Outsourcing Strategy With Patent Licensing in an Electronic Product Supply Chain

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ABSTRACT
An electronic product like a smartphone might involve hundreds of thousands of patents. The risks caused by infringement make it necessary for enterprises to consider patent licensing when outsourcing production activities in the electronics industry. This paper studies the outsourcing strategy considering patent licensing in an electronic product supply chain composed of a patent-holding firm, an original equipment manufacturer (OEM) and a contract manufacturer (CM). In addition to outsourcing manufacturing to the CM, OEM also considers outsourcing the patent license obtaining as well. We construct two outsourcing modes, called Turnkey and Consignment. No matter under which outsourcing mode, the patent-holding firm will charge unit royalty and a fixed fee paid in a lump sum. The results show that the OEM tends to choose Consignment without considering fixed fees, while the CM prefers Turnkey. When considering fixed fees, the patent-holding firm could align their preferences by coordinating fixed fees borne by OEM and CM. What’s more, considering the environmental pollution caused by the production of electronic products, both strategies may lead to higher social welfare than the other strategy.

INDEX TERMS
OEM, patent licensing, outsourcing, coopetition supply chain.

I. INTRODUCTION
Since 2010 the number of lawsuits, counter-suits, and trade complaints based on patents and designs in the electronics industry has increased significantly. According to Wikipedia, almost all the worldwide famous smartphone manufacturers involved these patent lawsuits and patent litigation, including Sony Mobile, Google, Apple, Samsung, Microsoft, Nokia, Motorola, Huawei, LG Electronics, ZTE, and HTC. For example, in 2014, Xiaomi was sued by Ericsson in India for suspected infringement of Ericsson’s patent [1]. In 2016, Nokia sued Apple for using its technology on many products without paying patent fees [2]. And in 2017, Qualcomm sued Apple for infringement of its patent and asked to ban the sale of related products [3]. Similar cases occur from time to time, and the patent protection has attracted the attention of the whole society.

In addition to raw material procurement and manufacturing, the original equipment manufacturer (OEM) procedure in the electronics industry may also involve the licensing of some patented technologies. Therefore, in the outsourcing mode, the OEM may not only outsource the procurement and manufacturing activities but also outsource the obtaining of relevant patent license to a contract manufacturer (CM). For example, Apple entrusts Foxconn with processing, and the payment includes part of the cost of using Qualcomm’s technology [4]. In this case, the patent-holding firm authorizes the patent to the CM and enters into a relevant patent license agreement with CM. The CM produces products after obtaining patent rights. In addition to Apple’s royalty included in the payment of processing fees, there are also cases in which OEM first applies for a patent license from the patent-holding firm and then entrusts the CM to process and produce the products.

Based on whether the obtaining of patent license is outsourced, there are two modes: Turnkey and Consignment. In Turnkey, OEM will give the CM full responsibility for patent license obtaining and product manufacturing. The CM is the patent licensee and pays royalties to the patent-holding firm to use the patent for production activities. In this case,
the fee paid by OEM to the CM includes the patent royalty. In Consignment, OEM and CM are both licensees, and the OEM’s payment doesn’t include the royalty.

Hence, the purpose of this paper is to study the issues of mode selection in the outsourcing supply chain from the perspective of obtaining patent licenses, to contribute to the literature on outsourcing strategy and patent licensing, and also to provide a reference for the relevant enterprise.

This paper mainly answers the following questions: (1) When OEM and CM compete in the product market, how will Turnkey or Consignment mode affect the decision-making process and profit of supply chain members, and which outsourcing mode do they prefer respectively? (2) How will the form of the patent license fee affect the outsourcing strategy? (3) Which outsourcing mode is more beneficial to social welfare considering the environmental pollution caused by the production of electronic products?

The structure of this paper explores the questions above. The literature review is presented in Section 2. Mathematical models are created in Section 3 and followed by the results and strategy selection analysis in Section 4 and 5. In Section 6, the environmental pollution caused by the production is considered to discover which outsourcing mode that would be more beneficial to social welfare.

II. LITERATURE REVIEW

This paper is related to three research fields. The first is the OEM and outsourcing supply chain. Guo et al. [5] established a two-stage model composed of OEM, contract manufacturer, and supplier. The study found that if the supplier considers the continuous information update of long-term profit and demand, the Turnkey may be better than the Consignment. Wang et al. [6] studied the influence of three different power structures on supply chain members in outsourcing and found that OEM and competitive manufacturers may choose to be leaders or followers under different conditions. Shen et al. [7] compared the different performance of supply chain members under OEM and ODM, and found that profit-sharing contracts can achieve the overall coordination of the supply chain. Bolandifar et al. [8] studied the optimal strategy of an outsourcing supply chain composed of a supplier, a manufacturer, and two competing OEMs under the situation of the raw material price is an exogenous variable and an endogenous variable separately. Niu et al. [9] studied the optimal outsourcing strategy of OEM and ODM considering profit and sustainability by establishing a three-layer fashion supply chain outsourcing model. Dong et al. [10] considered that the manufacturer has more bargaining power due to its larger purchase scale and this bargaining power belongs to private information. The research found that CM could create a win-win situation under certain conditions. Niu et al. [11] studied the purchasing outsourcing strategy of OEM and pointed out that economic sustainability and environmental sustainability could be coordinated by demand, profit and resource consumption. Through a stochastic modeling approach, Wang et al. [12] studied the strategic choice for manufacturers to acquire core materials through self-remanufacturing or outsourcing new cores. They pointed out that distribution bounds play a key role in determining this strategic option under a random recovery rate. Chen et al. [13] studied the impacts of multi-dimensional uncertainties of supply chain system on the outsourcing supply chain decision-makings. In addition to the outsourcing of production or raw material procurement, there are relevant research on transportation outsourcing. Cai et al. [14] established a game theory model to study the logistics outsourcing of fresh food. Tang [15] used the group and Benders decomposition methods to optimize the transportation outsourcing problem. Current research on the OEM outsourcing supply chain mostly focuses on production outsourcing, procurement outsourcing and transportation outsourcing while the research on patent licensing outsourcing is few. This paper will extend the literature on outsourcing strategy by considering the patent licensing.

