The Impact of Secondary Market Competition on Refurbishing Authorization Strategies

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**Abstract**

Secondary market where used or refurbished products are traded has attracted many independent refurbishers (IRs) to engage in refurbishing. It poses competitions for new product sales of the original equipment manufacturer (OEM) and presents new market opportunities for OEMs as well. Many OEMs have adopted refurbishing authorization as one form of cooperation. As a result, it is common that authorized refurbished products and non-authorized refurbished products coexist in the secondary market. This paper investigates a supply chain consisting of an OEM and two competing IRs. To this end, we model the decision-making processing of the OEM and two IRs as a Stackelberg game. We provide the conditions for the OEM to implement refurbishing authorization and for IRs to accept authorization. We identify that the critical trade-off is whether the indirect benefit from refurbishing authorization, such as authorization fee, can outweigh the direct cannibalization effect of the sales of refurbished products on new products sales. The comparative analyses show that the OEM can benefit from the secondary market only when the IRs gain enough profit from authorized refurbishment, and a high authorization fee is not always beneficial for the OEM.

**Key words:** Secondary market; game theory; refurbished product authorization; independent refurbishers

## 1. Introduction

The secondary market is defined as the market where used or refurbished products are traded. The scale of the secondary market has been growing steadily due to enterprises’ increasing awareness of environmental protection. Compared to purchasing new products, customers can obtain similar utilities and achieve cost saving by using refurbished products. For refurbished product suppliers, they establish price advantages and more importantly gain profit from the secondary market (Nidhi, 2015). A typical secondary market consists of independent refurbishers (IRs) who actively engage in refurbishment and selling refurbished products, and customers who are willing to purchase refurbished products (Liu et al., 2018). IRs do not manufacture their own products, but instead collect and refurbish used products produced by original equipment manufacturers (OEMs). The vast market has attracted many IRs in addition to OEMs (Ferguson et al., 2006). In a survey conducted in 2002, out of 187 IT executives 77% reported that they purchased secondary market equipment and 46% expected to increase their spending on refurbished equipment in the next year by an average of 15% (Berinato, 2002). Facing the ever expanding market, many OEMs have developed strategies for the secondary market and have the ability to interfere with the secondary market by using direct or indirect approaches. In practice, some OEMs conduct refurbishment themselves, and others choose to not directly participate in the secondary market (Oraiopoulos et al., 2012). In this paper, we only consider the scenario under which the OEM adopts a strategy of not directly participating in the secondary market itself and instead entering the market by authorizing IRs as its authorized refurbisher with an authorization fee. In this business model, the OEM can focus on its new products, obtain shared profit from the secondary market, and fulfill its extended environmental responsibility. It is worth noting that refurbishing is defined as a form of remanufacturing (Abbey et al., 2015). Following the industry usage, in this paper we will use the terms “refurbishing” and “remanufacturing” interchangeably (see Thierry et al., 1995 for the detailed definition).

In the existing literature, most supply chain management models focus on the new product market. Compared to the new product market, the decision making in the secondary market is more complicated. One challenge is from the demand side. The existence of refurbished products may erode the demand for OEM’s new products and pose competition pressure on OEMs (Atasu et al., 2008; Wassenhove, 2009; Agrawal et al., 2015; Oraiopoulos et al., 2012). Consumer’s preference for new products is normally higher than that for refurbished products, and this assumption is supported by empirical evidence (Guide and Li, 2010; Subramanian et al., 2012; Ma et al., 2017) and practitioner literature (Hauser and Lund, 2003; Kandra, 2002; and Zhang et al., 2018). Besides that, consumer’s preference for authorized products is higher than that for non-authorized products. Authorized refurbished products’ quality and service can be guaranteed because they must follow industry best practices and the OEM’s standard. Some OEMs also provide warranty services for authorized refurbished products. For example, Apple provides a year of warranty service for its refurbished iPad (Apple, 2018). eBay highlights that the authorized refurbished products sold on its platform “have been inspected, cleaned, and repaired to meet manufacturer specifications and is in excellent condition” (eBay, 2017). Therefore, consumers’ different preferences toward new products, authorized refurbished products and non-authorized refurbished products affect the market share, and consequently affect the OEM’s authorization strategy and IR’s decisions on obtaining an authorization.

In practice, it is common for an OEM to collaborate with one or some of the IRs as its authorized refurbisher. Xin Meifu, the largest automobile gearbox remanufacturer in China, is authorized by two largest gearbox manufacturers, in the world i.e., ZF Friedrichshafen AG and Aisin (Xin Fumei, 2017). In the electronics industry, Apple named Ifengpai as its authorized refurbisher (Ifengpai, 2017), while Huawei signed an agreement with Aihuishou to collect, refurbish, remanufacture, and resell its used products in the market (Huawei, 2017). In the collaboration between OEMs and IRs, OEMs offer maintenance and inspection support for IRs and charges an authorization fee. For example, IBM and Hewlett Packard have earned a high profit from the secondary market in terms of authorization fees. Instead of licensing a refurbishment authorization, some OEMs do not enter the secondary market at all (Souza, 2013). That is, these OEMs only focus on the new product market when the size and potential of the secondary market are not promising.

Although some IRs only refurbish products with OEM’s authorization, some IRs refurbish and resell both authorized and unauthorized products, which makes the development of optimal supply chain decisions more challenging. For example, Aihuishou as Huawei’s authorized refurbisher also collects used Apple products (Aihuishou, 2017). However, Aihuishou is not authorized by Apple, because Apple only licenses its remanufacturing operations to Ifengpai. Therefore, there may be “manufacturer or manufacturer-approved refurbished” products and “seller refurbished” products existing in the market (eBay, 2017). Refurbished Apple products sold by Ifengpai are called manufacturer-approved refurbished products or authorized refurbished products, whereas those sold by Aihuishou can only be called seller refurbished products or non-authorized refurbished products. The coexistence of authorized and non-authorized refurbished products will cannibalize the sale of the OEM’s new products to some degree. For authorized refurbished products, OEMs can exploit the profit by charging an authorization fee. For non-authorized products, it is difficult for OEMs to exploit any profit as they have no control of the IRs. Although Apple has already licensed Ifengpai as its authorized remanufacturer, it can still sign an authorization agreement with Aihuishou due to the fact that Aihuishou has already participated in the collection and refurbishment of Apple products. Therefore, the competition among new products, authorized refurbished products and non-authorized refurbished products poses challenges for OEMs in developing marketing and channel strategies. The existing literature has not well modeled this type of competition. Therefore, we fill this gap by modeling the coexistence of new products, authorized refurbished products and non-authorized refurbished products in the same market. Our demand function reflects two possible market outcomes: the existence of refurbished products cannibalizes the sale of new products; and the sale of authorized refurbished products can also affect the market share of non-authorized refurbished products.

