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Coopetition Strategy Choice of Duopoly Manufacturers with Key Component Technology Transfer

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Abstract: This paper investigates the strategic choice of key component technology transfer between two rival manufacturers. A benchmark competition model and two coopetition models (including fixed-fee licensing coopetition and two-part tariff licensing coopetition) where the manufacturers compete for end-customer demand while simultaneously collaborating on key component technology transfer through licensing. By comparing the outcomes of the competition model and coopetition models, it is shown that: (1) The optimal strategy choice for manufacturers depends on the degree of product substitution, the interfirm power relationship as well as the production cost difference of key components. Among them, the interfirm power relationship has the most significant impact on the optimal strategy choice. (2) Under certain conditions, fixed fees and two-part tariff patent licensing coopetition can achieve Pareto improvement and reduce the retail price of products, which is beneficial to both manufacturers and consumers. (3) The production cost difference of key components significantly affects whether manufacturers can achieve Pareto improvement under two coopetition models.

Keywords: Competition, Technology transfer, Fixed-fee licensing coopetition, Two-part tariff licensing coopetition.

1. Introduction

In the complex and severe international environment, the impact of the epidemic has put increasing pressure on the integration of global value chains. Therefore, to achieve the integration of global value chains and improve the efficiency and productivity of enterprises, further cooperation among enterprises is needed[1]. Meanwhile, the specialization of R&D and production has made patent licensing cooperation one of the core concerns of high-technology companies[2]. Many industries have seen the phenomenon of patent licensing cooperation among firms with competitive relationships in upstream activities of producing and developing key components. For example, in the field of hybrid vehicles, Ford and Tesla have allowed competitors to adopt their patented electric vehicle technologies for production[3]. OPPO has signed flash charging patent licensing agreements in the smartphone industry with dozens of companies. Such partnerships that license key component production technologies to competitors are known as patent licensing competitions and are now prevalent in areas such as smartphones, personal computers, automobile manufacturing, and pharmaceuticals, where technology advances rapidly, R&D costs are high, and competition is intense[4]. However, when patent licensing competition exists among competing firms, it can have two opposite effects. On the one hand, patent licensing competition can reduce the licensee's production costs of key components and increase the profitability of the licensor[5]. On the other hand, patent licensing competition increases the demand for the licensee's products, enhances the competitive intensity of the market, and erodes the original profit margin of the licensor, but the resulting royalties increase the economic burden of the licensee[6].

Common patent licensing cooperation models include fixed-fee patent licensing, unit-fee patent licensing, and two-part fee-based patent licensing (fixed fee plus unit fee). However, the unit fee patent licensing cooperation model is not only difficult for patent-holding enterprises to obtain a return on investment, but also the most unstable[7]. Therefore, in practice, patent-holding enterprises prefer the fixed-fee and two-part fee-based patent licensing model. For example, Qualcomm cooperates with Xiaomi, OPPO, Vivo, Lenovo, and other companies in two-part fee-based patent licensing, while it cooperates with Apple in fixed-fee patent licensing. In a fixed-fee patent licensing competition, the licensor licenses key component patent technology to the licensee for a fixed fee. Although a fixed-fee patent licensing competition can provide a quick return on investment for the patent holder, the benefit is limited to the fixed fee set upfront[8]. In a two-part fee-based patent licensing competition, the licensor charges the licensee a smaller fixed fee to cover certain losses, and then charges a certain unit fee per unit of product to ensure a long-term revenue effect, but is vulnerable to long-term uncertainty[9]. Therefore, firms need to choose the optimal patent licensing model to maximize profits according to the market situation[10]. Therefore, it is important to explore the choice between competing fixed-fee patent licenses and competing two-part fee-based patent licenses for firms with competitive relationships.