The second is research related to patent licensing. Hill [16] analyzed whether enterprises should license patents to potential competitors, and showed that licensing fees play an important role in patent licensing. Wang [17] analyzed the influence of a fixed licensing fee and unit licensing fee on the duopoly Cournot competition. Bagchi and Mukherjee [18] studied the impact of different patent licensing forms on the profits of technology holders under product differentiation and market competition. Chen and Dimitrov [19] considered the competition between manufacturers of green ecological products and manufacturers of ordinary products, studied the issue of green patent technology licensing, and found that under certain conditions, green product manufacturers will lose their competitive advantage through patent technology licensing. Yan and Yang [20] studied different forms of patent licensing contracts and how patent holders should choose licensing contracts. Zhang et al. [21] studied the optimal patent technology licensing strategy of OEM for a supply chain composed of an OEM and a contract manufacturer, considering the joint R&D investment of two enterprises to improve product quality; Wu [22] constructed a dynamic game model to study the price competition and patent technology licensing of differentiated competitive enterprises, considering the random market demand. Wang et al. [23] studied on a technology-supplier’s licensing decision in networked supply chain. Yang et al. [24] studied how the risk of supply disruption affects the patent-holding supplier’s willingness to license its technology to a rival supplier considering two forms of the fees. Unlike most of the research on patent licensing is studied from the perspective of the patent-holder’s authorization, this paper will study the obtaining of the patent license from the perspective of the patent-licensee, which will contribute to literature on patent licensing.

The cooperation supply chain coordination is also related to this paper. Ozkan and Wu [25] studied the best time for contract manufacturers to establish their brands and enter the downstream competitive market when they establish an upstream cooperative relationship with OEM and discussed...
the output distribution of them. Niu et al. [26] studied the influence of pricing order on ODM and OEM with coopetition relationship, and analyzed two different market situations. Pun [27] studied two OEMs that compete in a downstream market but need to buy raw materials from each other and found that cooperating with competitors can be harmful. Xu et al. [28] studied the coopetition in the service outsourcing supply chain, and set the service commission contract as two parts: fixed and unit commission. Wang et al. [29] analyzed the coopetition problems of OEM and manufacturer from the perspective of information asymmetry. Song et al. [30] studied the role of two revenue-sharing contracts, namely, unilateral cost-sharing contracts, and consolidated rebate contracts, in promoting supply chain coordination. The study found that these two types of contracts increase the profits of supply chain members and is conducive to promoting coordination of the supply chain. Wang et al. [31] found that it is possible to coordinate the OEM and the third-party remanufacturer by establishing a revenue-sharing contract so that the two parties can achieve Pareto gains, but this may not be good for the environment. Jiang et al. [32] researched the influence of sub-coordination, that is, the coordination among some members of the supply chain, on the profit of the supply chain, and found that it is related to the degree of product substitution. Niu and Xie [33] studied the competition between refurbished products and brands in the downstream market. Due to consumers’ distrust of refurbished products, refurbished products may need to obtain quality certification from brands. Therefore, there is a coopetition relationship between remanufacturers and brands, and it is found that cooperation is easy to achieve when the competition is fierce. In the coopetition supply chain, it’s important to achieve cooperation between competing members, this paper will also study how to coordinate supply chain members to achieve a win-win situation.

III. THE MODEL

In an electronic product supply chain composed of a patent-holding firm (P), a contract manufacturer (CM) and an original equipment manufacturer OEM, the OEM outsources production to the CM who produces competitive products. Since both CM’s and OEM’s products involve a patent held by the patent-holding firm, the production has to be licensed by the patent-holding firm before the products are produced. For OEM, there are two outsourcing strategies: (1)Turnkey: OEM does not directly obtain the patent license from the patent-holding firm but outsources the obtaining of patent license and manufacturing to the CM. CM produces its products and OEM’s products after it gets permission from the patent-holding firm, and finally deliver the products to OEM. Under the Turnkey, the patent-holding firm only authorizes the patent to the CM. (2) Consignment: OEM negotiates with the patent-holding firm and obtains the patent license from the patent-holding firm directly, and then OEM designs the products and entrusts CM to produce the electronic products. At the same time, CM also needs to obtain patent licenses for its products. Under the Consignment, OEM and CM are licensed by the patent-holding firm respectively.