This study considers a setting in which the end market includes an OEM and two competing IRs. The OEM sells new products, while the two IRs collect used products and sell refurbished products in the market. The OEM needs to choose one of three strategies in face of the secondary market: not involving in the secondary market at all, authorizing one of the IRs as its authorized refurbisher, or authorizing both IRs in the secondary market. The two IRs can also decide whether to accept the OEM’s authorization. If an IR accepts authorization, an authorization fee should be paid to the OEM in return for the supports such as technological support and manufacturer-approved signs on their products. The OEM’s objective is to maximize its profit by optimizing its sales quantity and authorization fee. The IRs’ objective is to maximize their profit by deciding the sales (refurbished) quantity and whether or not to accept the OEM’s authorization. Our goal is to investigate when the OEM should implement authorization policy and when the two competing IRs should accept authorization. More specifically, we attempt to address the following research questions:

1. What is the equilibrium outcome for the OEM and the two competing IRs in different authorization strategies?
2. Under what conditions should the OEM implement authorization policy?
3. Under what conditions should the two competing IRs accept authorization?
4. Will the authorization strategy produce a win-win outcome for the three parties?

Liu et al., (2018) is one of the recent literatures on this research stream. Their models considered one OEM and one IR structure. In our paper, we focus on a boarder market competition by considering one OEM and two competing IRs. Therefore, our model structure and results are unique. To the best of our knowledge, our findings extend the literature in several ways. First, we provide the equilibrium conditions for the OEM’s authorization decision and the IR’s production quantity and authorization acceptance decisions. We show that the OEM charging a high authorization fee may decrease the sale of new products, which consequently affects the OEM’s profits. Second, we analyze the impact of the key factors (e.g., costs and consumer preferences) on the supply chain performance. We find that when only one IR accepts authorization its market size decreases as the authorization fee increases, while the other IR’s market size increases. This indicates that in certain conditions, the authorized IR may enter a disadvantageous position in the competition with the non-authorized IR. Third, we provide the conditions under which the OEM is willing to issue authorization and both IRs accept authorization. This study is originally motivated by an industry practice, the refurbishing market competition between Ifengpai and Aihuishou in electronic devices collection and refurbishing. However, the models and results can also be applied to other products with similar characteristics, such as, automobile engines and household appliances.

The rest of this paper is organized as follows. In the following section, we review the previous work related to our topic. Section 3 introduces our model setting and assumptions. Section 4 models three authorization strategies available for the OEM and the two IRs and provides the optimal solutions. Section 5 presents a comparative analysis of the three models presented in Section 4 and identifies the optimal decisions for the three supply chain players. Section 6 provides managerial implications of our research. Section 7 concludes the paper and all proofs are provided in the Appendix.

## 2. Literature review

In this section, we review the related literature and highlight our contributions to the operations and supply chain management literature.

First, the coexistence of new products and refurbished/remanufactured products and the corresponding competition between the OEM and IRs have been studied by many scholars in operations management area (Majumder et al., 2001; Debo et al., 2005, Heese, et al., 2005; Atasu et al., 2008; Wu, 2013; Orsdemir et al., 2014). Although most of the existing literature have investigated the competition between new products and refurbished/remanufactured products and revealed that the existence of refurbished/remanufactured products may cannibalize the demand for new products, they only focused on one IR’s refurbishing strategy and did not consider the competition in the secondary market. Recently, Liu et al. (2018) investigated the secondary market’s refurbishing authorization problem by introducing authorized and non-authorized refurbished products. Feng et al. (2019) showed that the existence of secondary market reduces the OEM’s production quantity. A service percentage fee can compensate the OEM in terms of its profit. Therefore, they concluded that the secondary market does not hurt the OEM. Wang et al. (2019) showed that collaboration with a third-party remanufacturer is always beneficial for the OEM. They also suggested revenue sharing contracts for the collaboration. In this paper, we contribute to this research stream by modeling the cannibalization effect not only between new products and refurbished products, but also between authorized refurbished products and non-authorized refurbished products. In addition, we consider the consumer’s preference for a product in the cannibalization effect analysis. Thus, we show that the competition from IRs has both positive (the authorization fee) and negative (the cannibalization of new products sales) effect on the OEM’s overall profit and the OEM can benefit from the competition between the refurbishers and the positive effect can offset against the negative effect sometimes.

Second, there have been multiple findings on the effect of the number of entrants on OEM’s profit. Debo et al. (2005) found that the OEM’s profit decreases as the number of remanufacturers increases because of the increase of the cannibalization effect. Wu et al. (2016) found that the OEM will obtain a profit increase from the IR’s entry to the market regardless of the number of IRs. However, multiple IRs’ entry will lead to a higher profit for the OEM compared to one IR. Oraiopoulos et al. (2012) showed that the OEM can benefit from an intense competition in the secondary market under the relicensing fee mechanism. Those findings show that the number of entrants has an impact on the OEM’s profit and should lead to different model settings in the research. Based on that, we consider a secondary market which consists of two competing IRs. The two IRs can both be authorized as refurbisher or function as a non-authorized refurbisher without authorization. We intend to investigate the effect of the IRs’ authorization decision on the OEM’s profit and authorization policy.

Third, there have been several studies on whether OEMs should enter the secondary market and refurbish used equipment. Heese et al. (2005) showed that an OEM should first deter competing OEMs from refurbishing if it has cost or market advantages. Ferrer et al. (2006) found that OEMs would have a higher participation in the secondary market if remanufacturing cost saving was high. Örsdemir et al. (2014) compared two scenarios: the OEM has the remanufacturing capability and the OEM does not have the remanufacturing capacity. They found that the OEM may either take a preemptive strategy or deter the IRs’ entry to the secondary market based on IRs’ competition position. Oraiopoulos et al. (2012) found that the OEM would price out the third party if it decides to refurbish its own products in conjunction with the relicensing fee mechanism. The OEM can take over the secondary market, if it enters the secondary market. In this paper, we only consider the secondary market strategy under which the OEM does not directly participate in the secondary market by refurbishing used products itself. This secondary market strategy is popular in electronics industry practices, like Apple, Huawei, IBM and Hewlett Packard. Li et al. (2019) showed that entering the secondary market can help increase the OEM’s profit without considering upfront investment. In addition, they found that the existence of a low production cost competitor will discourage an OEM to enter the secondary market, and an OEM will be more likely to consider the secondary market when it has cost advantage over its competitors.

