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Distribution channel and licensing strategy choice considering consumer online reviews in a closed-loop supply chain

Haike Qiao [a,b,c,d], Qin Su [b,c,*]

[a] School of Management, Xi'an Jiaotong University, Xi'an 710049, China
[b] The Key Lab of the Ministry of Education for Process Control & Efficiency Engineering, Xi 'an 710049
[c] The Key Lab of the Ministry of Education for Process Control and Efficiency Engineering, Xi'an 710049, China
[d] School of Data Science, City University of Hong Kong, Hong Kong

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ABSTRACT

This research builds two-period game models to address the choice issues of the Original Equipment Manufacturer (OEM)'s licensing strategy and the Independent Remanufacturer (IR)'s distribution channel, considering consumer online reviews in a closed-loop supply chain. In both periods, the OEM sells new products by the direct distribution channel. In period 2, the OEM determines the licensing strategy (the fixed or royalty fee) to authourize the IR to remanufacture, and then the IR chooses the distribution channel (direct or indirect) for remanufactured products. Interestingly, our results show that the IR prefers the direct channel when the remanufacturing cost is smaller. And the obtained willingness-to-pay (WTP) from consumer online reviews has a positive impact on the threshold value of the remanufacturing cost. Moreover, we find that the OEM's licensing strategy choice depends on the sizes of the fixed licensing fee and the obtained WTP. The OEM will choose the royalty licensing strategy to the IR who has chosen the direct channel, when the fixed fee and the obtained WTP are smaller. Finally, we find the optimal royalty fee, numerically examine the impact of the interaction among these factors on consumer surplus and social welfare, and relax the basic assumption to show the robustness of our model.

1. Introduction

In the past decades, many products, such as computer, cell phone, camera, printer, and so on, are updated at a faster speed due to the rapid development of science and technology (Kitsara, 2014), which results in serious environment pollution and resource consuming. The United National reporteded that the quantity of electronic waste (e-waste) in 2017 had almost reached 45 million tons in the world (Baldé et al., 2017). In China, the annual average increased rate of the e-waste has reached 10.4%, and the quantity in 2030 will arrive at 27.22 million tons (Wang et al., 2020a; and Greenpeace Report, 2019). It is urgent for human beings to address these issues. For firms' production and operation, remanufacturing, which collects end-of-use products to manufacture the products which are like-new condition (Govindan et al., 2015; and Zou et al., 2016), is a good method (Giutini and Gaudette, 2003; Chen and Chang, 2012; Ovchinnikov et al., 2014; and Kadambala et al., 2017). CHINA DAILY (2013) reported that remanufactured (we use "rem" to represent "remanufactured") products could save 70% of raw materials, 60% of energy and 80% of emissions. On the other

* Corresponding author at: School of Management, The State Key Laboratory for Manufacturing Systems Engineering, the Key Lab of the Ministry of Education for Process Control & Efficiency Engineering, Xi'an Jiaotong University, Xi 'an 710049, China.
E-mail addresses: qiaohaike@stu.xjtu.edu.cn (H. Qiao), qinsu@mail.xjtu.edu.cn (Q. Su).

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hand, remanufacturing decreases 40–65% of the firm production cost (Ginsburg, 2001), but only expands 20% of the effort than manufacturing new products (Jayaraman and Luo, 2007; and Huang and Wang, 2017b). Besides, plenty of legislation has been made to force firms to collect and remanufacture, such as the Waste Electrical and Electronic Equipment (WEEE) Directive in the European Union (Esenduran et al., 2017), Japanese Automobile Recycling Law (Genc and De Giovanni, 2017), and Administrative Regulations for Recycling and Disposal of WEEE in China (Wang et al., 2020a).

Considering the greenness and economy of remanufacturing (Galbreth et al., 2013), some Original Equipment Manufacturers (OEMs), such as Caterpillar, Xerox, and HP, engage in it. In 2007, the business volume of Caterpillar remanufacturing had arrived at $2 billion (Ferguson and Souza, 2010). The remanufacturing program of Xerox had decreased by 40–65% manufacturing costs (Savaskan et al., 2004). HP had rem 566 million ink and toner cartridges by its cartridge recycling programme (Zhou et al., 2017). However, OEMs only account for 6% of over 2000 remanufacturing firms (Hauser and Lund, 2008). A great number of OEMs do not carry out remanufacturing because of the higher investment, transportation and inventory costs (Chai et al., 2020; and Huang and Wang, 2017b), and rem products' cannibalization (Ferguson and Toktay, 2006; and Guide and Li, 2010) and brand damage effect on new products (Hong et al., 2017). The remaining 94% is Independent Remanufacturers (IRs), such as Recycle Assist, Foxconn, Gazelle and so on, who remanufacture and compete with the OEM by selling rem products. The vast research has been conducted under the competition of the OEM and IR (Atasu et al., 2009, 2013; Wu and Zhou, 2016; and Huang et al., 2019). But, the recent patent lawsuits of Canon and Recycle Assist reminds researchers to recognize the setting of the competitor IR remanufacturing, because this denotes that OEMs have started to focus on their products' patent protection. If the IR remanufactures end-of-use products of the OEM, it needs to get the corresponding OEM's licensing. For example, Apple authorizes Foxconn to remanufacture end-of-life iPhones in China (Zou et al., 2016; and Huang and Wang, 2017b). And there are two kinds of licensing strategies which can be chosen for the IR, namely the fixed and royalty fee (Wang et al., 2018). The fixed fee licensing strategy represents the IR will pay a fixed fee to the corresponding OEM, which is not related to the IR's remanufacturing volume. But, the royalty fee licensing strategy represents the IR will pay a royalty fee for per unit rem product to the OEM. The occurrence of these fees will weaken the motivation of the IR to remanufacture, and change the cannibalization effect of rem products on new products. Considering the advantages and disadvantages of two licensing strategies, the OEM will make a choice. Naturally, new problems occur: *which one licensing strategy is optimal for the OEM? If the OEM chooses the royalty fee licensing strategy, how does the royalty fee affect the OEM and IR's decisions, and what is the optimal royalty fee?*

Once the OEM authorizes the IR to remanufacture the end-of-use products, the IR will market rem products, and face with a choice on the distribution channel for rem products. In general, the indirect distribution channel is a better choice because the retailer has deeply known consumers and provides more professional selling service. Hence, some IRs sell rem products by eBay, Amazon or the authorized distributors (Ferguson and Souza, 2010). For example, the rem Toughbook computers are sold through Buy Tough (Panasonic, 2014). But, other IRs give up this channel, and are more willing to sell rem products by their own-electronic channels (the direct distribution channel), such as GE Healthcare's own distribution channel called GoldSeal Refurbished Systems (GE Healthcare, 2020). The reasons are as follows. Firstly, the indirect distribution channel exists the double marginalization problem (As Spengler, 1950; Yan et al., 2015 point out, all channel members in the distribution channel independently seek to maximize their own profit, resulting in higher retail prices, and lower sales quantities and profits than in a vertically integrated channel). Secondly, there is more intense competition from other products in the indirect distribution channel. Thirdly, the related legislation, the Sales of Goods Act (SoGA), discourages the indirect distribution channel to sell rem products (Gray and Charter, 2007; and Yan et al., 2015). Furthermore, the supply constraint, cost saving, and the cannibalization effect of the remanufacturing also affect the channel choice for rem products. *Faced with the harms and benefits of the different distribution channels, which one distribution channel should the IR choose when the OEM licenses the IR to remanufacture?*

Moreover, on the demand side, recent consumers have become more active. And they will poster reviews on the manufacturer's own website or the indirect distribution channel platform (such as eBay, Amazon, and JD.com) after purchasing and using. It is reported that 88% of consumers regularly read the reviews before purchasing (DeMers, 2015). Even almost half of U.S. online consumers read the reviews at least once a month (Bernoff et al., 2008). A great number of researchers affirm a more huge impact of consumer online reviews on consumers' purchasing behavior than traditional media, such as advertising and newspapers (DoubleClick, 2004; and Deloitte, 2012), and remind practitioners to focus on the impact on their decisions and profits during operation (Bergemann and Välimäki, 2006; Kuksov and Xie, 2010; Liu et al., 2012; Yu et al., 2016; and Jiang and Yang, 2019), since consumer online reviews will convey the product quality information to latter consumers. These research provides many insights for the manufacturer who only sells new products. However, in the presence of rem products, consumer reviews for new products will also influence the latter consumer purchasing behavior for rem products, since rem products have the same quality property with new products (Atasu et al., 2010; Örsdemir et al., 2014; and Kleber et al., 2018). *If incorporating consumer online reviews under remanufacturing, how do consumer online reviews impact the practitioner's optimal results, and the choice of the licensing strategy and distribution channel?*