The potential market size of the electronic product is assumed to be $a$, the market price of the product is $p$, and the substitution coefficient of OEM’s product is $b$ ($0 \leq b \leq 1$). The OEM and CM sell the products in the market at the same time. The OEM is more likely to occupy the market for its superior brand reputation in quality over CM. Therefore, to depict the difference in brand value between the OEM and CM, $b_o = b \leq 1$, $b_m = 1$ are assumed to illustrate the full substitutability for OEM’s products due to its brand advantages while CM’s products cannot completely replace OEM’s. Under two outsourcing strategies, the inverse demand curve functions of OEM and CM are as follows:

$$p_o = a - q_o - bq_o$$  \hspace{1cm} (1)$$p_m = a - q_m - q_o$$  \hspace{1cm} (2)

Figure 1 is a schematic diagram of two modes. And the events and decision sequence under two strategies are shown in Figure 2. First, the patent-holding firm determines the patent fees \{r, f\}. $r$ is the royalty extracted from each unit product sale. $f$ is the fixed fee that is the one-off cost for the patent transfer. In Turnkey, the patent-holding firm only decides the patent fees to CM. While in Consignment, the patent-holding firm decides it to both OEM and CM. Then, the CM determines the wholesale price $w$, which reflects the cost of patent licensing and manufacturing in Turnkey but only processing fee in Consignment. At last, the OEM and CM decide their production at the same time.

IV. MODEL SOLUTION AND ANALYSIS

This section analyzes the equilibrium decision of supply chain members without considering the fixed fee which is
independent of the number of produced units. Backward induction is applied to get the equilibrium solutions for the OEM and CM, and compare them in different modes.

**A. EQUILIBRIUM DECISION UNDER TURNKEY**

In Turnkey, the OEM outsources both patent license obtaining and manufacturing to the CM. CM obtains patent license for OEM and its own products from the patent-holding firm (P). It pays the patent royalty \( r^T \) and delivers the products to OEM at the wholesale price \( w^T \) after processing. Thus, the profit functions for OEM, CM and the patent-holding firm are as follows:

\[
\begin{align*}
\pi^T_o &= (p^T_o - w^T)q^T_o \\
\pi^T_m &= (p^T_m - r^T)q^T_m + (w^T - r^T)q^T_o \\
\pi^T_p &= r^T (q^T_o + q^T_m)
\end{align*}
\]

Both the OEM and the CM make decisions to maximize their profits. The results of all equilibrium solutions can be obtained by using the backward induction, as shown in Table 1.

**TABLE 1. Results of all equilibrium solutions in Turnkey.**

|                | OEM                          | CM                           |
|----------------|------------------------------|------------------------------|
| quantity       | \( q^T_o = \frac{a(1-b)}{14 - 4b} \) | \( q^T_m = \frac{a(6-b)}{28 - 8b} \) |
| profit         | \( \pi^T_o = \frac{a^2(1-b)^2}{4(7-2b)^2} \) | \( \pi^T_m = \frac{a^2(8-4b+b^2)}{16(7-2b)} \) |
| wholesale price | \( w^T = \frac{a(24-10b+b^2)}{28-8b} \) | —                            |
| royalty        | —                            | \( r^T = \frac{a}{2} \)            |

**B. EQUILIBRIUM DECISION UNDER CONSIGNMENT**

In Consignment, the OEM obtains the patent license by itself and outsources the manufacturing to the CM. Under this situation, OEM only needs to pay the wholesale price \( w^C \) to CM. The OEM and CM negotiate separately with the patent-holding firm on the royalty. The patent-holding firm charges different royalties to OEM and CM, namely the royalty paid by OEM is \( r^C_o \) while the royalty paid by CM is \( r^C_m \). Therefore, the profit functions for OEM, CM and the patent-holding firm under Consignment are as follows:

\[
\begin{align*}
\pi^C_o &= (p^C_o - w^C - r^C_o)q^C_o \\
\pi^C_m &= (p^C_m - r^C_m)q^C_m + w^C q^C_o \\
\pi^T_p &= r^C_m q^C_o + r^C_m q^C_m
\end{align*}
\]

The equilibrium solutions for OEM and CM’s profit maximization are shown in Table 2.

**C. EQUILIBRIUM SOLUTION ANALYSIS**

Obviously, for different outsourcing modes, the equilibrium solution of each supply chain members is different. Therefore, this paper will further analyze the factors that affect the OEM and CM’s preference for outsourcing mode.

**TABLE 2. Results of all equilibrium solutions in Consignment.**

|                | OEM                          | CM                           |
|----------------|------------------------------|------------------------------|
| quantity       | \( q^C_o = \frac{a(2-b)}{2b - 8b-b^2} \) | \( q^C_m = \frac{2a(3-b)}{2b - 8b-b^2} \) |
| profit         | \( \pi^C_o = \frac{a^2(2-b)^2}{(2b - 8b-b^2)^2} \) | \( \pi^C_m = \frac{a^2(112 - 88b + 20b^2-b^2)}{2(2b - 8b-b^2)^2} \) |
| wholesale price | \( w^C = \frac{a(20-10b+b^2)}{2(28-8b-b^2)} \) | —                            |
| royalty        | \( r^C_o = \frac{a(14-3b-b^2)}{2(28-8b-b^2)} \) | \( r^C_m = \frac{a(14-3b-b^2)}{2(28-8b-b^2)} \) |