In addition, we contribute to the literature on refurbishing authorization in two dimensions. First, Zou et al. (2016) concluded that two different remanufacturing modes exist for OEMs: outsourcing mode and authorization mode. In the outsourcing mode, the OEM outsources its remanufacturing process to an IR and retains the marketing decision on remanufactured products. In the authorization mode, the marketing decision on remanufactured products is performed by the IR. In the former case, the OEM must make modifications to its strategies on new product production and marketing activities. In the latter case, the OEM can set the license fee as high as needed, which is “costless” for the OEM. In this paper, we do not consider the refurbishing mode selection, and only focus on the second mode. The OEM interferes with the secondary market by imposing an authorization fee on the IRs and this can capture the basic feature of this market. In addition, Ma et al. (2018) showed that it is always beneficial for an OEM to charge a license fee to an independent refurbisher. However, it is not always optimal for the independent refurbisher to accept OEM’s authorization.

Second, we find that license fee may come from different parties depending on products’ characteristics. Oraiopoulos et al. (2012) introduced a mechanism where the OEM charges a relicensing fee from the consumer who purchases a refurbished product. Examples exist in the IT industry, like software copyright or patents. Zou et al. (2016) and Liu et al. (2018) introduced a mechanism where the OEM charges a license fee from IRs for each refurbished product sold. This mechanism is more common in practice for electrical and electronic products. Consistent with the mechanism for charging a license fee from the IR, we incorporate operational factors such as production cost and marketing factors such as consumers’ preference to model the authorization fee strategy and identify the conditions under which the OEM and the IRs should cooperate with each other.

## 3. Model Setting

We consider a supply chain consisting of an OEM and two IRs. The OEM produces and sells new products, while the two IRs, denoted by A and B, collect used products produced by the OEM and sell partially different refurbished products in the same market. The OEM does not engage in refurbishing itself as discussed in the previous section. Instead, it can influence the secondary market by charging an authorization fee to the IRs. The two IRs can engage in refurbishing with or without the OEM’s authorization. If they accept authorization, their cost structure and consumers’ acceptance may change. This type of supply chain structure is quite common in the refurbishing industry. For instance, the OEM may refer to Apple, and the two IRs can be viewed as Ifengpai and Aihuishou. Therefore, in the supply chain game the OEM determines its new product sales quantity and authorization fee first. Then, the two IRs determine whether or not to accept the OEM’s authorization and the refurbished quantity.

### 3.1. Demand function

We assume that consumer types are uniformly distributed in the interval [0, 1], where a consumer type  has a willingness to pay  for a new product, and a willingness for a refurbished product, where (Oraiopoulos et al., 2012; Liu et al., 2018). A consumer with a willingness to pay 1 for the authorized channel has a willingness to pay  for the non-authorized channel, where  (Ferrer et al., 2006). Without loss of generality, the market size is normalized to 1. As such, 1, and can be viewed as the market recognition degrees on new products, authorized refurbished products and non-authorized refurbished products, respectively. The competition between new products, authorized refurbished products and non-authorized refurbished products is characterized in one production period.

The products offered by the two competing IRs are perfectly substitutable if they both accept authorization or neither accepts authorization. In this paper, we assume that the OEM’s and two IRs’ prices on new, authorized refurbished products and non-authorized refurbished products to be ,  and , and corresponding sales quantities to be ,  and , respectively.

A consumer will derive a net utility from purchasing a new product, a net utility from purchasing an authorized refurbished product, and a net utility from purchasing a non-authorized refurbished product. Consumers will compare the utilities before making any purchasing decisions and make a purchase if and only if the net utility is positive.

When it comes to refurbishing authorization policy, the options available to the two competing IRs are to either accept authorization or not. Therefore, there are four possible scenarios: neither IR accepts authorization (i.e., the OEM does not involve in the secondary market), which is denoted as *NN*, both IRs accept authorization, which is denoted as *LL*, and one IR accepts authorization and the other IR does not, which is denoted as *LN or NL*.

When neither IR accepts authorization, new products and non-authorized refurbished products coexist in the market. Then we derive the demand functions for new products and non-authorized refurbished products through simple integral calculations as follows.

 (1)

Based on the demand functions, we derive the inverse demand functions as follows.

 (2)

Using a similar method, we derive the inverse demand functions as follows for the scenarios under which both firms accept authorization and only one firm accepts authorization.

 (3)

(4)

Superscripts *NN*, *LL* and *LN* index model *NN*, model *LN* and model *LL* mentioned above.

### 3.2. Profit function

Irrespective of consumers’ preference, refurbishing authorization can also help the IR improve its cost structure because the OEM may provide some technical support. In this paper, we assume that the OEM’s refurbishing authorization can save the authorized IR’s unit refurbishing cost by ().The two competing IRs refurbish used products at a cost of and if both firms accept authorization, and if neither firm accepts authorization, the production cost on refurbished products is and , respectively. The OEM produces new products at a cost of , and and . We assume that the quantity that the IR collects equals the quantity that the IR refurbishes, and the collection cost is included in the refurbishing cost.

We assume the OEM charges an authorization fee *S* for every piece of authorized refurbished products sold. In this paper, we only consider the scenario under which the OEM charges the same authorization fee from the two IRs, because refurbished products sold by the two IRs are perfectly substitutable.

In order to better investigate different scenarios, let index the OEM and IRs, and  index model *NN*, model *LN* and model *LL*. Further, let  denote player *i*’sprofit in model *j*. The OEM is to maximize its profit by optimizing its sales quantity *qn* and authorization fee *S*, and the optimization problems in three models are developed as follows.

 (4)

The OEM’s profit function includes the profit from selling new products and (for *LL* and *LN*) the authorization fee obtained from the IRs who accept authorization.

The IR A’s optimization problems in three models are

 (5)

Similarly, the IR B’s optimization problems in three models are

 (6)

For an IR, the profit function is the profit from selling refurbished products subtracted by the authorization fee when it accepts authorization.