Based on these practices, we build two-period game models to discuss the interaction between the licensing strategy and the distribution channel, considering consumer online reviews in a closed-loop supply chain (CLSC). To pay attention to the issue of the distribution channel choice for rem products, we consider the setting where the OEM, like Apple, Canon, and so on, chooses the direct distribution channel to sell new products in both periods (Shi et al., 2020). After consumers purchase and use in period 1, they will poster their reviews for the product on the websites. In period 2, considering patent protection, the OEM will choose the licensing strategies: the fixed or royalty fee, to the IR. The authorized IR enters the market and applies the end-of-use products of period 1 to remanufacture, and choose the distribution channel (direct or indirect) for rem products. Consumers of period 2 will read consumer reviews of period 1 for new products before purchasing. Based on the OEM's two licensing strategies and the IR's two distribution channels for rem products in period 2, there are four alternative operation models: the fixed fee and the direct distribution channel, the fixed fee and the indirect distribution channel, the royalty fee and the direct distribution channel, and the royalty fee and the indirect

distribution channel, in our research. Besides, considering the appearance of consumer online reviews in period 2, we mainly have the following assumptions: a. consumers in period 1 purchase new products, and have an original willingness-to-pay (WTP) for new products without consumer reviews, based on the product description, advertisement, etc. (Liu et al., 2017). b. Before purchasing in period 2, consumers will read the reviews of period 1. Since consumer online reviews will convey the product quality information to consumers of period 2 (Zhao et al., 2013; Kwark et al., 2014; Liu et al., 2017; He and Chen, 2018; and Li et al., 2019), and rem products have the same quality property with new products (Atasu et al., 2010; Örsdemir et al., 2014; and Kleber et al., 2018), we assume that consumer reviews of period 1 for new products have the same impact on consumer WTP for new and rem products in period 2 in the main body.

Our research demonstrates that if the fixed or royalty fee licensing strategy is adopted, the profit of the IR who sells rem products by the direct distribution channel is higher than that in the indirect distribution channel for a lower remanufacturing cost, which is different from the research of Yan et al., (2015). It is because in the direct distribution channel, a lower remanufacturing cost will significantly improve the quantity of rem products, which increases the profit of the IR. And the obtained WTP has a positive impact on the threshold value of the remanufacturing cost. And more surprisingly, the results indicate that the OEM always obtains a higher profit if the IR chooses the indirect distribution channel. This is because the higher price of new products in the indirect distribution channel will improve the profit of the OEM, and even can offset the loss due to the lower quantity of new products. Besides, we find that the OEM's licensing strategy choice is determined by the sizes of the fixed fee and the obtained WTP. For example, the OEM will choose the royalty licensing strategy to the IR who sells remanufactured products by the direct channel, if the fixed fee and the obtained WTP are smalller. And there are higher prices, lower quantities and lower environment impact under the royalty fee licensing strategy. Moreover, when we compare four models simultaneously, we interestingly find that the OEM always prefers the model where rem products are sold by the indirect distribution channel. The optimal model of the OEM is either the fixed fee or the royalty fee and the indirect distribution channel. It is because that the double marginalization problem of the indirect distribution channel for the IR will further strengthen the advantages of the OEM's competition.

Furthermore, our results present that the retail prices, quantities and profits will increase with the obtained WTP of consumers from online reviews. It is because a larger obtained WTP means that consumers are more willing to purchase the products. And we find that the price of new products with considering consumer reviews is always lower than that without. However, for rem products, the result indicates that the price of rem products with consumer reviews is higher than that without if the obtained WTP is sufficiently large. Moreover, there are some interesting findings on the impact of the royalty fee. When the royalty fee increases, the quantities and the profit of the IR decrease, but the retail prices and the profit of the OEM increase. The reasons are as follows. For a larger royalty fee, the IR needs to lower the quantity of rem products to decrease the total royalty fees. Whilst, the lower quantity will improve the retail prices of rem products. The negative effect of the lower quantity on the profit makes the profit of the IR decrease with the royalty fee. On the other hand, facing the lower quantity of rem products, the OEM will lack the motivation to produce new products due to fewer returns needed. Thus, the quantity of new products decreases, which increases the retail price of new products. The higher prices and royalty fee improve the profit of the OEM.

Finally, we make some extensions in our basic research. Firstly, the optimal royalty fees respectively are respectively obtained from the OEM's and whole supply chain's perspective if the royalty fee licensing strategy is adopted. And we find that the optimal royalty fee in the indirect distribution channel is larger than that in the direct distribution channel. The intuition is that the double marginalization problem on the IR benefits the OEM. Besides, we also numerically compare consumer surplus and social welfare among four models in a remanufacturing setting which incorporates the licensing strategy, the distribution channel and consumer online reviews. The observation demonstrates that if both the fixed fee licensing strategy and the direct distribution channel are adopted, consumer surplus and social welfare are the largest. Furthermore, we relax the assumption about the obtained WTP of consumer online reviews to show the robustness of our basic model.

There are three main contributions to our research. Firstly, we introduce the licensing strategy in a remanufacturing setting, which is previously studied in a manufacturing setting. Secondly, our research focuses on the distribution channel choice for the authorized IR's rem products when the IR pays the licensing fee to the OEM. Thirdly, we model consumer online reviews in our research, and discuss its impact on the practitioner's optimal results. To the best of our knowledge, this is the first paper that combines these three aspects: the licensing strategy, the distribution channel and consumer online reviews.

The remainder of this paper is organized as the following. Section 2 summarizes the related literature and positions our research. Section 3 describes all model assumptions and presents all parameters in our research. Section 4 solves the optimal results for four models, and compares them to provide the distribution channel and licensing strategy choice for the practitioners. Section 5 extends our basic model to explore the optimal royalty fee, and numerically discuss the impact of the interaction between the licensing strategy and the distribution channel on consumer surplus and social welfare. Section 6 summarizes all conclusions of our research, and lists limitations and future research directions.

2. Literature review

The related literature to our research includes the following three streams: channel choice under remanufacturing, licensing strategy, and consumer online reviews.

2.1. Channel choice under remanufacturing

The first stream of literature is on channel choice under remanufacturing. The literature is mainly from two aspects.

One is about the channel choice for new products. Ryan et al. (2012) consider a setting in which the retailer can sell products through its website or the marketplace platform, and discuss the question of marketplace contract. Mantin et al. (2014) use a stylized model to character the bargaining between the manufacturer and the retailer considering the introduction of the third party marketplace. Hagiu and Wright (2015) specify the decision who the supplier or the platform can better hold the marketing activity under online platform. Abhishek et al. (2016) apply a theoretic model to discuss when e-tailers should introduce the marketplace mode. Their research shows that if sales in the online retailing harm the demand in the offline retailing, e-tailers will choose the marketplace mode. Li et al. (2018) character a setting in which there are two competitive manufacturers under the marketplace mode, and explore the impact of recommender systems on social welfare, customer surplus and parties. Yan et al. (2018) examine how the manufacturer's sales efficiency, the platform fee and the online spillover affect the introduction of the marketplace mode. Yan et al. (2019) develop a theoretic model to investigate whether the retailer and manufacturer should adopt the online marketplace mode under the disadvantages of manufacturer's demand information and sales efficiency. Zhang et al. (2019) discuss the interrelationship between product quality and contract choices (the fixed fee and the revenue sharing) under platform selling. Tian et al. (2018) focus on the optimal mode choice among online marketplace mode, reseller mode and hybrid mode, considering fulfillment cost and the supplier competition. They find that if suppliers have a lower competitive intensity and order-fulfillment cost is low, the online marketplace mode is optimal. Zhang and Zhang (2020) investigate the demand information sharing strategy of the e-tailer, when the supplier has online (reseller and marketplace) and offline channels. Liu and Ke (2020) explore the impact of the cap-and-trade regulation on the platform choice between reseller and marketplace modes. Pu et al. (2020) study the manufacturer's online selling mode choice among marketplace, reseller and direct selling, and the manufacturer also sells products by the traditional offline mode. Wang et al. (2020b) build a model to discuss information sharing strategies of the marketplace platform when there are a reseller platform and a marketplace platform in the market. The result indicates that information sharing strategies are related to the revenue sharing rate and the channel competitive intensity. Zhen et al. (2020) introduce the manufacturer's capital constrain and financing strategy under the marketplace platform. Liu et al. (2020) use the game model to study the manufacturer's mode choice between the reseller and marketplace modes when there are two competition online platforms. However, they mainly focus on new products, and lack in the research of the distribution channel choice for rem products.