**Proposition 1:** \( \forall b \in (0, 1), (i) r^C_o > r^T, r^C_m < r^T; (ii) \frac{\partial r^C_o}{\partial b} > 0, \frac{\partial r^C_m}{\partial b} < 0; (iii) (r^C_o - r^T) + (r^C_m - r^T) < 0. \)

Proposition 1 compares patent royalty under different outsourcing modes, (i) shows that the CM pays higher royalty under Consignment while OEM pays lower royalty for products. Because the patent-holding firm can’t distinguish the products of CM from those of OEM in Turnkey, the royalty of patent is low and the CM obtains cost advantage. In Consignment, the patent-holding firm can use differential pricing strategy and increase the royalty to CM, which increases CM’s production cost and eliminate its cost advantage. At the same time, the patent-holding firm can reduce the cost of the OEM, which would intensify the downstream market competition and balance the profit, to gain the most profits. (ii) indicates that in Consignment, the higher the substitutability of CM’s product, the higher the royalty paid by CM. OEM changes are the opposite. The reason is that the CM will occupy a larger market share when \( b \) increases. In order to balance the patent revenue between the two enterprises and intensify the competition, the patent-holding firm will increase the production cost of CM to weaken its competitive advantage. (iii) demonstrates that the increase of CM’s patent royalty is less than the decrease of OEM’s royalty under Consignment, which may be caused by the dominant position of CM in the production competition with OEM. The CM is more sensitive to the increase in cost, i.e.

\[
\left| \frac{\partial q^C_m(r_m,r_o)}{\partial r^C_m} \right| > \left| \frac{\partial q^C_o(r_m,r_o)}{\partial r^C_o} \right|.
\]

By comparing the patent royalty, Proposition 1 shows that CM prefers Turnkey because of the low royalty and production cost, and it has higher competitiveness in the consumer market. The OEM prefers to choose the Consignment due to the differential pricing of the patent-holding firm. OEM can reduce production costs and increase competitiveness in the downstream market.

**Proposition 2:** (i) \( \forall b \in (0, 1), \frac{\partial q^T_o}{\partial b} < 0, \frac{\partial q^T_m}{\partial b} < 0 \) and \( q^T_o > q^T_m \); (ii) \( \forall b \in (0, 1), \frac{\partial q^C_o}{\partial b} > 0; (iii) \) when \( b \in (0, 3 \sqrt{3}) \), \( \frac{\partial q^C_o}{\partial b} < 0, \) while \( b \in (3 \sqrt{3}, 1) \) \( \frac{\partial q^C_o}{\partial b} > 0; (iv) \) \( \forall b \in (0, 1), q^T_m > q^C_m \) and \( q^C_o - q^T_o > (q^C_m - q^T_m) > 0. \)

Proposition 2 compares the production of OEM and CM under different outsourcing modes. (i) shows that when \( b \) increases, whichever outsourcing mode OEM chooses,
the production will decrease. With the increase of the product substitutability of CM’s, CM will occupy a larger market. In addition, the production of OEM in Consignment will be greater than that in Turnkey. As stated in Proposition 1, the OEM pays fewer royalty, which reduces the production cost and improves the competitiveness of OEM’s products. (ii) implies in Turnkey, the production of CM increases with the increase of product substitutability. However, in Consignment, its production first decreases before it increases. When \( b = 3 - \sqrt{3} \), the production is the lowest. The case of low substitutability, the increased production cost due to the increasing royalty under Consignment has a negative effect on the production of CM. However, with the increase of substitution, this negative effect will be offset. In addition, we find \( q_m^C > q_m^C \), which can be explained by the differential pricing of the patent-holding firm that increases the CM’s production cost and reduces its competitiveness in the downstream market. (iv) reveals that the differential pricing makes the increase of OEM’s production more than the decrease of CM’s.

By comparing the production of OEM and CM under two modes, Proposition 2 shows that OEM prefers to choose Consignment because of the lower production cost. While CM is more inclining to Turnkey for its price advantage in the quantity competition.

Corollary 1: (i) \( q_o^C - q_o^C > 0 \); (ii) \( q_m^C - q_m^C < 0 \); (iii) \( (q_o^C - q_o^C > 0) + (q_m^C - q_m^C) > 0 \).

Propositions 1 and 2 show that the differential pricing in Consignment reduces the royalty for the OEM and intuitively reduces the production cost for OEM, but Corollary 1 (i) shows that OEM will pay more royalties under Consignment because the differential pricing has more influence on the increase of quantity than the reduced royalty costs. This means that in Consignment, OEM will spend more on patent licensing, which may be detrimental to OEM. (ii) shows that CM will pay lower patent royalty under Consignment. From the perspective of royalty, OEM is more likely to choose Turnkey while CM prefers Consignment. (i) and (ii) indicate the cost of patent royalties and the profit of the patent-holding firm. (i) indicates that the patent-holding firm will charge more patent royalties from OEM and (ii) indicates that the profit from CM will reduce. In a word, (iii) illustrates after differential pricing, the increase in profits from OEM is greater than the decrease in profits from CM.

Corollary 1 reflects the changes in royalty under different modes. For the OEM, although the royalty reduces in Consignment, the largely increased quantity results in a higher total patent licensing cost. For the CM, although the royalty increases, the largely decreased quantity results in the reduction of the patent licensing cost. For patent-holding firm, Corollary 1(iii) proves that patent-holding firm increases royalties from CM while reduces patent royalties from OEM to increase its profits.