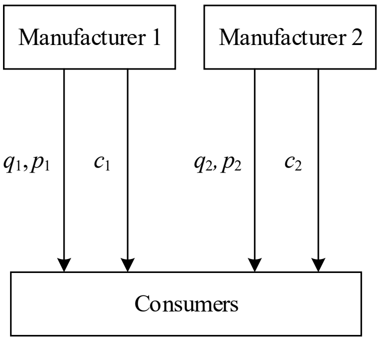
At present, numerous domestic and foreign scholars have studied the feasibility of competitive patent licensing strategies in a competitive environment. Some scholars have studied the competition between upstream patent-holding firms and downstream contract manufacturers and the choice of patent licensing competition strategies. For example, Zhang et al[11] studied the R&D strategies of original equipment manufacturers (OEMs) and contract manufacturers (CMs) and patent licensing decisions in a technology licensing environment and found that in most cases, supply chain members have the same preferences in terms of licensing strategies. Liu et al[12] studied the outsourcing strategies of considering patent licensing in an electronics supply chain consisting of patent-holding firms, OEMs, and CMs. Jin et al[13-14] constructed a two-stage game model for patent licensing and production outsourcing to study the optimal patent licensing contract design in the presence of information asymmetry in market demand. Chen and Hou[15] studied OEMs' technology licensing decisions under different outsourcing strategies of OEMs and found that a dual-source outsourcing strategy is better than a single-source outsourcing strategy for OEMs. The above studies focus on product-based patent licensing competition in vertical channels and do not involve the study of patent technology licensing competition based on key components in horizontal competition. Some scholars have studied the cross-licensing problem among competing manufacturers. For example, Hu et al[16] study whether patent-holding manufacturers open their proprietary technologies to competitors and find that cross-licensing may achieve coordination when manufacturers are in a prisoner's dilemma and shut down their technologies. He et al[17] consider the complementary technology strategy choice problem of two OEMs in a competitive market and construct three technology strategy choice models for OEMs: outsourcing, self-research, and cross-licensing, and find that technology outsourcing is unlikely to be the optimal strategy when manufacturers have the same strategic preferences, but cross-licensing or independent R&D may be the optimal strategy. The above literature mainly focuses on the choice between manufacturers' competition and single patent licensing competing strategies and does not address the choice of different patent licensing competing strategies among competing firms.

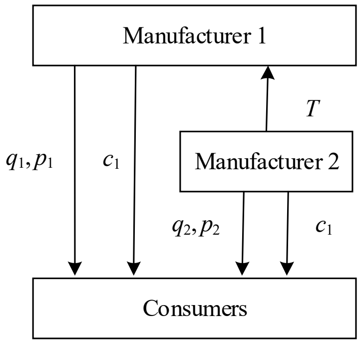
With the continuous advancement of patent licensing research, the problem of patent licensing strategy selection has attracted extensive attention from scholars at home and abroad. Chen et al[18] explored the patent licensing strategy of a patent-holding parts supplier facing patent licensing strategy when faced with a downstream duopoly manufacturer, and found that the supplier's preference for licensing strategy depends on factors such as market size and the difference in production costs between the two manufacturers. The aforementioned literature mainly focuses on patent licensing competition with vertical cooperation among downstream firms in vertical supply chains and has not yet considered the impact of horizontal competition on patent licensing competition. To this end, for a horizontal competitive supply chain system, Chai et al[19] investigate the choice of patent licensing competition strategies for original manufacturers by constructing three manufacturing models: remanufacturing, fixed-fee licensing, and unit-fee licensing under the study of carbon emission policies. Hong et al[20] explore the optimal pricing and recovery strategies of manufacturers in a closed-loop supply chain under two patent licensing scenarios: unit fee and fixed fee. The study shows that the manufacturer's optimal licensing strategy depends on the setting of a fixed-fee threshold. In addition, Sabbaghnia and Taleizadeh[21] investigated the impact of different patent licensing models on the closed-loop supply chain by considering the recovery rate and the quality level of the recovered products, and Cheng et al[22] used an evolutionary game approach to explore the strategy choice between fixed-fee and unit-fee patent licensing among competing firms. Sun et al[23] studied the recycling and patent licensing strategies of a closed-loop supply chain under a carbon cap-and-trade policy by considering carbon emission reduction and consumers' low-carbon preferences and found that for manufacturers, their profits are optimized when retailers recycle and remanufacture and pay a fixed royalty. Although the above-mentioned literature has studied the strategy choice between fixed-fee patent licensing competition and unit-fee patent licensing competition in a horizontal competitive environment, few papers have considered two-part fee-based patent licensing competition in a competitive environment, and related studies have not yet addressed the impact of inter-firm power relations on the choice of patent licensing strategy.

Based on this, this paper further expands and adds to the existing literature: firstly, it introduces fixed fee and two-part fee-based patent licensing competition into the horizontal competition among manufacturers; secondly, it considers the impact of key component cost differences and inter-firm power relations on patent licensing competition and explores the optimal strategy choice of manufacturers. Given this, this paper investigates the competition and patent licensing competition (fixed fee and two-part fee system) strategy choice between two competitive dual oligopolistic manufacturers, and explores the pricing and profit under the three strategies, to provide a reference for manufacturers' patent licensing competition strategy choice.