The other is on the distribution channel choice for rem products. To the best of our knowledge, there is little research discussing the related research (e.g. Yan et al., 2015; and Shi et al. 2020). Yan et al. (2015) pay attention to the issue of the monopoly OEM's distribution channel choice for rem products, and explore the environment performance considering channel structure and remanufacturing. Their finding presents that if the OEM sells rem products by the direct distribution channel, the firms will suffer some loss but the environment performance is greener. Shi et al. (2020) model a monopoly OEM who has two divisions: manufacturing and remanufacturing, and discuss how the organization structure (decentralized or centralized) of the firm influences the OEM's distribution channel choice for rem products. They find that the indirect selling channel is an optimal choice for the decentralized firm.

But, the above-mentioned research on the distribution channel for rem products mainly cares about the monopoly OEM remanufacturing scenario. We consider the setting where the OEM competes with the remanufacturing IR, and discuss the distribution channel choice for rem products when the OEM chooses different licensing strategies for the IR. Besides, we contribute to the related research by modeling consumer online reviews in the introduction stage of rem products.

2.2. *Licensing strategy*

Licensing strategy has attracted the focus of many researchers. Arrow (1972) conducts the earliest research on the licensing strategy. Since then, much research focuses on the licensing strategy (e.g. Rockett, 1990; Mukherjee and Pennings, 2006; Lin and Kulatilaka, 2006; Crama et al., 2013; Arora et al., 2013; Bagchi and Mukherjee, 2014; Zhao et al., 2014; Avagyan et al., 2014; Savva and Taneri, 2015; Sen and Stamatopoulos, 2016; Zhang et al., 2016; Cheng et al., 2018; Wu, 2019; Yang et al., 2019; and Jeon, 2019). For example, Lin and Kulatilaka (2006) compare the fixed and royalty fee licensing strategies in the presence of network effects. They find that the technology innovators prefer the fixed fee licensing strategy for stronger network effects. Following the research of Lin and Kulatilaka (2006), Zhao et al. (2014) further propose the two-part tariff licensing strategy within network effects, and find that this strategy is beneficial for the society and the licensor. Arora et al. (2013) incorporate licensing strategies and organization structures in their model, and explore the interrelationship between them. Avagyan et al. (2014) construct a differential game model to study whether/how the licensing strategy speeds up the product diffusion. Savva and Taneri (2015) introduce asymmetric information in their licensing strategy model, and compare the equity and fixed fee contract in university technology transfer. Sen and Stamatopoulos (2016) present that licensing emerges when the cost of the product is superadditive for drastic technologies. Cheng et al. (2018) use the evolutionary game to address the problems of technology licensing cooperation. They find that the probability of two firms' cooperation depends on the cost saving and the fixed fee. Wu (2019) builds a dynamic duopoly model to analyze the price competition in a technology licensing setting, when network effects strengthen consumers' utility. The result shows that a dynamic royalty can efficiently mitigate the price competition intensity. Yang et al. (2019) shed light on the importance of supply disruption when the suppliers adopt the licensing strategy. Jeon (2019) investigate a license contract considering information asymmetry and the competitor's challenge. However, these research mainly incorporates the licensing strategy in a setting in which the firms only manufacture new products. Once rem products are introduced to the market, how the licensing strategy affects the remanufacturing is not clear.

Recently, some research has noticed this issue and investigated the licensing strategy in a remanufacturing setting (e.g. Oraiopoulos et al., 2012; Zou et al., 2016; Hong et al., 2017; Huang and Wang, 2017a, 2019; and Chai et al., 2020). Oraiopoulos et al. (2012) build a model to examine the OEM's strategy in the secondary market, when the OEM charges a relicensing fee to the third party remanufacturing. Hong et al. (2017) extend the research of Oraiopoulos et al. (2012) by considering the case where both the OEM and the IR

collect used products to remanufacture, and simultaneously focus on the competition of the forward and reverse channels. They find that the royalty fee licensing strategy more benefits environment and consumer, compared with the fixed fee licensing strategy. Huang and Wang (2017a) propose the issue of information sharing when the OEM adopts the technology licensing in a remanufacturing area, and analyze the impact of information sharing for three different remanufacturing scenarios. The results show that information sharing will enhance the profits of the OEM and the third party, but hurt the profit of the distributor. Huang and Wang (2019) develop a Stackelberg game to explore how the remanufacturing cost and strategic consumers affect the OEM and the IR if the OEM licenses the IR to remanufacture. They indicate that although the emergence of strategic consumers will decrease the profit of the OEM, the licensing strategy can moderate this profit loss. Chai et al. (2020) simultaneously introduce licensing strategies and the cap-and-trade regulation under remanufacturing, explore the impact of cap-and-trade regulation on the practitioners' decisions, and discuss the effectiveness of licensing strategies to coordinate the competition of the OEM and the IR. Their results demonstrate that licensing strategies will help not only the practitioners' profit but also the environment.

However, none of these papers considers the problem of the distribution channel choice for rem products under the licensing strategy. On the other hand, the above research does not explore the impact of consumer online reviews on remanufacturing. Our research fills these gaps.

2.3. Consumer online reviews

There is extensive research on consumer online reviews. Some use the method of empirical research to explore the impact of consumer online reviews from different perspectives. Duan et al. (2008) investigate the persuasive and awareness effect of consumer reviews on the movies. Li and Hitt (2010) analyze how price-affected reviews influence consumer welfare and the firm's optimal decisions. Sun (2012) research the interaction between consumer review rate and demand. Maslowska et al. (2017) study how consumer reviews affect consumers' purchasing behavior considering price and review exposure. The results show that many reviews, higher price and consumer reading reviews have a stronger valence effect. Wu et al. (2018) explore the impact of consumer engagement on its review. Xu (2020) discusses the impact of consumer online reviews on the consumer's demand and overall satisfaction in the sharing economy. They find that information search cost has an important impact on consumer purchasing behavior. These research causes widespread concern of the firms on operation management, such as price decisions, considering consumer online reviews.

Recently, others apply the method of model research to address the problem of operation management in the presence of consumer online reviews, which is highly related to our research. Chen and Xie (2008) construct a normative model to discuss the operation problems of firms when consumer reviews are considered. Li et al. (2011) focus on the firm's pricing strategy when consumers provide reviews and repeat purchase products. Kwark et al. (2014) propose the importance of consumer review on mitigating consumers' uncertainty for product quality and fitting consumers' demand, when there are two competitive manufacturers to sell substitutable products to consumers by a retailer. They point out that consumer reviews are critical for upstream competition. Following the research of Kwark et al. (2014), Zhang et al. (2017) analyze the influence of consumer reviews on social welfare. Crapis et al. (2017) discuss the optimal pricing of a monopolist when consumers can learn from other consumer reviews and past purchasing decisions. Liu et al. (2017) develop a two-period model to discuss the impact of sales volume and consumer reviews on consumer purchasing behavior and the firm's optimal decisions. They find that sales volume information and consumer reviews will mutually enhance the firm's profit. He and Chen (2018) build a dynamic pricing model for electronic products when consumer reviews covey the information on product quality. Cai et al. (2018) model consumer reviews in a supply chain when three competitive manufacturers sell substitutable products to consumers by e-retailer. Zhao and Zhang (2019) establish a dynamic programming model to set the optimal price and quality considering consumer reviews. They find that if the consumer intensity is large, the supplier should determine a higher price and quality with consumer online reviews. Li et al. (2019) characterize joint reviews from consumers and manufacturers in their model, and focus on the research of product design crowdsourcing. Yang et al. (2020) incorporate consumer reviews in their dual-channel supply chain model, and discuss the firms' pricing problem under a centralized or decentralized channel. The results show that consumer reviews always hurt the retail price in a centralized channel.