Based on the profit functions, we model the supply chain game as a single-period game to optimize the firms’ decisions. The single-period model can be interpreted as a representation of the maturity stage of the product’s life cycle where prices (as well as collection and refurbishing) are steady. Such single-period, steady-state models have been frequently used in recent remanufacturing and refurbishing literature (e.g., Galbreth et al., 2013, Örsdemir et al., 2014 and Esenduran et al., 2017). Please note that the refurbished products selling quantities of the two IRs must satisfy , which means the sales quantity of refurbished products is no greater than the number of units that can be collected from consumers.

In the following section, we present three models and derive the optimal decisions for the OEM and two IRs.

## 4. Game Model

In this section, we first characterize the OEM’s and two IR’s optimal decisions in equilibrium in the three models described above. We then analyze the properties and market dynamics with respect to key parameters.

### 4.1. Characterization of Equilibrium

In all the models, the equilibrium regions are characterized and bounded by the IRs’ refurbishing costs (and ). We first characterize the OEM’s and two IRs’ optimal decisions in equilibrium. Like Miao et al., (2017), Zhu et al., (2016), and Esenduran et al., (2017), we argue that there are three types of optimal collection and refurbishing strategies, namely, (1) collect or refurbish any used products; (2) collects and refurbishes some but not all the available used products; and (3) collects and refurbishes all available used products. Furthermore, as in Majumder and Groenevelt (2001), Ferguson and Toktay (2006), and Atasu et al. (2009), we assume the OEM and IRs engage in Cournot competition in the market. The OEM decides how many new items to manufacture. Simultaneously, the two IRs decide how many used products to collect and refurbish.

**Definition 1.** In models *NN*, *LL* and *LN*, each IR plays one of the following three strategies:

Strategy 0: Does not collect or refurbish any used products.

Strategy +: Collects and refurbishes some but not all the available used products in the market.

Strategy =: Collects and refurbishes all available used products in the market.

Equilibrium arises in one of nine regions indexed by  and , where  denote the two IRs’ strategies, respectively. It is worth noting that and can never arise in the equilibrium, because  and cannot exist at the same time. Hence, there are seven possible combinations of strategies in the equilibrium. The two IRs’ strategies are summarized in Table 1.

We model the three parties’ decision-making process as a Stackelberg game. First, the OEM sets an authorization fee. Second, the two IRs decide if they accept authorization and make refurbishment quantity decision. The OEM makes production quantity decision according to if the IRs accept authorization. We do not consider a joint authorization fee-production quantity decision for the OEM because the production quantity decision is difficult to make without knowing IRs’ responses to the authorization fee. Therefore, a joint decision may not be feasible in real practice.

**Table 1** Summary of the two IRs’ possible strategies in model *NN,* model *LL* and model *LN*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | IR B’s strategies | | |
| IR A’s strategies | | 0 | + | = |
|  |  |  |
| 0 |  |  |  |  |
| + |  |  |  | N/A |
| = |  |  | N/A |  |

We can derive the optimal solutions of models *NN*, *LL* and *LN* in Proposition 1 based on KKT necessary conditions.

**Proposition 1.** Inmodels *NN*, *LL* and *LN*, there exist several critical values that define seven regions with the optimal solutions as shown in Tables 2-4. The bounds characterizing the equilibrium regions in each model are summarized in Appendix B.

Proposition 1 demonstrates the following key insights:

1. The two IRs will not engage in refurbishing under certain conditions. For example, the two IRs will not engage in refurbishing under in the condition and  in model *NN*, under the condition  and  in model *LL*, or under the condition  and  in model *LN*. It indicates that the higher the refurbishing cost becomes, the less likely the two IRs will engage in refurbishing. We also have to note that the value of  and  depends on ,,,and , which means the manufacturing cost of the OEM, consumers’ preference for refurbished products and non-authorized channel, cost saving from refurbishing, and authorization fee are highly related to the two IRs’ strategy.
2. The two IRs will engage in refurbishing under the condition  and or and. The two IRs may not engage in refurbishing simultaneously, under some conditions. It means that sometimes one IR may take the entire refurbishing market. For example, in model *NN*, under the partial collection scenario, if the refurbishing cost of the two IRs satisfies, then IR B will not engage in refurbishing; and if the refurbishing cost of the two IRs satisfies, then IR A will not engage in refurbishing. Under the full collection scenario, if , then IR B will not engage in refurbishing, though IR A will collect all used products; if , then IR A will not engage in refurbishing.

We can depict the characterization of the equilibrium solution in model *NN* inFigure 1, and the figures for models *LL* and *LN* are quite similar to that of model *NN*. Hence, we omit those.



**Figure1.** Characterization of the equilibrium solution in model *NN*.

**Table 2** Equilibrium optimal solutions of model *NN*.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Optimal Solutions |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
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**Table 3** Equilibrium optimal solutions of model *LL*.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Optimal Solutions |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |

**Table 4** Equilibrium optimal solutions of model *LN*.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Optimal Solutions |  |  |  |  |  |  |  |
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### 4.2. Structural Results and Comparative Statics

In this section, we analyze the properties and market dynamics with respect to the key parameters such as product costs, consumer preference, and refurbishing cost saving. The analysis is focused on the most prevailing cases, where all the market segments appear in the equilibrium, namely, strategy, and. We first analyze the impacts of the parameters on sales quantities of new products, authorized refurbished products and non-authorized refurbished products in Propositions 2-4. We then analyze supply chain players’ profit functions with respect to authorization fee in Proposition 5.

In model *NN*, consumers only choose between OEM’s new products and the two IR’s non-authorized refurbished products. Here we define , .  refers to the degree of market recognition on non-authorized refurbished products.

**Proposition 2.** In model *NN*, when all market segments exist (strategy), the impacts of the parameters on the sales quantities of new products and non-authorized refurbished products are summarized as follows:

1. the size of the new products market  increases in and , and decreases in and ;
2. the size of IR A’s secondary market increases in ,and , and decreases in and ;
3. the size of IR B’s secondary market increases in ,and , and decreases in and .

Proposition 2 indicates that one supply chain player’s market size increases in other supply chain players’ production costs, while decreases in its own production cost. This is understandable, because as the manufacturing or refurbishing cost increases, it becomes less attractive for the players to engage in manufacturing or refurbishing. However, as other players’ production cost increases, manufacturing or refurbishing becomes attractive again. For example, the size of the new product market  decreases in its own production cost, while increases in the two IRs’ refurbishing cost and. As  increases, the degree of market recognition on non-authorized refurbished products increases. This means more consumers are willing to pay for non-authorized refurbished products, and the two IRs can earn more profits from engaging in refurbishing because of the increased size of the two IRs’ secondary market. However, as the degree of market recognition on non-authorized refurbished products increases, the degree on new products decreases if the total market size is constant (which is normalized to 1), and this may affect the OEM’s profit. Consequently, the size of new product market shrinks. In addition, the size of the two IRs’ refurbishing market also decreases with the unit cost saving of refurbishing because of the authorization fee. This is because, the higher  becomes, the higher refurbishing cost of the two IRs and thereby the smaller size of the refurbishing market will be.