2. Problem Description and Model Assumptions

In two duopoly manufacturers 1 and 2 capable of producing substitutable products, manufacturer $i(i=1,2)$ produces qi of the product while selling its end product to consumers at a retail price p_i and both manufacturers can independently produce the key components required for the product. However, the production costs of their key components differ due to differences in the manufacturers' production technologies of key components. Among them, manufacturer 1 has a higher level of key component production technology and the production cost is c_1. while manufacturer 2 has a lower level of key component production technology and the production cost is c_2, and $c_2>c_1$. when manufacturer 1 and manufacturer 2 conduct technology transfer, manufacturer 2 (the licensee) can adopt the patented technology of manufacturer 1 (the licensor) and reduce the key component production cost. At this point, there is patent licensing cooperation between the two manufacturers in the production of upstream key components and both have production costs of c_1. For the question of whether manufacturers 1 and 2 engage in technology transfer for the production of key components, three models are considered: the competition model, the fixed-fee patent licensing competition model (FL model), and the two-part fee-based patent licensing competition model (ML model). In the competitive model, manufacturer 1 does not license the patented technology of key components to manufacturer 2. They use their technology to produce key components with production costs of c1 and c2, respectively, as shown in Figure 1. In the FL model, manufacturer 1 licenses the patented technology of the key component to manufacturer 2 by charging a certain fixed fee (T), and the fixed fee (T) charged by manufacturer 1 is independent of the production volume of manufacturer 2, as shown in Figure 2. In the ML model, manufacturer 1 charges manufacturer 2 a fixed fee (T) when licensing the patented technology for the production of critical components to manufacturer 2, and charges a unit fee (r) based on manufacturer 2's production volume, as shown in Figure 3. The relevant parameters are shown in Table 1.





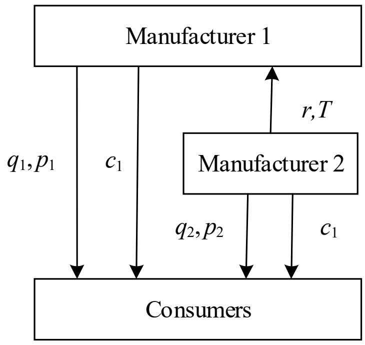


Figure 1. Competition model **Figure 2.** FL model **Figure 3.** ML model

Table 1. Parameter symbols (i=1,2)

Symbols	Meaning
c_i	The unit cost of key components produced by the manufacturer i
Δ_c	The difference in cost per unit of the key component produced by two manufacturers, $\Delta_c = c_2 - c_1$, and $c_2 > c_1$
m	The unit production cost of the manufacturer's product, in addition to the cost of producing key components
q_i	Demand for manufacturer i
p_i	Manufacturer i's product retail price
r	Unit fees for competing patent licenses
T	Fixed fees for competing patent licenses
δ_i	Manufacturer i Maximum profit per unit, $\delta_1 = \alpha - m - c_1 > 0$, $\delta_2 = \alpha - m - c_2 > 0$
π_i^n	Profit for manufacturer i in competitive mode
π_i^f	Profit of manufacturer i in FL mode
π_i^l	Profit of manufacturer i under ML model
π^n	The total profit of manufacturers in the competitive model, $\pi^n = \pi_1^n + \pi_2^n$
π^f	The total profit for manufacturers in the FL model, $\pi^f = \pi_1^f + \pi_2^f$
π^l	The total profit for manufacturers in the ML model, $\pi^l = \pi_1^l + \pi_2^l$
μ	Bargaining power of manufacturer 1, $0 \le \mu \le 1$

Consider the effect of the manufacturer's output on the retail price of the product and, drawing on the literature [7,24], introduce an inverse demand function:

$$p_i = \alpha - q_i - \beta q_j , i, j = 1,2 \text{且} i \neq j \tag{1}$$

Where α represents the highest retail price of the manufacturer's product; q_i represents the output of manufacturer i; and β represents the degree of product substitution between manufacturer 1 and manufacturer 2. If β is small, it indicates that the degree of substitution between the two products is low; if β is large, it indicates that the degree of substitution between the two products is high. And a high degree of product substitution often leads to more intense market competition [24].

3. Model Construction

3.1. Competition model

In the competitive model, manufacturers 1 and 2 use their production technologies for the production of key components. The two manufacturers simultaneously determine their respective production volumes to maximize their benefits. The profit functions of manufacturer 1 and manufacturer 2 are:

$$\pi_1^n = (\alpha - q_1 - \beta q_2 - c_1 - m) q_1 \tag{2}$$

$$\pi_2^n = (\alpha - q_2 - \beta q_1 - c_2 - m) q_2 \tag{3}$$

Constructing the Gounod competition model and using the inverse solution, we can obtain the optimal solution as shown in Table 2. By examining Table 2, in the competitive model, the effect of the degree of product substitution (β) on the manufacturer i's retail price and profit is further explored, yielding the following Property 1.

