different technology levels can find innovation results that match their own technologies within the market. This results in a situation in which "all flowers bloom together" in the transfer market of innovation results.

In cases of different R&D capacities, the R&D institution with low capacity (a = 0.5) transfers successfully three times, while the institution with high capacity (a = 0.2) transfers four times. This indicates a higher transaction possibility for an R&D institution with a high R&D capacity. In cases of low R&D capability, the transfer prices are all R&D costs K, while the profits of the R&D institution are zero. In the case of high R&D capability, for three times, the transfer prices are the firm's valuation v, which is more than K, meaning the R&D institution obtains positive profits. This indicates that high R&D capacity helps R&D institutions obtain higher profits.

In contrast to the cases where different technology gaps are involved, there is a higher number of successful deals (four times) under a small technical gap than the number of successful deals (three times) under a medium technical gap. Given that all transfer prices in the case of the small technical gap are not less than those in the case of the medium technical gap. This is because a narrowed technical gap aggravates competition between demanders, which causes the transaction possibility and price to increase.

Conclusions

This study investigated how improvement effects were influenced by the match between innovation results and the level of firm technology. As such, we constructed a pricing model for the innovation result and revenue model for the institution. Through matching and game equilibrium, we further analyzed both the bidding between firms and decision of the R&D institution.

First, with matching considered, the improvement effect of the innovation result on the firm's technology was more accurately simulated. Firms bid for innovation results based on their existing technology levels. Herein, high technology firms can more easily obtain high innovation results, while low technology firms obtain low innovation results; however, these results are suitable in each case. In other words, firms with different technology levels thereby obtain appropriate innovation results. Because different levels of innovation results can be achieved with suitable buyers, R&D institutions are not forced to blindly pursue high innovation results, but can instead choose appropriate innovation results that reflect their own R&D abilities and capital situations. To some extent, this explains the diversity of demand and supply in the transfer market for innovation results.

Second, greater benefits are derived when innovation results match the existing level of firm technology. Here, different firms require different levels of innovation. When aiming for development, it is thus more suitable to encourage a situation in which "all flowers bloom together". Of course, different innovation incentive policies must be designed to reflect the respective technology levels in each industry, especially to address international competitiveness. For example, high-level innovation is appropriate for industries with world-leading technologies, while those with low-level innovation should be more restrained ingathering high-tech resources. For general industries, innovations of all levels may coexist, thus promoting overall technological improvements to catch up with leading international levels. For industries that follow technology, policies should concentrate resources on innovations that match the level of firm technology, thus improving overall technology levels and facilitating the pursuit of high-level innovation.

Third, technology competition between firms affects both the potential for transfer and the price of innovation results. Improved technical competition between firms can increase the possibility of transferring innovation results and raise the possible price. This can both activate the transfer market for innovation results and drive R&D institutions to continually engage in research by increasing their profits. As such, steady and healthy competition between firms is conducive to innovation and its transfer, thereby promoting the production and commercialization of real innovation.

Our findings show that the income-based approach to estimate the price of innovation results is reasonable and the competition is an important factor to promote innovation and innovation transfer, which are the supports of the existing research results. The framework of this paper is not suitable for the analysis disruptive innovation and complementary innovation. However, as two important types of innovation, the research on disruptive innovation or complementary innovation can be future research directions.

As this study focused on clarifying the transfer pricing of innovation results, to some extent, the decision of R&D institution was ignored. In fact, the R&D decision would affect the supply of innovation results, so developing our analysis further in this direction is a promising avenue for future research.

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Author contributions

Conceptualization, H. L.; methodology, X. L. and D. S.; validation, T.B. and D. S.; data curation, X. L.; writing–original draft preparation, H. L.; writing–review and editing, S. Z. and T. B. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

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