**Proposition 3.** In model *LL* when all market segments exist (strategy), the impacts of the parameters on the sales quantities of new products and authorized refurbished products are summarized as follows:

1. the size of the new products market increases in and , and decreases in ,and ;
2. the size of IR A’s secondary market increases in ,and , and decreases in and ;
3. the size of IR B’s secondary market increases in ,and , and decreases in and .

Proposition 3 also indicates that the size of the supply chain players’ market is highly related to its own production or refurbishing cost, and other participated players’ production cost. In model *LL,* when both IRs accept the authorization the two IRs have to pay an authorization fee to the OEM. Therefore, the size of the two IRs’ refurbishing market decreases as the authorization fee increases. However, it is also surprising to notice that the market size of new products also decreases as  increases, even though the OEM can benefit from the development of the refurbishing market by charging an authorization fee. The profits of the OEM are driven by two opposing forces, the sales of new products and the authorization fee. When more consumers are willing to pay for authorized refurbished products, fewer consumers will purchase new products, which consequently reduces the size of the new product market. This implies an important observation in this paper, which is cooperating with both IRs may not always be a good choice for the OEM. In addition, the impacts of consumers’ preference for new products versus authorized refurbished products on the size of the players’ market are similar to those in Proposition 2.

**Proposition 4.** In model *LN*, when all market segments exist (strategy), the impacts of the parameters on the sales quantities of new products, authorized refurbished products and non-authorized refurbished products are summarized as follows:

1. the size of the new products market increases in , ,  and , decreases in, and is unimodal (first increasing, then decreasing) in and . increases in if  and decreases otherwise; increases in if  and decreases otherwise;
2. the size of IR A’s secondary market increases in ,and , decreases in and , and is unimodal in and . increases in if and decreases otherwise; increases in if ;
3. the size of IR B’s secondary market increases in , and  , decreases in and , and is unimodal in . increases in if and decreases otherwise.

Most insights of Proposition 4 are similar to those of Propositions 2 and 3. In model *LN* when only one IR accepts authorization (e.g., IR A accepts authorization and IR B does not accept authorization), the size of IR A’s secondary market decreases as the authorization fee increases, while the size of IR B’s secondary market increases as the authorization fee increases. As increases, the authorized refurbisher’s profit decreases while the non-authorized refurbisher’s profit increases. The market shares show a similar relationship with the authorization fee.

It is also worth noting that the size of new product marketalso increases in , though in model *LL*, decreases in. Although a higher  provides the OEM with more profits from the authorization and development of the secondary market, it has the opposite effect on the size of new product market in models *LL* and *LN*. As  increases, the price advantage of authorized refurbished products shrinks. The profit that an authorized IR obtains from refurbished products correspondingly declines, and it may also cause under-development in the refurbishing market. Therefore, consumers will tend to purchase new products and this consequently expands the new product market. This also leads to another interesting observation in this paper, that is, sometimes, the OEM should name one of the IRs as its authorized refurbisher rather than cooperating with both of them.

The effect of andon the market sizes is unimodal, except that the size of IR B’s secondary market increases as  increases. As  and  increases, consumers’ preference for refurbished products increases, which can benefit the development of the two IRs’ secondary market. In addition, high values of  and can also make the market more competitive because it becomes more difficult for the consumers to make purchase decision.

**Proposition 5**. The relationship between supply chain players’ profit and authorization fee are summarized as follows:

1. The OEM’s profit is concave in authorization fee  in models *LL* and *LN.*
2. The authorized IR A’s profit decreases in authorization fee  in models *LL* and *LN.*
3. IR B’s profit decreases in authorization fee  when it accepts authorization (model *LL*), and increases in authorization fee when it does not accept authorization (model *LN*).

We can see that a higher authorization fee does not necessarily result in a higher profit for the OEM. It would be intuitive to think that the OEM’s profit increases, as the authorization fee increases, because the OEM charges an authorization fee from the two IRs for every refurbished product sold under this license mechanism. However, the size of refurbished product market and the profit of the two IRs will significantly decline with a high authorization fee, and refurbishing becomes less attractive to the IRs. Consequently, despite an increased authorization fee, the overall profit of the OEM decreases. In addition, the authorized IR’s profit always decreases in the authorization fee, while IR B’s profit increases in the authorization fee when it does not accept authorization. This is because a higher authorization fee would decrease the authorized IR’s profit and make the refurbishing activity less attractive to the authorized IR, which benefits the non-authorized IR.

## 5. Comparisons of Different Models

Based on the analyses in the preceding section, we provide a comprehensive comparison of the two IRs’ profits and the OEM’s profits in the three models with respect to the key parameters and identify the optimal authorization strategies. The analyses focus on comparing the strategies with positive demand for the three supply chain players, namely, strategies, and. We first study the conditions under which one IR would accept authorization when the other IR’s strategy is given, then analyze the equilibrium outcome for the two IRs and identify the conditions under which both IRs would accept authorization, and finally provide the conditions for the OEM choosing refurbishing authorization.

### 5.1. Conditions for one IR to accept authorization

In this section, we focus on one IR’s optimal strategy when the other IR’s strategy is given. For instance, Apple named Ifengpai as its authorized refurbisher. However, Aihuishou also collects used Apple products for refurbishing without authorization from Apple. From the perspective of Aihuishou, the authorized refurbisher Ifengpai’s strategy is given. In that sense, we need to identify whether Aihuishou should accept authorization when Ifengpai has already accepted authorization. In the analyses provided in the previous section, we assumed that the two IRs are symmetric. In this section, we analyze the problem from the IR A’s perspective. We first investigate the conditions under which IR A would accept authorization when IR B does not accept authorization, and then identify the condition under which IR A would accept authorization when IR B has accepted authorization.

### 5.1.1 Conditions for one IR to accept authorization when the other IR does not accept authorization

The condition for IR A to accept authorization when IR B does not accept authorization is that its profit increases if it accepts authorization, meaning that . IR A will accept authorization when IR B does not accept authorization if and only if, where.