Property 1. In the competitive model, (1) if $0 < \Delta_c < \Delta_{c1}$, then $\partial p_1^n / \partial \beta < 0$; $\partial \pi_1^n / \partial \beta < 0$; if $\Delta_{c1} < \Delta_c < \Delta_c^H$, then $\partial p_1^n / \partial \beta > 0$; $\partial \pi_1^n / \partial \beta > 0$ 。(2) $\partial p_2^n / \partial \beta < 0$; $\partial \pi_2^n / \partial \beta < 0$ 。

Property 1 indicates that an increase in the degree of product substitution (β) will result in lower retail prices and profits for manufacturer 2, which suggests that increased market competition will negatively affect manufacturer 2's profitability. This is because manufacturer 2 has a lower level of key component production technology and its production cost is higher than that of manufacturer 1's key component production cost, which is more vulnerable to the degree of market competition, and the intense market competition may lead to a price war between manufacturer 2 and its competitors. The impact of the degree of product substitution (β) on manufacturer 1's retail price and profit is more complex. When the production cost difference of key components (Δ_c) is small, manufacturer 1's retail price and profit decrease as the degree of product substitution (β) increases. When the production cost variance (Δ_c) of the key component is large, the retail price and profit of manufacturer 1 increase with the increase in the degree of product substitution (β). This indicates that the positive impact on manufacturer 1 is more significant when the production cost advantage of manufacturer 1's key components is larger. Thus, with a larger key component cost advantage, manufacturer 1 can offset the negative effects of intense market competition. The more competitive the market is, the more Manufacturer 1 can fully utilize its cost advantage and compete for market share. For example, Huawei has strong R&D and production capabilities and has an advantage over its competitors in the production costs of some key components. Therefore, Huawei usually adopts a more traditional pricing strategy for price wars when competing in the low-end market; while when tapping into the high-end market, Huawei adopts a high price strategy in its smartphone pricing model, which indicates more intense competition in the high-end market.

Table 2. Optimal Solutions for the Three Models

Models	Competition model(*=*n*)	FL model (*=*f*)	ML model(*=*l*)
q_1^*	$\frac{(2-\beta)\delta_1+\beta\Delta_c}{(2-\beta)(2+\beta)}$	$\frac{\delta_1}{(\beta+2)}$	$\frac{\delta_1(4-2\beta-\beta^2)}{2(4-3\beta^2)}$
q_2^*	$\frac{(2-\beta)\delta_1-2\Delta_c}{(2-\beta)(2+\beta)}$	$\frac{\delta_1}{(\beta+2)}$	$\frac{2\delta_1(1-\beta)}{4-3\beta^2}$
T^*	/	$\frac{\delta_1^2(2\mu-1)}{(\beta+2)^2}$	$\frac{\delta_1^2((4-3\beta^2)(\beta^2-8\beta+8)\mu+3\beta^2(2-\beta)(6-\beta)-16)}{4(4-3\beta^2)^2}$
r^*	/	/	$\frac{\beta(2-\beta)^2\delta_1}{2(4-3\beta^2)}$
p_1^*	$q_1^n+m+c_1$	$\frac{\delta_1}{(\beta+2)}+m+c_1$	$q_1^l+m+c_1$
p_2^*	$q_2^n+m+c_2$	$\frac{\delta_1}{(\beta+2)}+m+c_1$	$\frac{\beta^3-4\beta^2+4}{4(1-\beta)}q_2^l+m+c_1$
π_1^*	$\left(\frac{(2-\beta)\delta_1+\beta\Delta_c}{(2-\beta)(2+\beta)}\right)^2$	$\frac{2\delta_1^2\mu}{(\beta+2)^2}$	$\frac{\mu\delta_1^2(\beta^2-8\beta+8)}{4(4-3\beta^2)}$
π_2^*	$\left(\frac{(2-\beta)\delta_1-2\Delta_c}{(2-\beta)(2+\beta)}\right)^2$	$\frac{2\delta_1^2(1-\mu)}{(\beta+2)^2}$	$\frac{(1-\mu)\delta_1^2(\beta^2-8\beta+8)}{4(4-3\beta^2)}$