Proposition 3: \( \forall b \in (0, 1), (i) \frac{\partial (w^T - r^T)}{\partial b} < 0, \frac{\partial w^C}{\partial b} < 0; \) (ii) \( w^T - r^T < w^C \).

Proposition 3 shows how processing fee changes under different modes. In Turnkey, the processing fee is the wholesale price minus the royalty, i.e. \( w^T - r^T \). (i) shows that the processing fee always decreases with the increase of the substitutability of CM’s product under two modes. The reason is that with the increase of \( b \), the production competition is intensified and there is a decrease in OEM’s production. In order to ensure the profit from the manufacturing business, CM will reduce the processing fee to attract more orders from the OEM. (ii) indicates that the CM will charge a higher processing fee under Consignment. There may be two reasons: on one hand, the OEM production increases while the production of CM decreases; on the other hand, the production cost of CM increases due to the increased patent royalty. These attribute to the raise of the processing fee by the CM, and transfer part of the profits from the sales department to the manufacturing department, i.e.

\[
\frac{(w^T - r^T) q_o^C}{\pi_o^C} < w^C \frac{d q_o^C}{db}.
\]

Proposition 3 reflects the impact of differentiated pricing on the processing fee. It leads the CM to focus more on manufacturing.

Corollary 2: (i) \( \frac{\partial (w^T - r^T)}{\partial b} < 0; \) (ii) \( \frac{\partial w^C}{\partial b} > 0 \).

Corollary 2 analyzes the changes in OEM’s processing fee in different modes. (i) points out that the proportion of processing fees in OEM’s production costs in Consignment is higher than that in Turnkey. OEM transfers part of the cost from patent licensing to manufacturing. (ii) indicates that the proportion of processing fees in total production costs decreases as CM’s products become more alternative. When \( b \) increases, CM has an advantage in the quantity competition with OEM, and it charges a lower processing fee. However, in Consignment, the proportion increases with the substitutability for the decreased royalty paid by OEM. Proposition 3 also indicates that the CM will increase the processing fee to transfer its profit from patent licensing to manufacturing.

Corollary 2 reflects the changes in processing fees from Turnkey to Consignment. In Consignment, the processing fee and its proportion in the total cost are increasing and the processing fee has a positive correlation with product substitutability. From CM’s perspective, this is a decision made by the CM to balance profits from two channels.

Proposition 4: \( \forall b \in (0, 1), (i) \frac{\partial p^T}{\partial b} > \frac{\partial p^T}{\partial b} > \frac{\partial p^C}{\partial b} > 0, \frac{\partial p^C}{\partial b} > 0 \).

Proposition 4(i) shows that the product price in Consignment is always lower than in Turnkey, that is to say, the patent-holding firm intensifies the competition between OEM and CM through differential pricing strategy in Consignment. (ii) indicates that the price of OEM decreases with the increase of CM product substitutability, and the price of CM increases with it. The product substitutability \( b \) influences the
acceptable price of OEM’s products and of the manufacturer’s own products.

Corollary 3: (i) $p_o^T q_o^T + q_o^C p_o^C > p_m^C q_o^C$, (ii) $p_m^T q_m^T > q_m^T q_m^C > p_m^C q_m^C$.

Corollary 3(i) reflects sales under different modes. OEM’s sale increases in Consignment since the production increase exceeds the price decrease, while CM’s sale decrease since the production and price both go down. Therefore, OEM might tend to choose Consignment and CM tends to choose Turnkey. (ii) shows that the profit of CM in Turnkey is greater than that in Consignment. There are two reasons: on the one hand, as stated in Proposition 1, the royalty paid by CM in Consignment increases, so it put the production cost higher; on the other hand, as shown in Proposition 4, the competition between OEM and CM makes which makes the price of products decrease.

Proposition 5: $\forall b \in (0, 1), \pi_o < \pi_o^C, \pi_m > \pi_m^C, \pi_p^T < \pi_p^C$.

Proposition 5 reflects the equilibrium profit of OEM, CM and the patent-holding firm under Turnkey and Consignment when considered patent royalty only. Proposition 5 shows that OEM always tends to choose the Consignment while CM prefers to choose Turnkey, and the patent-holding firm tends to Consignment when only considering the patent licensing profit.

Proposition 1-5 and Corollary 1-3 are simplified as shown in Figure 3, depicting the changes of parameters, where “+” represents an increase and “−” means a decrease.

![FIGURE 3. Equilibrium solution analysis.](image)

OEM’s profit increases in Consignment. Although patent royalty and processing fee increase (as shown in Corollary 1 and 2), the increase in sales exceeds the loss. As shown in Figure 3, the positive effect of increased quantity is greater than the negative effect of lower price and the increased cost. CM’s profit decreases in Consignment. Even though the CM increases the processing fee and makes more profit from manufacturing, it still cannot avoid the decrease of the overall profit. For CM, the reduction of product quantity has huge negative impact on its sales profit.

V. OUTSOURCING STRATEGY

This section will discuss the outsourcing strategy of OEM and CM when considering the fixed fee charged by the patent-holding firm. The dominant outsourcing strategy for OEM and CM from the perspective of profit and their preference under different conditions are analyzed. What’s more, whether a consistent decision, a win-win situation, exists between them is discussed.