In model *LN*, the OEM’s profit is concave in authorization fee , . For the OEM, the optimal authorization fee is,and. increases if and decreases otherwise.

For the OEM, the optimal authorization fee increases in and , but decreases inand . Although the refurbishing costs (i.e., and ) bound an IR’s market share, they have opposite effects on . For the authorized IR, a higher refurbishing cost  increases the price of authorized refurbished products and reduces the demand. As a result, the OEM tries to sustain the secondary market by reducing the authorization fee. In contrast, for the non-authorized IR, a higher refurbishing cost  can also drive up the price of non-authorized refurbished products and increase the number of consumers who are willing to pay for authorized refurbished products. Therefore, the authorized IR (i.e., IR A) will benefit from accepting authorization. The OEM exploits this by driving up its authorization fee. As increases, the refurbishing cost for non-authorized IR (i.e., IR B) increases. This can also increase the authorized IR’s (i.e., IR A) profitability, which consequently leads the OEM to increase its authorization fee. In addition, decreases as the production cost increases. A higher production cost can certainly decrease the OEM’s profit and discourage consumers to purchase new products. It also means that the two IRs’ refurbishing costs will increase at the same time. Although the OEM can increase the authorization fee to make up its profit loss, this will eventually hurt the secondary market.

The condition for IR A to accept authorization when IR B does not accept authorization is , while for the OEM, the optimal authorization fee is . Hence, we provide Proposition 6 as follows for the relationship between and.

**Proposition 6.** andis related as follows:

1. If , the optimal authorization fee for IR A and the OEM is . As such, IR A will accept authorization and the OEM can achieve its highest profit, which is a win-win outcome for both firms.
2. If , the optimal authorization fee for the two firms is . With , IR A will accept authorization, but the OEM cannot achieve its highest profit. Therefore, authorization refurbishing agreement may not be reached.

Figure 2 shows the numerical study result when to better interpret Proposition 6, where .



Figure 2. Supply chain profits when 

Proposition 6 indicates that for a high value of and a low value of , the OEM and IR A are unlikely to cooperate with each other. The two firms only cooperate when the OEM’s optimal authorization fee is no higher than IR A’s acceptable authorization fee. Since it is difficult to prove the monotonicity of , we provide this proposition from the perspective of. We have shown that increases in and , but decreases in and . If 1) IR B’s refurbishing cost is relatively high, 2) unit cost saving from authorization is high, 3) IR A’s refurbishing cost  and OEM’s production cost are sufficiently low, then the optimal authorization fee for the OEM will be lower than . As such, if the authorized refurbisher has a cost advantage and can refurbish used products at a cost much lower than the non-authorized refurbisher, then refurbishing and accepting refurbishing authorization becomes attractive. In that case, IR A will accept authorization and the OEM can benefit from the refurbishing authorization.

### 5.1.2 Conditions for one IR to accept authorization when the other IR has accepted authorization

The condition for IR A to accept authorization when IR B has accepted authorization is that its profit does not decrease if it accepts authorization, meaning that . IR A will accept authorization when IR B has accepted authorization if and only if , where (seein Appendix).

The OEM’s profit function in model *LL* is concave in , . Define , and increases if and decreases otherwise.

We know that the OEM’s optimal authorization fee decreases in ,and . In model *LL* when both IRs accept authorization, as andincrease, the demand for refurbished products decreases. As a result, the OEM attempts to sustain the development of the secondary market by lowering the authorization fee. The impact of production cost on authorization fee is similar to that in model *LN*. Hence, we omit the analysis.

The condition for IR A to accept authorization when IR B has accepted authorization is different from the OEM’s optimal authorization fee. We provide Proposition 7 for the relationship between and .

**Proposition 7.** andare related as follows:

1. If , the optimal authorization fee for IR A and the OEM is . As such, IR A will accept authorization and the OEM can achieve its highest profit, which is a win-win outcome for both firms.
2. If , the optimal authorization fee for the two firms is . With , IR A will accept authorization, but the OEM cannot achieve its highest profit. Therefore, authorization refurbishing agreement may not be reached.

Proposition 7 implies the condition under which the OEM and the IR can achieve a win-win outcome or an authorization refurbishing agreement may not reached when the OEM and the IR have different optimal authorization fees. The impact of and on firms’ strategy is similar to that in Proposition 6. Hence, we omit the analysis.

### 5.2. Conditions for both IRs to accept authorization

In the previous analyses, we assume that one IR’s strategy is given and focus on the other IR’s optimal strategy. Here we include both IRs’ decision on authorization acceptance. Across all of the four possible strategies, it is clear that there are no asymmetric equilibria. Furthermore, depending on parameter values, one of the two symmetric strategies, *LL* and *NN*, can be observed in equilibrium.

The condition for both IRs to accept authorization is that their profit increases by accepting authorization, meaning that and . IR A will accept authorization if and only if, where . IR B will accept authorization if and only if, where.

The optimal authorization fee for the OEM is , while IR A will accept authorization if and only if, and IR B will accept authorization if and only if. From the IRs’ perspectives, we provide Proposition 8 for the relationship between and. Then we provide Proposition 9 for the equilibrium relationship among, andin the entire supply chain.

**Proposition 8.** When the two IRs make authorization decisions, and are related as follows:

1. If : (i) when , then both IRs will accept authorization; (ii) when , then neither of IRs will accept authorization; (iii) when , then only IR A will accept authorization.
2. If : (i) when , then both IRs will accept authorization; (ii) when , then neither of IRs will accept authorization; (iii) when , then only IR B will accept authorization.

**Proposition 9.** When the OEM charges , the optimal authorization fee for the two IRs and the OEM is . As such, both IRs will accept authorization and the OEM can achieve its highest profit. Otherwise, both IRs accepting authorization is not guaranteed.

Proposition 9 also implies that if the OEM’s cost of new products and the two IRs’ cost of refurbished products are sufficiently low, then the optimal authorization fee for the OEM is lower than and both IRs will accept authorization. The two IRs’ cost of refurbished products will decrease if both firms accept authorization, while a lower refurbishing cost drives down the prices for refurbished products and increases the number of consumers who are willing to pay for authorized refurbished products. As a result, the two IRs can earn more profit from refurbishing business by accepting authorization. In addition, the OEM can also obtain additional profit from the secondary market by charging an authorization fee. As such, cooperation becomes possible for the three supply chain players.