3.2. FL Model

In the FL model, Manufacturer 1 licenses its key component production technology to Manufacturer 2 by charging a fixed fee. Manufacturer 2 produces the critical component through Manufacturer 1's proprietary technology, reducing the production cost of the critical component to the same level as that of Manufacturer 1. The decision sequence between the two manufacturers is as follows: First, manufacturers 1 and 2 negotiate a fixed fee for licensing the critical component. Second, the two manufacturers simultaneously determine the production volume. At this point, the profit function for manufacturers 1 and 2 is:

$$\pi_1^f=(\alpha-q_1-\beta q_2-c_1-m)q_1+T \tag{4}$$

$$\pi_2^f=(\alpha-q_2-\beta q_1-c_1-m)q_2-T \tag{5}$$

Since manufacturers 1 and 2 negotiate to determine the entry fee T, asymmetric Nash negotiation is introduced and modeled as:

$$\max_T \pi^f=(\pi_1^f(T))^{\mu}(\pi_2^f(T))^{1-\mu} \tag{6}$$

where μ is the bargaining power of manufacturer 1 and $1-\mu$ is the bargaining power of manufacturer 2.

By using the inverse induction method, we can obtain the optimal solution as shown in Table 2. By examining Table 2, in the FL model, the effect of the degree of product substitution (β) on manufacturer *i*'s retail price p_i^f and profit π_i^f is explored, yielding property 2, as follows.

Property 2. In the FL mode: (1) $\partial p_1^f/\partial\beta<0$; $\partial p_2^f/\partial\beta<0$; $\partial p_2^f/\partial\beta<0$; $\partial\pi_1^f/\partial\beta<0$; $\partial\pi_2^f/\partial\beta<0$. (2) $\partial T^f/\partial\beta<0$.

Property 2(1) shows that under the FL model, the retail price and profit of both manufacturer 1 and manufacturer 2's products decrease as the degree of product substitution (β) increases. This indicates that the degree of market competition negatively affects both manufacturers 1 and 2 when manufacturer 1 and manufacturer 2 engage in key component technology transfer in a fixed-fee patent licensing competition model. This is consistent with the trend in manufacturer profits when the difference in production costs of key components is small in the competitive model, indicating that fixed-fee patent licensing competition does not change the negative impact of the degree of product substitution (β) on the profits of both manufacturers when the difference in production costs of key components is small. Compared to the competitive model, fixed-fee patent licensing competition is detrimental to manufacturer 1 when the difference in production costs of key components is large. This is because Manufacturer 1 loses the advantage of production costs of key components in a highly competitive market, exacerbating the negative effects of market competition. Property 2(2) shows that the optimal fixed cost (T^f) decreases as the degree of product substitution (β) increases. This is because when the market is highly competitive, manufacturers offering lower fixed fees can attract competitors to engage in patent licensing cooperation, which in turn alleviates the intense market competition.

3.3. ML Model

In the ML model, manufacturer 1 licenses the key component production technology to manufacturer 2 by charging a fixed fee and charging a unit fee based on manufacturer 2's production volume. At this point, manufacturers 1 and 2 both use manufacturer 1's proprietary technology to produce the key component, and both have a production cost of c1. The decision sequence for these two manufacturers is as follows: First, manufacturers 1 and 2 negotiate to determine the fixed fee and unit cost for licensing the key component. Second, the two manufacturers simultaneously determine the production volume. At this point, the profit function for manufacturers 1 and 2 is:

$$\pi_1^l = (\alpha - q_1 - \beta q_2 - c_1 - m)q_1 + T + rq_2 \tag{7}$$

$$\pi_2^l = (\alpha - q_2 - \beta q_1 - c_1 - m)q_2 - T - rq_2 \tag{8}$$

Manufacturers 1 and 2 determine the entry fee T and unit cost r through negotiation. Therefore, asymmetric Nash negotiation is introduced, and the model is established as follows:

$$\max_{r,T} \pi^l = (\pi_1^l(r,T))^{\mu}(\pi_2^l(r,T))^{1-\mu} \tag{9}$$

The inverse induction method is used to solve the problem. The optimal solution can be obtained as shown in Table 2. By examining Table 2, in the ML model, the effect of the degree of product substitution (β) on the manufacturer i's retail price p_i^l and profit π_i^l is explored, resulting in Property 3, as follows.

Property 3. In the ML mode, (1) if $0 < \beta < \beta_1$, then $\partial p_1^l/\partial\beta < 0$ and $\partial p_2^l/\partial\beta < 0$; if $\beta_1 < \beta < \beta_2$, then $\partial p_1^l/\partial\beta > 0$ and $\partial p_2^l/\partial\beta < 0$; if $\beta_2 < \beta < 1$, then $\partial p_1^l/\partial\beta > 0$ and $\partial p_2^l/\partial\beta > 0$; (2) $\partial\pi_1^l/\partial\beta < 0; \partial\pi_2^l/\partial\beta < 0; \partial T^l/\partial\beta < 0; \partial r/\partial\beta > 0$.