It is worth noting that the aforementioned research about consumer online reviews only focuses on new products, and provides many operational suggestions for the firms who do not remanufacture. We incorporate consumer online reviews in our two-period model to discuss its impact on remanufacturing for different licensing strategies and distribution channels.

3. Model assumptions

In our research, we develop a two-period game model to explore the choice problem of the IR's distribution channel and the OEM's licensing strategy in the presence of consumer online reviews in a CLSC. In period 1 and 2, the OEM does not remanufacture but offers new products by the direct distribution channel. In period 2, the OEM will choose whether to license its patent to the IR who remanufactures the end-of-use products of period 1. Once the OEM chooses to authorize, it will offer two alternative licensing strategies: a fixed or royalty fee, to the IR. The fixed fee licensing strategy represents that the OEM will charge the IR a fixed fee, F, which is independent of the quantity of rem products. The royalty fee licensing strategy denotes that the OEM will charge a royalty fee η for per unit rem product. If the licensing strategy occurs, the IR will produce rem products and compete with the OEM in period 2. Simultaneously, the IR will choose the distribution channel for rem products between the direct and indirect distribution channels. The direct distribution channel means the IR directly sells rem products to consumers by its own-electronic channel. The indirect distribution channel means that the IR firstly sells rem products to the reseller at a wholesales price, and then the reseller offers them to

consumers. In general, there are four alternative models, based on two different licensing strategies and two alternative distribution channels, in period 2. We use F and R to respectively denote the fixed and royalty fee licensing strategy. D and I respectively represent the direct and indirect distribution channel for rem products. Specially, four models can be written as: Model FD, Model FI, Model RD and Model RI). Model FD (FI) denotes that the fixed fee licensing strategy is chosen and rem products are sold by the direct (indirect) distribution channel. Model RD (RI) represents that the OEM chooses the royalty fee licensing strategy and the IR sells rem products by the direct (indirect) distribution channel. Table 1 summarizes all parameters. Table 2 shows the construction of four models in period 2.

3.1. Demand and price

Consumers are heterogeneous and uniformly distributed between 0 and 1. They choose among new, rem products or none, based on their utility. In addition, we normalize both market sizes to 1 in period 1 and 2, since the product has a period life cycle.

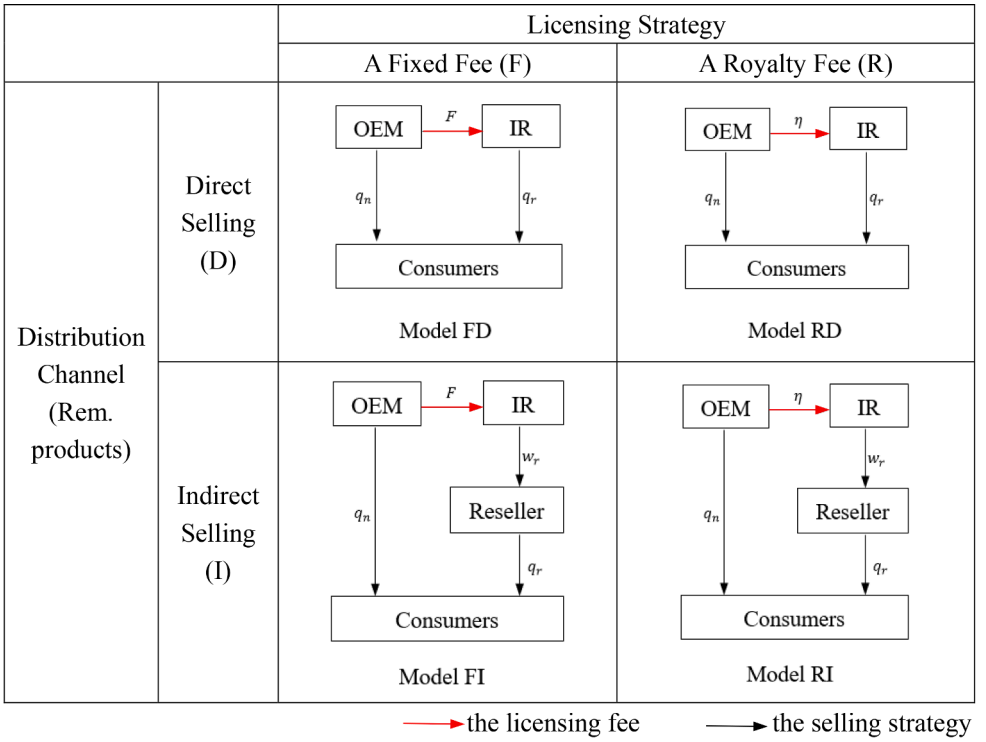
In period 1, the OEM introduces new products and sells them at the retail price p_1, and there is no consumer review and rem product. A consumer will have an original willingness-to-pay (WTP) v for new products based on the product description, the advertisement or other sources. Consumer's utility for new products is $v - p_1$ in period 1. If $v - p_1 > 0$, consumers will purchase new products and poster their reviews on the website. Thus, we have the inverse demand function for new products: $q_1 = 1 - p_1$, in period 1.

In period 2, both new and rem products are offered to consumers. Consumers' original WTP for new products is still v. Similar to Subramanian and Subramanyam (2012), Agrawal et al. (2015), Jin et al. (2016), Ma et al. (2017), and Abbey et al. (2017), we assume that consumers' original WTP for rem products is a fraction α of that for new products, $\alpha \in (0, 1)$, where α denotes the discount of consumers' WTP for rem products. A higher α represents that consumers accept rem products more easily (Abbey et al., 2015; and Chai et al., 2020). Thus, consumers' original WTP for rem products is αv before reading consumer online reviews (Esenduran et al., 2016; and Zheng et al., 2017). However, different from without consumer online reviews in period 1, consumers in period 2 will read consumer reviews of period 1 to have a more clear recognition for the product quality, before consumers of period 2 purchase the products. We assume consumers in period 2 will obtain a WTP λ, $\lambda \in (-1, 1)$for new product quality from consumer online reviews of period 1 after reading consumer reviews. We named λ as the obtained WTP in our research. λ mainly characterizes the product quality information that consumer obtain from consumer online reviews (Zhao et al., 2013; Kwark et al., 2014; Liu et al., 2017; He and Chen, 2018; and Li et al., 2019). Since the IR produces rem products according to the quality standard of new products, consumer online reviews for new products convey the same quality information for new and rem products (Atasu et al., 2010; Örsdemir et al., 2014; and Kleber et al., 2018). And in reality, new and rem products are manufactured by the same product quality, such as new and remanufactured iPhone, HP computers, Canon cameras, and so on. Thus, we assume consumers will obtain the same WTP λ from consumer online reviews for new and rem products. Based on the method of minimum variance estimation (Kwark et al., 2014; and Yang et al., 2020), we have the expected posterior WTPs for new and rem products: $(1 - \beta)v + \beta\lambda$ and $(1 - \beta)\alpha v + \beta\lambda$, in period 2, $\beta \in (0, 1)$, where β represents the weight of the obtained WTP of consumers from consumer reviews. We named β as the weight in our research. Hence, in

Table 1
Parameters.