### 5.3. Conditions for the OEM to choose refurbishing authorization

In order to identify when the authorization strategy is beneficial for the OEM, we compare the OEM’s profits from three models (i.e., NN, LN, and LL) in Proposition 10.

**Proposition 10.** The OEM’s profits in the three models are related as follows:

1. If , then , , and the OEM should cooperate with the two IRs in refurbishing by using authorization strategy;
2. If or , then ,, and the OEM should not cooperate with the two IRs in refurbishing; otherwise, ,, and the OEM should name one of the IRs as its authorized refurbisher.

Proposition 10 indicates that there is no dominant strategy for the OEM among the three strategies: authorizing both IRs (*LL*), not authorizing any of the IRs (*NN*) and authorizing one of the IRs (*LN*). This implies that when two IRs exist in the market, it is not always optimal to embrace the secondary market by cooperating with two of them, or it is not always optimal to eliminate the refurbishing market without authorization. And the OEM sometimes should cooperate with the two parties, and sometimes it is only optimal for the OEM to name one of the IRs as its authorized refurbisher. We also notice that the condition for the two IRs to accept authorization can only be realized in certain scenarios. From the OEM’s perspective, if it wants to achieve its highest profit, it should take the two IRs’ meeting condition point into consideration when it sets its authorization policy. Only when an authorization agreement is reached, a win-win or a win-win-win outcome exists for the participated supply chain parties.

We know that consumers’ preference and impact the firm’s profit, sales quantity and strategy selection. However, it is difficult to analyze its monotonicity. Therefore, we use a numerical study to show the impact of and on the OEM’s profit with respect to the three strategies (i.e., *NN, LN, LL*). Here . Figure 3 shows the OEM’s profit for the three strategies when and are large (); andare small (); is large and is small ();is small and is large (), respectively.



Figure 3. OEM’s profit for different strategies.

Figure 3 (a) shows that when consumers’ preference for refurbished products and consumers’ preference degree on non-authorized refurbished channel are high, if the OEM charges a moderate authorization fee, it is always optimal for the OEM to cooperate with the two IRs in refurbishing. A higher consumers’ preference for refurbished products means that consumers are willing to pay a relatively high price for refurbished products, and this can increase the two IRs profits. As a result, the OEM exploits this by cooperating with the two IRs. If the OEM charges a low authorization fee, it is not beneficial for the OEM to embrace the secondary market; while if it charges a high authorization fee, it will make it difficult for the two IRs to sustain the refurbishing market. Figure 3 (b) implies that when consumers’ preference for refurbished products and consumers’ preference degree on non-authorized refurbished channel are low, the strategy of not cooperating with any of the IRs is favorable. A lower consumers’ preference for refurbished products makes refurbishing business less attractive to the two IRs. As such, the two IRs will not accept authorization. Figure 3 (c) and (d) show that when is large and  is small, or when  is small and  is large, all three strategies could be optimal for the OEM depending on the values of the parameters.

In our models, we assumed that the OEM’s refurbishing authorization can save the authorized IRs’ unit refurbishing cost because the OEM can provide technical support to improve IRs’ production efficiency. The other scenario is that an IR may incur additional costs in order to obtain the authorization qualification (Liu et al., 2018). Those costs can be from activities like new technology investment and labor training cost. This scenario is possible in practice because the additional costs can be justified by improved product quality and higher market demand. Hence, we relax the assumption on cost saving and consider the scenario under which the IRs do not have refurbishing cost saving to verify the robustness of our results (i.e., ).

**Proposition 11**. The OEM’s profit increases in refurbishing unit cost saving () in models *NN* and *LN*, andhas no impact on the OEM’s profit in model *LL*.

In this paper, refurbishing unit cost saving () represents the cost advantage due to accepting the OEM’s authorization. As defined in the preceding sections, when , an authorized IR has a cost advantage and will be a strong competitor in the market. In other words, a higher indicates that the IRs will have a higher refurbishing cost without the OEM’s authorization. Unauthorized IRs will be less competitive than the OEM in the market because of their high refurbishing cost, which enhaces the OEM’s profit. When , an IR will have a cost disadvantage if it accepts authorization, and accepting authorization becomes less attractive for the two IRs. Therefore, in models *NN* and *LN*, the OEM’s profit increases in . In model *LL*, has no impact on the OEM’s profit because the two IRs have cost advantage or disadvantage at the same time when both IRs accept authorization. Next, we examine the conditions for the OEM to choose refurbishing authorization with respect to .



Figure 4. OEM’s profits with respect to .

Figure 4 shows the impact of consumers’ preference for refurbished products, consumers’ preference degree on non-authorized refurbished channel, and unit refurbishing cost saving on OEM’s refurbishing authorization strategy choosing. Figure 4(a) shows that it is always optimal for the OEM to cooperate with two IRs in refurbishing when  and  are high. Figure 4(b) shows that the strategy of not cooperating with either of the IRs is favorable when consumers’ preference for refurbished products and consumers’ preference degree on non-authorized refurbished channel are low. The two IRs’ profit loss when they have to pay an extra cost (i.e., ) is offset by consumers’ high willingness to pay for refurbished products. Therefore, in this scenario, the IRs will choose to cooperate with the OEM in refurbishing by accepting authorization. However, when consumers’ preference for refurbished products and consumers’ preference degree on non-authorized refurbished channel are low, the two IRs may not accept authorization, and *NN* strategy may dominate most of the time. Figure 4 shows that our results still hold when we relax our assumption on authorization cost saving and also reveal the unique role played by refurbishing cost.

## 6. Managerial implications

In this section, we emphasize several implications from the preceding analyses. First, a higher authorization fee always discourages the IRs from accepting the OEM’s authorization. For the OEM, it does not always benefit from a higher authorization fee. Therefore, the OEM should consider that an affordable and profitable authorization fee can lead to a win-win situation. In the scenario under which one IR has accepted authorization and the other IR has not, the authorized IR’s profit always decreases in authorization fee, while the non-authorized IR’s profit increases in authorization fee. This indicates that it may not be the best decision for an unauthorized IR to seek for authorization to compete with an authorized IR. If the OEM has been raising the authorization fee, the unauthorized IR may consider remaining unauthorized because the OEM may continue to raise the authorization fee, which will benefit the unauthorized IR. For the authorized IR, it may consider ending the authorization agreement with the OEM if the authorization fee continues to rise.