From Property 3(1), it can be seen that in the ML model, when the degree of product substitution (β) is less than β_1, the retail prices of both Manufacturer 1 and Manufacturer 2 tend to decrease with the increase of β. At this point, the effect of competition on retail price is higher than the effect of the ML model on retail price. When the degree of product substitution (β) is between β_1 and β_2, the retail price of manufacturer 2 decreases with the increase of β, but the retail price of manufacturer 1 increases with the increase of β. This is consistent with the trend in the retail prices of manufacturers 1 and 2 when the difference in production costs of key components in the competitive model is large, at which point the two-part fee-based patent licensing competition does not change the effect of the degree of product substitution on retail prices. When the degree of product substitution (β) is greater than β_2, the retail price tends to increase with the increase of β. At this time, the effect of competition on retail prices from the two-part fee-based patent licensing competition is higher than the effect of competition on retail prices. This indicates that when the market competition is high, the two-part fee-based patent licensing competition can alleviate the intense market competition. Property 3(2) shows that the profits of both Manufacturer 1 and Manufacturer 2 decrease as the degree of product substitution (β) increases in the ML model, which is consistent with the trend of manufacturer profits when the difference in production costs of key components is small in the competition model, indicating that two-part fee-based patent licensing competition does not change the effect of the degree of product substitution (β) on the negative impact of both manufacturers' profits. Meanwhile, the lower fixed cost (T) decreases as the degree of product substitution (β) increases, because when the market is highly competitive, manufacturers offering lower fixed costs can attract competitors to participate in technology transfer and thus alleviate the intense market competition. The optimal unit fee increases with the increase of the degree of product substitution (β), which indicates that patent-holding firms tend to charge higher unit fees when they reach licensing agreements with competitors in a more competitive market. Because unit cost is one of the main costs in the two-part fee-based patent licensing competition model, a higher unit cost can increase the market share of the licensor and decrease the market share of the licensee. Property 3 illustrates that in the ML model, the revenue (or cost) of the licensing agreement has a knock-on effect on the retail price of manufacturer 1 (or manufacturer 2). For manufacturer 1, technology transfer can generate additional revenue and mitigate the profit loss it suffers when the market is highly competitive, while for manufacturer 2, the cost of the licensing agreement is a factor that must be considered when setting the retail price of the product. For example, technology giant Nokia compensates for the loss of profits due to intense competition in the telecom market by entering into licensing agreements with multiple smartphone manufacturers to obtain additional licensing fees.

4. Optimal Strategy Selection

This section focuses on the profitability of the manufacturer under the competitive, FL, and ML models and explores the optimal strategy choice of the manufacturer, leading to Proposition 1.

Proposition 1.

(1) If $0 < \Delta_c < \Delta_c^H$ and $\mu^l < \mu < 1$, then the ML model is the optimal strategy;

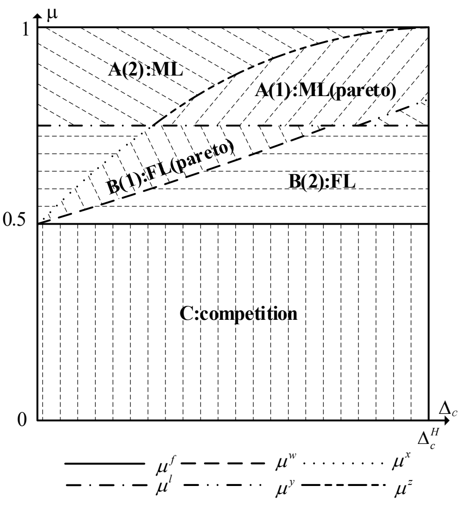
(2) if $0 < \Delta_c < \Delta_c^H$ and $\max\{\mu^l, \mu^y\} < \mu < \mu^z$, then $\pi_1^l > \pi_1^n$ and $\pi_2^l > \pi_2^n$, the ML model can achieve a Pareto improvement in profits and $p_1^l < p_1^n, p_2^l < p_2^n$.