Proposition 6: As shown in Figure 4, there is a unique threshold $f_o^0$. When $f_o < f_o^0$, $\pi_o^C - f_o > \pi_o^T$; when $f_o \geq f_o^0$, $\pi_o^C - f_o \leq \pi_o^T$. The threshold $f_o^0$ is defined as:

$\begin{align*}
f_o^0 &= \frac{a^2 b (784 - 980b + 272b^2 + 39b^3 - 14b^4 - 5b^5)}{4(196 - 112 + 9b^2 + 2b^3)^2 f_o^0}.
\end{align*}$

Through Figure 4, it can be found that the outsourcing strategy made by OEM is influenced by the market competition degree $b$ and the fixed patent fee $f_o$. As shown in the figure, when CM’s products become more substitutable, OEM’s acceptable fixed fee decreases greater, meaning the possibility of choosing the Consignment increases. It can be seen from Proposition 5 that the OEM’s profit in Consignment is always greater than that in Turnkey when the fixed fee is not considered. However, with the substitutability increases, OEM’s profit becomes larger so that it can accept a higher fixed fee. As long as $f_o < \pi_o^C - \pi_o^T$, the OEM will choose the Consignment.

Assuming that the total fixed fee charged by the patent-holding firm is fixed in different modes, i.e. $f = f_o + f_m$. The fixed fee paid by the CM in Consignment is $f_m = f - f_o$, and the profit of the CM in Consignment is $\pi_m^C - (f - f_o)$. Comparing it with $\pi_m^T - f$, Proposition 7 is obtained.

Proposition 7: As shown in Figure 5, there is a unique threshold $f_o^m$ making $\pi_m^T - f > \pi_m^C - (f - f_o)$ when $f_o < f_o^m$ and $\pi_m^T - f \leq \pi_m^C - (f - f_o)$ when $f_o \geq f_o^m$. The threshold $f_o^m$ is defined as:

$\begin{align*}
f_o^m &= \frac{a^2 b^2 (112 + 24b - 64b^2 + 12b^3 + 4b^4)}{16(7 - 2b)(28 - 8b - b^2)^2}.
\end{align*}$

Through Figure 5, it can be found that the outsourcing strategy for CM is affected by the market competition degree $b$ and OEM’s patent licensing fixed fee $f_o$ charged by the patent-holding firm. As shown in the figure, with the increase of the substitution of CM products, the patent-holding firm should make the OEM share more fixed costs to reduce the fixed costs undertaken by CM. By reducing CM’s patent costs, the profit of CM in Consignment increases and CM
leans towards Consignment too. As the substitution of CM products increases, the patent-holding firm should make OEM bear more fixed costs to promote CM’s preference for Consignment.

According to Proposition 5, OEM’s profit in Consignment is always less than that in Turnkey without considering fixed fees. However, in the case of fixed fees existing, the CM and OEM jointly bear the fixed cost from the patent-holding firm. The fixed fee shared by OEM can be partly regarded as the profit increase of the CM in Consignment.

According to Proposition 6 and 7, there are four areas representing different decision-making choices of OEM and CM, as shown in Figure 6 and followed by specific analysis.

(i) (T,C) indicates that OEM tends to choose Turnkey, while CM prefers Consignment. In this area, although the OEM’s profit increases in Consignment, i.e. \( \pi_C^C > \pi_T^C \), its fixed cost is high and makes \( \pi_C^C - f_o < \pi_T^C \) so that OEM would choose Turnkey; for CM, although \( \pi_m^C < \pi_m^T \), the fixed cost borne by the CM is less than that of Turnkey, which makes \( \pi_m^C - (f - f_o) > \pi_m^T - f \). The CM would choose Consignment.

(ii) (C,T) indicates that OEM tends to choose Consignment while the CM tends to choose Turnkey. In this area, \( \pi_C^T > \pi_T^T \) and the fixed cost \( f_o \) that OEM needs to share is still low. \( \pi_T^T - f_o > \pi_T^T \) exists so that OEM still tends to choose Consignment. For CM, although OEM shares a part of the fixed cost in Consignment, the fixed cost borne by CM is still high, making \( \pi_m^C - (f - f_o) < \pi_m^T - f \). CM tends to choose Turnkey.

(iii) (C,C) indicates that both the OEM and CM tend to choose Consignment. The patent-holding firm proportionally allocates the fixed fee between the OEM and CM in order to meet \( \pi_C^C - f_o > \pi_T^T \) and \( \pi_m^C - (f - f_o) > \pi_m^T - f \), which makes the OEM and CM both prefer Consignment.

(iv) (T,T) indicates that both the OEM and CM tend to choose. In this area, \( \pi_T^C > \pi_T^C > \pi_m^C - \pi_T^C \), meaning the reduction of CM’s profit is far greater than the increase of OEM’s profit in the case of high substitutability. Even though OEM accepts a higher fixed fee, it still cannot make CM to choose Consignment. Thus, both the OEM and CM prefer Turnkey.

To sum up, the patent-holding firm could coincide the equilibrium decisions of OEM and CM, namely (C,C) and (T,T), by allocating fixed fees. However, according to Proposition 5, the dominant strategy for the patent-holding firm is Consignment. Therefore, when the CM’s product is highly replaceable, the patent-holding firm should pay attention to the allocation of fixed fee to avoid (T,T) area.