Some OEM’s refurbishing authorization practices are consistent with our results. For example, Apple signed an agreement with Ifengpai for authorization. However, Aihuishou still collects Apple’s used products for refurbishing without authorization. Given that Ifengpai has been an authorized IR, it is always optimal for Aihuishou not to accept authorization if the authorization fee is high. Our results can serve as a guidance for Aihuishou to determine when to seek cooperation with Apple. In addition, since consumers’ preference for Apple’s refurbished products is still high, in the future, model *LL* may arise in equilibrium when the optimal authorization fee for the OEM is lower than the two IRs’ participating thresholds.

## 7. Conclusions

In the secondary market, authorizing IRs for their refurbished products has been adopted by many OEMs as an effective secondary market strategy. For the IRs, they can choose to accept authorization or not, given that authorized refurbished products normally receive a higher market recognition compared to unauthorized ones. In this paper, we consider one OEM and two competing IRs in the supply chain. There are three authorization strategies available to the OEM, namely, authorizing both IRs, authorizing one of the IRs, and not involving in refurbishing. This paper investigates the equilibrium outcomes for the OEM and the two competing IRs in different authorization strategies, the conditions under which the OEM should implement refurbishing authorization, and the conditions under which the two IRs would accept authorization.

Our analyses find that when neither of the IRs accepts authorization, one supply chain player’ market increases in the other two supply chain players’ production cost and decreases in its own production cost. In the existence of other product options, a high production cost leads to a high product sale price and thus pushes consumers to the competitors.

When both IRs accept authorization, one IR’s market size relate to the production costs and authorization fee. In this scenario, the OEM’s profit is concave in the authorization fee, while the two IRs’ profit monotonically decreases in it. It indicates that a higher authorization fee is not always better for the OEM. The OEM can only benefit from the secondary market when the authorization fee is reasonable enough for the IRs to improve their profit by conducting authorized refurbishment. When only one IR accepts authorization, the OEM’s profit is still concave in the authorization fee, and the authorized IR’s profit still decreases in the authorization fee. However, the non-authorized IR’s profit increases in the authorization fee, which indicates that the non-authorized IR is always the winner in the scenario.

By comparing the three scenarios, our paper identifies the conditions under which one IR accepts authorization, both IRs accept authorization, and the OEM chooses to authorize IRs, respectively. The conditions for IRs to accept authorization and the OEM’s optimal authorization fee may be different. The IRs only cooperate with the OEM when their acceptance limit for authorization fee is higher than the OEM’s optimal authorization fee. Therefore, there is no dominating strategy among the three strategies, and each strategy chosen should satisfy certain conditions. In addition, we find that the OEM’s strategy is highly related to consumers’ preference. When consumers’ preference for refurbished products and non-authorized refurbishment channel is high, it is always optimal for the OEM to cooperate with both IRs in the secondary market by charging a moderate authorization fee. When consumers’ preference for refurbished products is low, not authorizing IRs is dominant for the OEM.

Due to the increasing recognition of sustainability, refurbishing business has seen a steady growth in various sectors. Our paper provides valuable managerial insights for OEMs and IRs who are interested in refurbishing business. Our results can provide useful guidelines for supply chain players to assess refurbishing and authorization opportunities in different situations. As shown in the analyses, the decision makers need to take into account multiple factors in their decision-making process, including consumers’ preference for refurbished products and non-authorized channel, production costs, and authorization fee.

## Appendix A

**Proof of Proposition 1**

The decisions faced by the OEM and the two IRs are given by ,  and . Because the second-order sufficient condition, i.e., , ,,is strictly concave in , is strictly concave in , and is strictly concave in . The Lagrangian of IR A’s decision problem is , and the Lagrangian of IR B’s decision problem is . The OEM and the two IRs make decisions independently and simultaneously, we can derive optimal decisions by solving the first-order conditions. There are seven candidate solutions, which are summarized below:

**Region (,):**

Solving first-order conditions we get , .

Therefore, can be written as  and can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,,,.

Therefore,  can be written as , can be written as  and  can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,,,.

Therefore,  can be written as , can be written as  and  can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,.

Therefore,  can be written as , can be written as  and  can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,,.

Therefore,  can be written as and  can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,,.

Therefore,  can be written as and can be written as .

**Region**  **(**,**):**

Solving first-order conditions we get ,,,.

Therefore,  can be written as , can be written as  and  can be written as .

Proofs of model *LL* and model *LN* are similar to that of Proposition 1, so we omit the proving process. The critical bounds characterizing the equilibrium region in models *NN, LL* and *LN* obtained from the KKT conditions are summarized in Appendix B for simplicity.

**Proof of Proposition 2**

Under region, we examine the monotonicity of , and with respect to , , , and . We have , , , , , , , , , , , , , , .

**Proof of Proposition 3**

Under region, we examine the monotonicity of , and with respect to , , , and . We have , , , , , , , , , , , , , , .

**Proof of Proposition 4**

Under region, we examine the monotonicity of , and with respect to , , , ,and . We have , , , , ,,, , , ,,,,, , , , , , , .

**Proof of Proposition 5**

Under region , we have ,,. And . So The OEM’s profit is concave in authorization fee , while the two IRs’ profit decreases in authorization fee .

Under region , we have , , . And . So The OEM’s profit is concave in authorization fee , the IR A’s profit decreases in authorization fee , while the IR B’s profit increases in authorization fee .

**Proof of Proposition 7**

Since the two IRs are symmetric, using IR B’s profit functions in model *LN*, we can easily calculate IR A’s profit functions in model *NL*, which is . IR A’s profit difference between model LL and model NL is given as follows:

 When ,. Where , ,

.

**Proof of Proposition 10**

The profit difference between model *LL* and model *NN* is given as follows:



When ,.

The profit difference between model *LL* and model *LN* is given as follows:

when ,.

The profit difference between model *LN* and model *NN* is given as follows:



When ,. Where,,,,,, , , .

For simplicity, we let,, ,, ,.

**Proof of Proposition 11**

We examine the monotonicity of ,,and with respect to . We have,,.

## Appendix B

**Table B1** Critical bounds characterizing the equilibrium region in model *NN*.

|  |  |
| --- | --- |
| Bound | Expression |
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**Table B2** Critical bounds characterizing the equilibrium region in model *LL*.

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| --- | --- |
| Bound | Expression |
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**Table B3** Critical bounds characterizing the equilibrium region in model *LN*.

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| --- | --- |
| Bound | Expression |
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|  |  |

This completes the proof.

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