(3) If $0 < \beta < 2\sqrt{2} - 2$, $0 < \Delta_c < \Delta_c^H$ and $\mu^f < \mu < \mu^l$ or if $2\sqrt{2} - 2 < \beta < 1$, $0 < \Delta_c < \Delta_c^A$ and $\mu^f < \mu < \mu^l$, then the FL model is the optimal strategy;

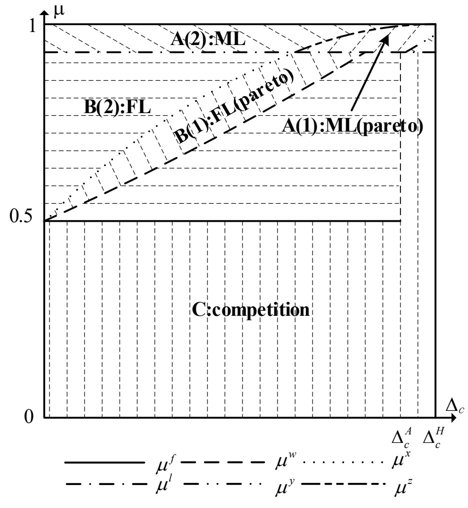
(4) If $0 < \beta < 2\sqrt{2} - 2$, $0 < \Delta_c < \Delta_c^H$ and $\mu^w < \mu < \min\{\mu^x, \mu^l\}$ or if $2\sqrt{2} - 2 < \beta < 1$, $0 < \Delta_c < \Delta_c^A$ and $\mu^w < \mu < \min\{\mu^x, \mu^l\}$, then $\pi_1^f > \pi_1^n$ and $\pi_2^f > \pi_2^n$, then the FL model achieves a Pareto improvement in profits and $p_1^f < p_1^n$, $p_2^f < p_2^n$.

(5) Otherwise the competitive model is the optimal strategy.

From Proposition 1 it can be seen that the manufacturer's strategy choice is related to the manufacturer's bargaining power (μ), the production cost difference of key components (Δ_c), and the degree of product substitution (β). As shown in Figure 4, the decision region is divided into three parts, and the characteristics of each decision region are discussed under different degrees of product substitution (β).



(a) $0<\beta<2\sqrt{2}-2$



(b) $2\sqrt{2}-2<\beta<1$

Figure 4. Optimal strategy selection

From Figure 4, it can be seen that in region A ($\mu > \mu^l$), the ML model is the optimal strategy. Regardless of whether the degree of product substitution is lower ($0<\beta<2\sqrt{2}-2$) or higher ($2\sqrt{2}-2<\beta<1$), when the bargaining power of manufacturer 1 is higher than μ^l that, the profits obtained by the manufacturer under the ML model are higher than those under the competitive model or the FL model ($\pi^l > \left\{\pi^n, \pi^l\right\}$). Also, in region A(1) ($\max\left\{\mu^l, \mu^y\right\} < \mu < \mu^z$), the two-part fee-based patent licensing competition can achieve a Pareto improvement in profits. Combined with Proposition 1(2), it can be seen that when the two-part fee-based patent licensing competition achieves the Pareto improvement in profits, the retail price is also reduced compared with the competitive model. Therefore, in region A(1), the two-part fee-based patent licensing competition positively impacts both manufacturers and consumers. In region A(2) ($\mu^l < \mu < \mu^y$ or $\mu^z < \mu < 1$), the total profits gained by manufacturers 1 and 2 increase, but there is always a loss of profits for one party. At this point, if the manufacturer with increased profits is willing to enter into a revenue-sharing contract with the manufacturer with impaired profits so that both manufacturers receive higher profits than under the competitive model, then technology transfer can be implemented between manufacturers in a two-part fee-based patent licensing competition model.

In Region B, the FL model is the optimal strategy. When the degree of product substitution is low ($0<\beta<2\sqrt{2}-2$), the FL model is the optimal strategy if the bargaining power of manufacturer 1 is between the threshold and the threshold, as shown in Figure 4(a); when the degree of product substitution is high ($2\sqrt{2}-2<\beta<1$), the FL model is the optimal strategy only when the difference in production costs of key components (Δ_c) is less than the threshold and the bargaining power of manufacturer 1 is between μ^f and μ^l, as shown in Figure 4(b) shows. Combined with Proposition 1(4), it can be seen that in region B(1) ($\mu^w < \mu < \min\{\mu^x, \mu^l\}$), fixed-fee patent licensing competition can achieve Pareto improvement in profits and also reduce the retail prices of both manufacturers' products. In region B(2) ($\mu^w < \mu < \min\{\mu^x, \mu^l\}$ or $\mu^x < \mu < \mu^l$), the FL model, although it can increase the total profit of both manufacturer 1 and manufacturer 2, always decreases the profit of one of the manufacturers. Moreover, the profit-impaired manufacturer has no desire to implement a fixed-fee patent licensing competition for key component technology transfer. Therefore, in region B(2), if a manufacturer competes for critical component technology transfer with a fixed-fee patent license, the beneficiary manufacturer must redistribute profits to compensate for the other manufacturer's loss of profits so that both manufacturers earn higher profits than under the competitive model.