Parameters	Description
c_n	The unit manufacturing cost
c_r	The unit remanufacturing cost
p_1	The retail price of new products in period 1
p_n	The retail price of new products in period 2
w_r	The wholesale price of rem products in period 2
p_r	The retail price of rem products in period 2
q_1	The quantity of new products in period 1
q_n	The quantity of new products in period 2
q_r	The quantity of rem products in period 2
η	The royalty fee
F	The fixed fee
μ	The interest rate
v	Consumer type
λ	The obtained WTP of consumers from consumer reviews
β	The weight of the obtained WTP of consumers from consumer reviews
α	The discount of consumers' WTP for new products relative to rem products
E	The environment impact of unit new product
e	The environment impact of unit rem product
π	The practitioner's profit
CS	Consumer surplus
TE	The total environment impact
SW	Social welfare

Table 2
The construction of four models.



period 2, consumer's utilities for new and rem products are respectively are $(1-\beta)v+\beta\lambda-p_n$ and $(1-\beta)\alpha v+\beta\lambda-p_r$. If $(1-\beta)v+\beta\lambda-p_n>(1-\beta)\alpha v+\beta\lambda-p_r$ and $(1-\beta)v+\beta\lambda-p_n>0$, consumers will buy new products. If $(1-\beta)v+\beta\lambda-p_n<(1-\beta)\alpha v+\beta\lambda-p_r$ and $(1-\beta)\alpha v+\beta\lambda-p_r>0$, consumers will purchase rem products. Refer to Örsdemir et al. (2014), Chai et al. (2018), Liu and Xiao (2019), and Qiao and Su (2020a), we have the demand functions for new and rem products in period 2: $q_n=1-\frac{p_n-p_r}{(1-\beta)(1-\alpha)}$ and $q_r=\frac{\alpha p_n-p_r+(1-\alpha)\beta\lambda}{\alpha(1-\beta)(1-\alpha)}$. Besides, considering consumers may distrust rem products during purchasing (Atasu et al., 2013; Huang et al., 2019; and Qiao and Su, 2020b), we characterize a case where consumers purchasing rem products will obtain a lower WTP $\alpha\lambda$ rather than λ from consumer online reviews to prove the robustness of our basic model in Section 5.4. We find the qualitative results cannot be changed.

For the indirect distribution channel, the IR first sells rem products to the reseller at the wholesale w_r. And then the reseller sells them to consumers at the retail price p_r.

3.2. Cost

New products are manufactured by raw material and have a manufacturing cost c_n in both periods. Rem products are produced by end-of-use products and raw material at a remanufacturing cost c_r. Following Xiong et al. (2013), Zhou et al. (2013), and Kovach et al. (2018), we assume that the unit remanufacturing cost c_r is lower than the unit manufacturing cost c_n, since rem products use parts of end-of-use products to replace raw material, which significantly diminishes the cost. And, if the fixed fee licensing strategy is adopted, the IR will pay a fee F to the OEM; if the royalty fee licensing strategy is adopted, the IR will pay a royalty fee η for per unit rem product.

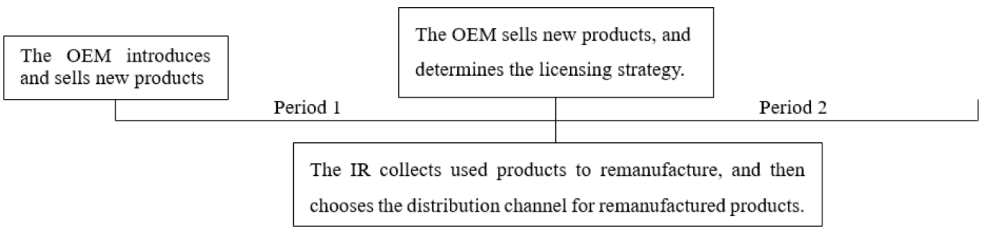


Fig. 1. The period.

3.3. Period

Our research is based on a two-period model to focus on the introduction stage of new and rem products (Ferrer and Swaminathan, 2010; and Mutha et al., 2016). At the beginning of period 1, the OEM introduces and sells new products by the direct distribution channel. At the beginning of period 2, the OEM offers new products to consumers by the direct distribution channel, and determines the licensing strategy for the IR if it chooses to license. Once the licensing strategy occurs, the IR will collect end-of-use products of period 1 to conduct remanufacturing, and then choose the distribution channel for rem products. The period is shown in Fig. 1. During deriving the equilbirum results, we use the backward induction. Since the decisions of the OEM in period 1 cannot be affected by the OEM's licensing strategy choice and the firms' optimal decisions of period 2, we choose the licensing strategy at the beginning of Period 1 to simplify the analysis process (Hong et al., 2017; Huang and Wang, 2019; and Chai et al., 2020).

3.4. Environment impact

Because rem products do not need to produce some parts from raw material, there is less resource consuming and pollution emission (Yan et al., 2015; and Yenipazarli, 2016). Consistent with Atasu and Souza (2013) and Örsdemir et al. (2014), we assume that the environment impact of unit rem product e is lower than that of unit new product E. Hence, in our model, we have the total environment impact $E(q_n + q_1) + eq_r$. A larger total environment impact means worse environment performance.

4. Model formulation

In this section, four different models are respectively discussed in order to generate insights on the interaction between the licensing strategy and the distribution channel in the presence of consumer online reviews in period 2. Since there is a multi-stage decision problem, backward induction is used to derive the results. Firstly, given the licensing strategy, the optimal distribution channel for rem products is discussed. Section 4.1 (4.2) discusses the issue of the distribution channel choice if the fixed (royalty) fee licensing strategy is adopted, and compares the situations between with and without consumer online reviews. Then, we provide the guidelines for the OEM's licensing strategy choice to the IR in section 4.3. Finally, four models are compared from the respective of the OEM in section 4.4. The proofs of all propositions and Lemmas are shown in the Appendix A. The boundaries of all conditions, such as $c_{r1}^{FD}, c_{r2}^{FD}, c_{r1}^{FI}$, and so on, are summarized in Table A of the Appendix. Besides, to discuss the impact of consumer online reviews on optimal prices, we first obtain the optimal prices of four models under without consumer online reviews, which are shown in Table 3. The derivation is provided in the Appendix B.

4.1. Licensing strategy–the fixed fee

In this subsection, we assume that the OEM chooses the fixed fee licensing strategy to the IR. And the OEM sells new products by the direct distribution channel in both periods. The IR sells rem products by the direct (Model FD) or indirect (Model FI) distribution channel. The optimal decisions of the OEM and the IR, prices, quantity, and profits, are firstly derived in these two models. Furthermore, we compare the optimal results between the two models to address the problem of the distribution channel choice of the IR when the fixed fee licensing strategy is adopted.

4.1.1. Model FD

In the Model FD, the IR pays a fixed fee, F, for the OEM to remanufacture the end-of-use products, and sells rem products by the direct distribution channel at the retail price p_r. The OEM respectively sells new products at the retail prices $p_1 and p_n$ in both periods. The profits of two firms are as written:

$$\pi_{OEM}(p_1, p_n) = (p_1 - c_n)q_1 + \mu((p_n - c_n)q_n + F)$$

$$\pi_{IR}(p_r) = \mu((p_r - c_r)q_r - F)$$

$$\text{s.t.} q_1 > q_r$$

The constraint represents the quantity of rem products in period 2 is less than that of new products in period 1. To ensure a unique interior solution (Gilbert and Cvsa, 2003; and Yan et al., 2015), c_r should satisfy $c_{r1}^{FD} < c_r < c_{r2}^{FD}$. Maximizing the profits, we can obtain the following Lemma.