VI. OUTSOURCING STRATEGY UNDER SOCIAL WELFARE

The production of electronic products may cause pollution. How to promote the green economy has been widely concerned by the government, whose target is to achieve economic sustainability and social sustainability. In this paper, the index of social welfare is added to reflect the impact of these two outsourcing strategies on the economy and society. Social welfare is also a key factor considered by the government and expanding social welfare is one of the government’s policy objectives. Similar to the research of Singh [34] and Krass [35], social welfare (SW) consists of consumer surplus (CS), enterprise profit and environmental impact index (EI).

Consumer surplus and social welfare can be expressed as:

\[
CS = aq_o + \alpha q_m - \frac{1}{2} \left( q_o^2 + q_m^2 + (b + 1) q_o q_m \right) - p_o q_o - p_m q_m
\]

\[
= \frac{1}{2} \left( q_o^2 + q_m^2 + (b + 1) q_o q_m \right)
\]

\[
SW = CS + \lambda (q_o + q_m)
\]

where \( \lambda \) stands for the pollution degree of electronic products to the environment. Large \( \lambda \) means the serious pollution that is extremely adverse to social welfare.

By substituting equation (10) with the equilibrium solutions from Table 1 and 2, the functions of social welfare in two outsourcing strategies could be (11) and (12), as shown at the bottom of the next page. By comparing \( SW^T \) and \( SW^C \) in Turnkey and Consignment, the following propositions can be obtained:

Proposition 8: There is a unique threshold \( \lambda^* \), as shown in Figure 8, when \( \lambda > \lambda^* , SW^T > SW^C \); when \( \lambda < \lambda^* , SW^T < SW^C \). The threshold value \( \lambda^* \) is defined as: According to Figure 7, it can be found that both strategies may lead to higher social welfare which depends on product
and enterprise profit increase under Consignment. Although environmental impact.
sumer surplus and enterprise profit is greater than the negative
π_o and
enterprise profit is still greater than the increased negative
than that in Turnkey. The increase of consumer surplus and pollution, the production increase in Consignment is less
although the production of electronic products causes serious
article explores the issue of patent licensing when outsourcing
important contributions in this research. On the one hand, this
This paper studies the outsourcing strategy considering patent
adopt some policies to encourage enterprises to choose
Proposition 5-7, OEM and the patent-holding firm pre-
rentment
λ, specifically:
(i) When λ is relatively small, the social welfare under the Consignment is always higher than that under the Turnkey.
According to Proposition 2 and 5, (q_o^C - q_o^T) + (q_m^C - q_m^T) > 0 and π_o^T < π_o^C, π_m^T < π_m^C. Consumer surplus and enterprise profit increase under Consignment. Although the production increase degrades the environment, the λ is insignificant and the positive impact of the increase on consumer surplus and enterprise profit is greater than the negative environmental impact.
(ii) When λ is relatively large and b is relatively small, although the production of electronic products causes serious pollution, the production increase in Consignment is less than that in Turnkey. The increase of consumer surplus and enterprise profit is still greater than the increased negative impact on the environment caused by the increased output.
(iii) When λ and b are both large, the significantly increased total production leads to serious environmental pollution and reduced overall social welfare. According to Proposition 5-7, OEM and the patent-holding firm prefer Consignment for they can get more profits, and the patent-holding firm can coordinate the fixed costs to coincide them on Consignment. Therefore, the government could adopt some policies to encourage enterprises to choose Turnkey, to reduce production and thereby reduce pollution.

VII. CONCLUSION

This paper studies the outsourcing strategy considering patent licensing in an electronic product supply chain. There are two important contributions in this research. On the one hand, this article explores the issue of patent licensing when outsourcing production to competitors, which will extend the literature on outsourcing strategy. On the other hand, unlike previous research from the perspective of the patent holder’s authorization, the research study how to obtain the authorization of the patent license from the perspective of the patent-licensee, which will contribute to the literature on patent licensing.

We get some interesting outcomes through the research. The profit of OEM in Turnkey is always less than that in Consignment without considering the fixed patent licensing fee, while that of CM is the opposite. Therefore, the CM tends to Turnkey, while OEM prefers to choose Consignment. As OEM’s profits increase and CM’s profits decrease after the transition from Turnkey to Consignment, the patent-holding firm can coordinate OEM to share part of the fixed patent costs for CM to make their decisions consistent, that is, a win-win result. However, it should be noted that the increase of OEM’s profit cannot make up for the decrease of CM’s profit when the product substitution rate is too high. Improper coordination from the patent-holding firm may lead to both OEM and CM choosing the Turnkey, while the patent-holding firm always prefers the Consignment. In addition, considering the environmental impact caused by the production of electronic products, we found that there is a threshold that makes it possible for both strategies to lead to higher social welfare than the other strategy, which may be helpful to policy.

Even though this paper studies the outsourcing strategy in an electronic product supply chain from the new perspective of patent licensing, there are still some limitations. Firstly, the OEM and CM may not be limited to seek one patent-holding firm when a patent is granted. If there are multiple patent-holding firms competing, the monopoly position of the patent-holding firm will be greatly influenced, and OEM’s probability of choosing Turnkey may also increase. Secondly, the uncertainty of market demand is another important factor affecting the outsourcing strategy of enterprises. Finally, the uncertainty of cost is worthy of further study.