In Region C, the competitive model is the optimal strategy. When the bargaining power of manufacturer 1 is less than a threshold value μ^f , the profit gained by the manufacturer in the competitive model is greater than the profit gained by the manufacturer in the ML or FL model ($\pi^n > \left\{\pi^f, \pi^l\right\}$). For many firms with proprietary technology but small size, when their bargaining power is smaller than that of competitors, it is the optimal strategy not to engage in technology transfer with competitors, otherwise, it may harm the firm's interests. In addition, when the degree of product substitution is high ($2\sqrt{2}-2<\beta$), competition is the optimal strategy if the bargaining power of manufacturer 1 is greater than the threshold μ^f but does not exceed the threshold μ^l, then the difference in production costs of key components (Δ_c) is greater than the threshold Δ_c^A , as shown in Figure 4(b). It shows that in a competitive market, if the production cost difference of key components (Δ_c) is large, then the manufacturer is more likely to choose the competition model unless the bargaining power of manufacturer 1 (μ) is larger than the threshold μ^l .

Figure 4 shows that the bargaining power of manufacturer 1 (μ) significantly affects the manufacturer's strategy choice. In contrast, the impact of the production cost difference of key components (Δ_c) on the manufacturer's strategy choice depends on the degree of product substitution (β). When the degree of product substitution (β) is small ($0 < \beta < 2\sqrt{2} - 2$) or the degree of product substitution is large ($2\sqrt{2} - 2 < \beta < 1$) and the production cost variance of key components (Δ_c) is less than the threshold value Δ_c^A , the production cost variance of key components (Δ_c) does not affect the manufacturer's strategy choice. When the degree of product substitution is large ($2\sqrt{2} - 2 < \beta < 1$), the optimal strategy will not be a fixed-fee patent licensing competition model if the difference in production costs of the manufacturer's key components (Δ_c) is greater than the threshold Δ_c^A . This is because in a highly competitive market, if the difference in production costs of key components (Δ_c) is large, the profits gained by the manufacturer under the fixed-fee patent licensing competition model cannot compensate for the profit loss suffered in the highly competitive market. Thus when weighing the gains from technology transfer against the loss of profits in a competitive market, a smaller key component production cost differential (Δ_c) does not have as much influence on the optimal strategy choice as the manufacturer's bargaining power. However, when market competition and cost differences are sufficiently large, key component production cost differences (Δ_c) may weaken the effect of the manufacturer's bargaining power on optimal strategy choice.

5. Conclusion

This paper addresses the technology transfer of key components among the duopoly manufacturers, examines the manufacturers' strategic choices between competition, fixed-fee patent licensing competition, and two-part fee-based patent licensing competition, and explores the pricing and profits under the three strategies to analyze the impact of key parameters on the manufacturers' strategic choices. The findings and management implications of the study are as follows:

(1) The manufacturer's strategy choice depends on the profit gained from patent licensing competition (fixed fee or two-part fee system) and the loss caused by competition. The profits gained from competitive patent licensing and the losses caused by competition are influenced by a combination of external and internal factors. Therefore, enterprises need to comprehensively analyze their own internal and external factors and appropriately adjust their bidding strategies according to the changes in their internal operational capabilities and external market environment to maximize their profits.

(2) Among the many influencing factors, the bargaining power of the manufacturer has the most significant impact on the optimal strategy choice. Therefore, it is extremely important to protect the intellectual property rights of the licensor and ensure their position of power.

(3) Under certain conditions, both patent licensing competition strategies can achieve a Pareto improvement in profits and lower the retail price of the product. At this point, patent licensing competition among manufacturers positively impacts both manufacturers and consumers.

(4) Whether patent licensing competition can achieve Pareto improvement in profits is closely related to the difference in production costs of key components. Therefore, when there is a large difference in the technology level of key components among competing companies, accelerating the technology transfer of key components in the market is conducive to improving the technology level of key components and enhancing the profitability of companies.

This paper is developed under the condition that manufacturers produce key components with the same level of quality, but manufacturers with production technology disadvantages have higher production costs. In further research, the impact of the quality level of key components on product demand can be considered, and the competition and patent licensing bidding strategy selection of manufacturers when two manufacturers produce different quality of key components can be studied.

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