Lemma 1:. *In Model FD, the optimal prices, quantities and profits are as written:*

$$p_1^{FD} = \frac{1 + c_n}{2}$$

$$p_n^{FD} = \frac{A - 2c_n}{\alpha - 4}$$

Table 3
The optimal prices of four models without consumer online reviews.

	p_{no}	w_{ro}	p_{ro}
Model FD	$\frac{2\alpha-2c_n-c_r-2}{\alpha-4}$;	–	$-\frac{\alpha c_n+\alpha+2c_r-\alpha^2}{\alpha-4}$;
Model FI	$\frac{2\alpha c_n+4\alpha-4c_n-c_r-4}{5\alpha-8}$;	$-\frac{\alpha^2c_n+2\alpha^2-2\alpha c_n+2\alpha c_r-2\alpha-4c_r}{5\alpha-8}$;	$-\frac{3\alpha^2c_n+6\alpha^2-6\alpha c_n+\alpha c_r-6\alpha-4c_r}{2(5\alpha-8)}$;
Model RD	$\frac{2\alpha-c_r-2c_n-2-3\eta}{\alpha-4}$;	–	$\frac{\alpha^2-\alpha c_n-2c_r-\alpha-\eta(2+\alpha)}{\alpha-4}$;
Model RI	$\frac{2\alpha c_n+4\alpha-c_r-4-4c_n-3\eta}{5\alpha-8}$;	$-\frac{\alpha^2c_n+2\alpha^2+\alpha\eta-4\eta-2\alpha c_n+2\alpha c_r-2\alpha-4c_r}{5\alpha-8}$;	$-\frac{3\alpha^2c_n+6\alpha^2-2\alpha\eta-6\alpha c_n+\alpha c_r-6\alpha-4\eta-4c_r}{2(5\alpha-8)}$;

$$p_r^{FD}=-\frac{B+2c_r}{\alpha-4}$$

$$q_n^{FD}=\frac{A+(2-\alpha)c_n}{(\alpha-4)(\alpha-1)(\beta-1)}$$

$$q_r^{FD}=-\frac{B+(\alpha-2)c_r}{(\alpha-4)(\alpha-1)(\beta-1)\alpha}$$

$$\pi_{OEM}^{FD}=\left(\frac{1-c_n}{2}\right)^2+\mu\left(\frac{(A+(2-\alpha)c_n)^2}{(\alpha-4)^2(\alpha-1)(\beta-1)}+F\right)$$

$$\pi_{IR}^{FD}=\mu\left(\frac{(B+(\alpha-2)c_r)^2}{(\alpha-4)^2(\alpha-1)(\beta-1)\alpha}-F\right)$$

$$A=\beta\lambda\alpha-2\alpha\beta-\beta\lambda+2\alpha+2\beta-c_r-2;B=\alpha^2\beta-2\alpha\beta\lambda-\alpha^2-\alpha\beta+\alpha c_n+2\beta\lambda+\alpha$$

Lemma 1 presents the optimal results in Model FD. We find that the fixed fee does not affect the optimal prices and quantities, but has an important impact on the profits of the OEM and the IR. A larger fixed fee benefits the OEM but harms the IR, which is consistent with our intuition. However, all results are related to the obtained WTP of consumers from consumer online reviews, the following lemma firstly discusses the impact. Besides, the below lemma compares the prices between the situations with and without consumer online reviews, which provides more insights for parties.

Lemma 2:. *a.* $\frac{\partial p_n^{FD}}{\partial\lambda}>0,\frac{\partial p_r^{FD}}{\partial\lambda}>0,\frac{\partial q_n^{FD}}{\partial\lambda}>0,\frac{\partial q_r^{FD}}{\partial\lambda}>0,\frac{\partial\pi_{OEM}^{FD}}{\partial\lambda}>0,\frac{\partial\pi_{IR}^{FD}}{\partial\lambda}>0$; *b.* $p_n^{FD}<p_{no}^{FD}$; $p_r^{FD}>p_{ro}^{FD}$ *if* $\lambda>\frac{\alpha}{2}$

Lemma 2a explores the impact of the obtained WTP λ on the optimal results. The findings indicate that the retail prices, quantities and profits will increase with λ. It is because a larger λ means that consumers obtain a higher WTP for the products from consumer reviews. For example, consumer's utility for new products is $(1-\beta)v+\beta\lambda-p_n$. A larger λ will increase consumer's utility. The OEM can increase the prices to improve its profit, which does not harm consumer's utility. In addition, a higher λ also improves the volume of consumers to purchase new products, which indirectly increases the demand for new products. The increased price and demand will have a positive impact on the profit of the OEM. Thus, the profit of the OEM will increase with λ. Similarly, we also find the same impact on rem products. Lemma 2b compares the optimal prices between with and without consumer reviews. The results indicate that the price of new products under the situation with consumer reviews is always lower than that without consumer reviews. When consumer online reviews are not considered, the related results are based on the assumption that consumers have full information on the product and think the functions of the products perfectly meet their demands (Örsdemir et al., 2014; Jiang and Yang, 2019; and Yang et al., 2020). However, consumer online reviews will convey a comprehensive information of the product, so that consumers have a reasonable rather than perfect recognition on the product (Kwark et al., 2014; He and Chen, 2018; Zhao and Zhang, 2019). That is to say, consumers will learn disadvantages of the products after reading consumer reviews, so that consumers doubt part functions of the product. Thus, consumers will decrease their WTP. On the one hand, consumers are only willing to pay a lower price for new products. On the other hand, to attract more customers to buy new products, the OEM will lower its price when considering consumer online reviews. However, for rem products, we surprisingly find that the price of rem products under the situation with consumer reviews is higher than that without online reviews if the obtained WTP λ is sufficiently large. A larger λ will significantly improve consumer's WTP for rem products, which offsets the lower WTP of rem products due to the discount level α. Hence, if the obtained WTP for rem products from online reviews is larger, consumers are willing to purchase rem products at a higher prices. Lemma 2b will help the parties in Model FD to adjust their optimal decisions when the parties change their strategy from without to with consumer reviews.

4.1.2. Model FI

In the Model FI, the OEM has the same licensing strategy with Model FD. The IR pays the fixed fee but sells rem products to the reseller, at the wholesale price w_r by the indirect distribution channel. The reseller offers rem products to consumers at the retail price

p_r. The profits of the OEM, the IR and the reseller are as follows:

$$\pi_{OEM}(p_1, p_n) = (p_1 - c_n)q_1 + \mu((p_n - c_n)q_n + F)$$

$$\pi_{IR}(w_r) = \mu((w_r - c_r)q_r - F)$$

$$\text{s.t.} q_1 > q_r$$

$$\pi_I(p_r) = \mu(p_r - w_r)q_r$$

Based on the constraint of the quantity of rem products, we can obtain the existing condition of the optimal decisions as $c_{r1}^{FI} < c_r < c_{r2}^{FI}$. Using the backward induction, the optimal results are obtained and shown in Lemma 3.

Lemma 3:. *In Model FI, the optimal prices, quantities and profits are as follows:*

$$p_1^{FI} = \frac{1 + c_n}{2}$$

$$p_n^{FI} = \frac{G + (2\alpha - 4)c_n}{5\alpha - 8}$$

$$w_r^{FI} = -\frac{H + (4 - 2\alpha)c_r}{5\alpha - 8}$$

$$p_r^{FI} = -\frac{3H + (4 - \alpha)c_r}{2(5\alpha - 8)}$$

$$q_n^{FI} = -\frac{(\alpha - 2)(G + (4 - 3\alpha)c_n)}{2(5\alpha - 8)(\alpha - 1)(\beta - 1)}$$

$$q_r^{FI} = -\frac{H + (3\alpha - 4)c_r}{2(5\alpha - 8)(\alpha - 1)(\beta - 1)\alpha}$$

$$\pi_{OEM}^{FI} = \left(\frac{1 - c_n}{2}\right)^2 + \mu\left(\frac{(2 - \alpha)(G + (4 - 3\alpha)c_n)^2}{2(5\alpha - 8)^2(\alpha - 1)(\beta - 1)} + F\right)$$

$$\pi_{IR}^{FI} = \mu\left(\frac{(H + (3\alpha - 4)c_r)^2}{2(5\alpha - 8)^2(\alpha - 1)(\beta - 1)\alpha} - F\right)$$

$$\pi_I^{FI} = \mu\frac{(H + (3\alpha - 4)c_r)^2}{4(5\alpha - 8)^2(\alpha - 1)(\beta - 1)\alpha}$$

$$\text{G} = 3\beta\lambda\alpha - 4\alpha\beta - 3\beta\lambda + 4\alpha + 4\beta - c_r - 4; H = \alpha^2\beta\lambda + 2\alpha^2\beta - \alpha^2 c_n - 5\alpha\beta\lambda - 2\alpha^2 - 2\alpha\beta + 2\alpha c_n + 4\beta\lambda + 2\alpha;$$

Lemma 3 shows all optimal results in Model FI. The results are similar to Model FD. Since the IR sells rem products by the indirect distribution channel, the wholesale price and the profit of the reseller occur. However, they still cannot be affected by the fixed fee. The main reason is that the fixed fee is independent of the prices or quantities, and the OEM determines it before selling. In what follows, the impact of the obtained WTP of consumers from consumer reviews on the optimal results is explored, and the prices between the situations with and without consumer online reviews are compared.