APPENDIX

Proof of Proposition 1:
(i) From tables 1 and 2, we can get r_m^C - r_T = \frac{a(2-b)b}{2(28-8b-b^2)} and r_p^C - r_T = \frac{-a(b-b)}{28-8b-b^2}. Since b \in (0, 1), we can get r_m^C - r_T > 0 and r_p^C - r_T < 0. The following proofs are also based on the equilibrium solutions in Tables 1 and 2.

\[
SW^T = \frac{a(a(396 - 274b + 55b^2 - 2b^3) - 8(56 - 37b + 6b^2)\lambda)}{32(7 - 2b)^2}
\]
\[
SW^C = \frac{a(a(396 - 270b + 35b^2 + 4b^3) - 2(224 - 148b + 16b^2 + 3b^3)\lambda)}{2(-28 + 8b + b^2)^2}
\]
\[
\lambda^* = \frac{-3136a - 4704ab + 7760ab^2 - 3100ab^3 + 334ab^4 + 23ab^5 - 2ab^6}{-12544b + 11872b^2 - 3264b^3 + 88b^4 + 48b^5}
\]
ii) \( \frac{\partial^2 C}{\partial b^2} = \frac{a(28-28b+5b^2)}{(28-5b)^2}, \quad \frac{\partial^2 C}{\partial b} = \frac{-a(84-56b+11b^2)}{(28-5b)^2}. \) Since 
\( b \in (0, 1), \) we can get \( \frac{\partial^2 C}{\partial b^2} > 0, \quad \frac{\partial^2 C}{\partial b} < 0. \) 

iii) \( (r'_o - r^T) + (r'_m - r^T) = \frac{(a^2-4b)}{(28-8b-5b^2)}. \) Since \( b \in (0, 1), \) we can get \( (r'_o - r^T) + (r'_m - r^T) < 0. \)

**Proof of Proposition 2:**

(i) \( \frac{\partial p'_o}{\partial b} = \frac{-5a}{(27-2b)}, \quad \frac{\partial p'_o}{\partial b} = \frac{a(12-4b)}{(28-8b-b^2)} \) \( q'_o - q^T_o = \frac{ab(4-3b-b^2)}{(28-2b-8b^2)}. \) Since \( b \in (0, 1), \) we can get \( \frac{\partial q'_o}{\partial b} < 0, \) \( \frac{\partial q'_o}{\partial b} < 0. \)

(ii) \( \frac{\partial q'_o}{\partial b} = 5a \frac{28-5b}{(27-2b)^2} \) \( q'_o - q^T_o = \frac{ab(4-14b-b^2)}{(28-5b)^2}. \) Since \( b \in (0, 1), \) we can get \( \frac{\partial q'_o}{\partial b} > 0, \) \( \frac{\partial q'_o}{\partial b} > 0. \)

(iii) Proof of Corollary 2:

(i) \( q'_o r'_o - q'_o r^T_o = \frac{ab(224-88b-86b^2+10b^3)}{(28-5b)^2}. \) Since \( b \in (0, 1), \) we can get \( q'_o r'_o - q'_o r^T_o > 0. \)

(ii) \( q'_m r'_m - q'_m r^T_m = \frac{-ab(824-240b-28b+5b^3)}{(28-5b)^2}. \) Since \( b \in (0, 1), \) we can get \( q'_m r'_m - q'_m r^T_m < 0. \)

(iii) \( (q'_o r'_o - q'_o r^T_o) + (q'_m r'_m - q'_m r^T_m) = \frac{a^2b(224-88b-86b^2+10b^3)}{(28-5b)^2}. \) Since \( b \in (0, 1), \) we can get \( (q'_o r'_o - q'_o r^T_o) + (q'_m r'_m - q'_m r^T_m) > 0. \)

**Proof of Proposition 3:**

(i) \( \frac{\partial (w' - r^T)}{\partial b} = \frac{-a(11-7b+b^2)}{2(27-2b)} \) \( \frac{\partial (w' - r^T)}{\partial b} = \frac{-a(20-16b+3b^2)}{(28-8b-b^2)}. \) Since \( b \in (0, 1), \) we can get \( \frac{\partial (w' - r^T)}{\partial b} > 0 \) and \( \frac{\partial w' - r^T}{\partial b} > 0. \)

(ii) \( w' - r^T - w^C = \frac{-ab(28-12b^2+b^3)}{(24-10b^2)^2}. \) Since \( b \in (0, 1), \) we can get \( w' - r^T - w^C < 0. \)

**Proof of Corollary 2:**

(i) \( \frac{w'(27-2b)}{w'^C} - \frac{w'(27-2b)}{w'^C} = \frac{2b-88+68b-16b^2+b^3}{24(10b-2b)^2}. \) Since \( b \in (0, 1), \) we can get \( \frac{(w'(27-2b))}{w'^C} < 0. \)

(ii) \( \frac{(w'(27-2b))}{w'^C}/\frac{(w'(27-2b))}{w'^C} = \frac{4(11-7b+b^2)}{(24-10b^2)^2}. \) Since \( b \in (0, 1), \) we can get \( \frac{(w'(27-2b))}{w'^C}/\frac{(w'(27-2b))}{w'^C} < 0. \) and \( \frac{(w'(27-2b))}{w'^C}/\frac{(w'(27-2b))}{w'^C} < 0. \)
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