Lemma 4:. *a.* $\frac{\partial p_n^{FI}}{\partial\lambda} > 0, \frac{\partial w_r^{FI}}{\partial\lambda} > 0, \frac{\partial p_r^{FI}}{\partial\lambda} > 0, \frac{\partial q_n^{FI}}{\partial\lambda} > 0, \frac{\partial q_r^{FI}}{\partial\lambda} > 0, \frac{\partial \pi_{OEM}^{FI}}{\partial\lambda} > 0, \frac{\partial \pi_{IR}^{FI}}{\partial\lambda} > 0, \frac{\partial \pi_I^{FI}}{\partial\lambda} > 0$*; b.* $p_n^{FI} < p_{no}^{FI}$*;* $p_r^{FI} > p_{ro}^{FI} if \lambda > \frac{\alpha}{6-3\alpha}$*;* $w_r^{FI} > w_{ro}^{FI} if \lambda > \frac{2\alpha}{4-\alpha}$

Lemma 4a reveals that the increased λ has a positive impact on all optimal results, which fits with our intuition. The reasons are as follows: firstly, the increased λ will improve consumer's WTP for new and rem products, which urges the firms to increase the retail price. Secondly, consumers who may not purchase the products will buy them due to the increased λ, which leads to an increase of the demand. Finally, the increased retail prices and quantities will improve the profit of the OEM and the reseller. For the IR, it maximizes its profit by setting the wholesale price. The increased demand of the reseller will make the IR improve the wholesale price of rem products. Thus, the wholesale price and the profit of the IR increase with λ. Lemma 4b shows the comparison results between the situations with and without consumer online reviews in Model FI. The result firstly shows that the OEM should set a lower price for new products when considering consumer online reviews. Then, we also find that the IR will choose a higher wholesales price and the reseller will decide a higher retailing price for rem products if consumer online reviews are considered and the obtained WTP is enough large. The reason is similar with Lemma 2b. Lemma 4b will guide the OEM, the IR and the reseller to change their optimal prices if they incorporate consumer online reviews during decisions.

4.1.3. Comparison of Model FD and Model FI

In the above section, we assume that the fixed fee licensing strategy is adopted in the market, but the IR chooses different distribution channels for rem products. Hence, which one distribution channel should the IR choose? To address this problem, we compare the optimal results, the prices, quantities and profits, between Model FD and Model FI, and find the following proposition. All results are obtained on the basis of the condition: $\max\{c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < c_{r2}^{FD}$.

Proposition 1: $p_n^{FI} > p_n^{FD}$, $p_r^{FI} > p_r^{FD}$;$q_n^{FI} > q_n^{FD}$ *if* $\max\{c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < c_{r1}$, $q_r^{FI} < q_r^{FD}$ *if* $\max\{c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < c_{r2}$; $\pi_{IR}^{FD} > \pi_{IR}^{FI}$ *if* $\max\{c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < c_{r3}$, $\pi_{OEM}^{FI} > \pi_{OEM}^{FD}$

Proposition 1 indicates that the retail prices of new and rem products are larger when the IR sells rem products by the indirect distribution channel for the fixed fee licensing strategy. For the indirect distribution channel, the introduction of the reseller will strengthen the vertical competition of channel, and results in a double marginalization problem. Since the reseller will share the unit revenue of rem products in Model FI, the price of rem products will be higher. For the OEM, it obtains revenues from two aspects: the selling of new products and the fixed fee. The fixed fee in Model FI and FD does not affect the OEM's optimal decision of price of new products. But faced with a higher price of rem products in Model FI, the OEM will increase the price of new products to improve its profit. It is because the improved profit due to the increased price is sufficiently large. Intuitively, the larger prices (p_r^{FI} and p_n^{FI}) of rem and new products will decrease their quantities. However, we surprisingly find that the impact of the distribution channel on quantities depends on the remanufacturing cost. Specially, if the remanufacturing cost is smaller, the quantity of new products in Model FI is larger than that in Model FD, but the quantity of rem products in Model FI is smaller than that in Model FD. In the direct distribution channel, the IR determines the volume of rem products, mainly based on the remanufacturing cost. However, in the indirect distribution channel, the IR's sale volume of rem products needs to conduct the trade-off between the remanufacturing cost and the negative effect of the vertical competition of the reseller. A smaller remanufacturing cost will extremely benefit the IR, and encourage the IR to produce more rem products in Model FI and FD. But the negative effect of the vertical competition of the reseller in Model FI weakens the motivation of the IR to remanufacture, which leads to $q_r^{FI} < q_r^{FD}$. For new products, the larger volume of rem products will seriously cannibalize the sales of new products in Model FD. As a result, the quantity of new products in Model FI is larger than that in Model FD if the remanufacturing cost is smaller. Moreover, the result indicates that the profit of the IR in Model FD is larger than that in Model FI if the remanufacturing cost is smaller. The reason is as follows: in this situation, the volume of rem products has a leading impact on the profit of the IR. From the comparsion results about the quantities of rem products, we find that the quantity of rem products in Model FD is larger if the remanufacturing cost is lower. Thus, we obtain the corresponding results on the profit of the IR. Also, we find that the profit of the OEM in Model FI is always larger. This is because the larger price of new products in Model FI will significantly improve the profit of the OEM, and even can offset the loss due to the lower quantity of new products.

This proposition can guide the OEM or the IR from the following three aspects. First, we can see from Proposition 1: $\pi_{OEM}^{FI} > \pi_{OEM}^{FD}$. That is to say, if the OEM adopts the fixed fee licensing strategy, it is a better choice for the OEM to choose the IR who sells rem products by the indirect distribution channel. Besides, we know from Proposition 1:$\pi_{IR}^{FD} > \pi_{IR}^{FI}$ *if* $\max\{c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < c_{r3}$. Thus, the IR should sell rem products by the direct distribution channel if the remanufacturing cost is smaller. Furthermore, based on $p_n^{FI} > p_n^{FD}$, and $p_r^{FI} > p_r^{FD}$ of Proposition 1, we can say when the IR changes the distribution channel from Model FD to Model FI in the setting of a fixed fee licensing strategy, the OEM and the IR should increase the retail prices to maximize their profits.

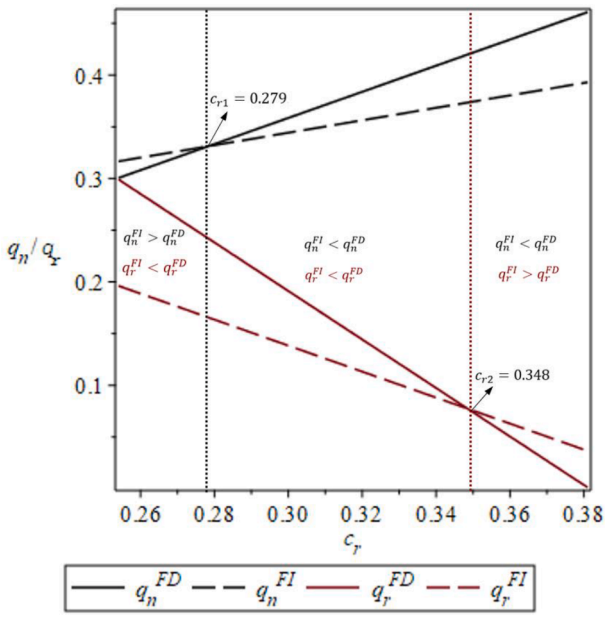


Fig. 2. The quantity of new and rem products ($\lambda = 0.4$).

To clearly illustrate our findings, we numerically analyze the impact of the distribution channel on the optimal results for the fixed fee licensing strategy, by assuming $\alpha = 0.7, \beta = 0.2, c_n = 0.4, \eta = 0.05, \mu = 0.99, and F = 0.0001$. Figs. 2–4 show the results. In Fig. 2 ($\lambda = 0.4$), when $c_{r1} < 0.279$, the quantity of new products in Model FI is larger than that in Model FD but the quantity of rem products in Model FI is smaller than that in Model FD; when $0.279 < c_r < 0.348$, the quantity of new and rem products in Model FI are smaller than those in Model FD; when $c_r > 0.348$, the quantity of new products in Model FI is smaller than that in Model FD but the quantity of rem products in Model FI is larger than that in Model FD. In Fig. 3 ($\lambda = 0.4$), we find if $c_{r3} < 0.292$, the IR will obtain a higher profit from the direct distribution channel. Fig. 3 also shows that if $\lambda = 0.3 and c_{r3} < 0.287$, the IR earns a higher profit from the direct distribution channel. For different values of λ ($\lambda = 0.3 or 0.4$) in Fig. 3, we find that it will indirectly affect the distribution channel choice of the IR, because a higher λ will mean a larger threshold value of c_{r3}. Otherwise, the IR may not choose an optimal distribution channel for rem products. Specially, if $c_{r3} = 0.290$, the choice of the IR distribution channel is different for $\lambda = 0.3 and 0.4$. When $\lambda = 0.3$, the IR prefers the indirect distribution channel; when $\lambda = 0.4$, the optimal one is the direct distribution channel. In reality, if parties do not capture consumer online reviews during decisions, the IR may not choose an optimal distribution channel for rem products, which leads to a loss. Thus, we discuss the impact of consumer online reviews on the choice issue of the IR distribution channel. From Fig. 4 ($\lambda = 0.4$),we can see that the profit of the OEM in Model FI is always larger than that in Model FD.

4.2. Licensing strategy—the royalty fee

In this subsection, the OEM charges a royalty fee η for each rem product from the IR, and sells its products by the direct distribution channel. After being authorized, the IR can choose the direct (Model RD) or indirect (Model RI) distribution channel to sell rem products. For each model, we firstly solve the optimal decisions and explore the impact of $\eta$and λ. And then the optimal results between the two models are compared so that the IR can choose the optimal distribution channel, and the OEM can adjust the optimal decisions when the IR changes its distribution channel.

4.2.1. Model RD

In this model, the IR pays a royalty fee η for each rem products in order to obtain the remanufacturing authority, and sells rem products by the direct distribution channel at the retail price p_r. The OEM offers new products to consumers by the direct distribution channel at the retail prices $p_1 and p_n$, and obtains the revenue of the royalty fee. The objections of the OEM and the IR can be written as:

$$\pi_{OEM}(p_1, p_n) = (p_1 - c_n)q_1 + \mu((p_n - c_n)q_n + \eta q_r)$$

$$\pi_{IR}(p_r) = \mu((p_r - c_r)q_r - \eta q_r)$$

$$\text{s.t.} q_1 > q_r$$

For the constraint condition, $q_1 > q_r$, we have the necessary condition with regard to c_r as follows: $c_{r1}^{RD} < c_r < c_{r2}^{RD}$. The following lemma shows the optimal results when satisfying this condition.

Lemma 5:. *In Model RD, the optimal prices, quantities and profits are as follows:*

$$p_1^{RD} = \frac{1 + c_n}{2}$$

$$p_n^{RD} = \frac{A - 2c_n - 3\eta}{\alpha - 4}$$

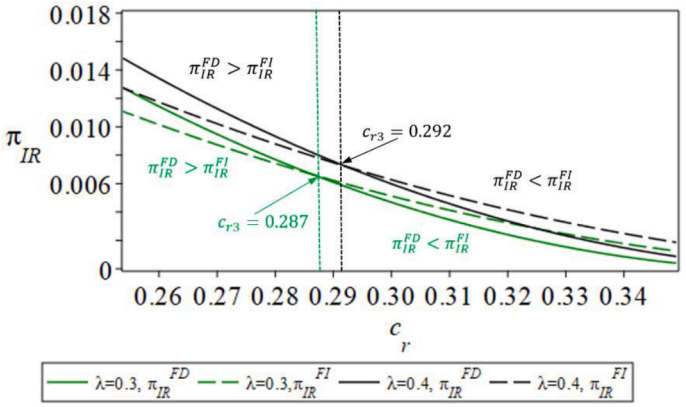


Fig. 3. The profit of the IR ($\lambda = 0.3$ or 0.4).

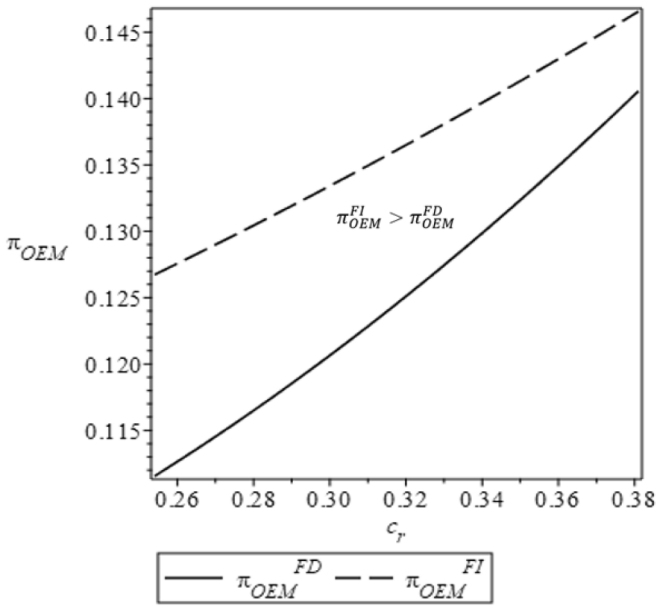


Fig. 4. The profit of the OEM ($\lambda = 0.4$).

$$p_r^{RD} = -\frac{B + 2c_r + \eta(2+\alpha)}{\alpha - 4}$$

$$q_n^{RD} = \frac{A + (2-\alpha)c_n + \eta(1-\alpha)}{(\alpha-4)(\alpha-1)(\beta-1)}$$

$$q_r^{RD} = -\frac{B + (\alpha-2)c_r + 2\eta(\alpha-1)}{(\alpha-4)(\alpha-1)(\beta-1)\alpha}$$

$$\pi_{OEM}^{RD} = \left(\frac{1-c_n}{2}\right)^2 + \mu\left(-\frac{(A + (2-\alpha)c_n - 3\eta)(A + (2-\alpha)c_n + \eta(1-\alpha))}{(\alpha-4)^2(\alpha-1)(\beta-1)} - \eta\frac{B + (\alpha-2)c_r + 2\eta(\alpha-1)}{(\alpha-4)(\alpha-1)(\beta-1)\alpha}\right)$$

$$\pi_{IR}^{RD} = \mu\frac{(B + (\alpha-2)c_r + 2\eta(\alpha-1))^2}{(\alpha-4)(\alpha-1)(\beta-1)\alpha}$$

WhenA $= \beta\lambda\alpha - 2\alpha\beta - \beta\lambda + 2\alpha + 2\beta - c_r - 2; B = \alpha^2\beta - 2\alpha\beta\lambda - \alpha^2 - \alpha\beta + \alpha c_n + 2\beta\lambda + \alpha.$

Lemma 5 presents the optimal results of Model RD. Except for p_1^{RD}, other results consist of the parameters: $\beta, \lambda, \alpha, and \eta$ in the presence of the royalty fee licensing strategy and consumer online reviews. Thus, it is important for the practitioners to focus on them when they set the optimal results. Otherwise, they will suffer from some loss.

In what follows, we discuss the impact of $\lambda and \eta$, and compare the optimal prices between the situations with and without consumer online reviews in Model RD. The related findings are described in the following lemma.

Lemma 6:. *a.* $\frac{\partial p_n^{RD}}{\partial\lambda} > 0, \frac{\partial p_r^{RD}}{\partial\lambda} > 0, \frac{\partial q_n^{RD}}{\partial\lambda} > 0, \frac{\partial q_r^{RD}}{\partial\lambda} > 0,$

$\frac{\partial\pi_{OEM}^{RD}}{\partial\lambda} > 0, \frac{\partial\pi_{IR}^{RD}}{\partial\lambda} > 0$

$; \frac{\partial p_n^{RD}}{\partial\eta} > 0, \frac{\partial p_r^{RD}}{\partial\eta} > 0, \frac{\partial q_n^{RD}}{\partial\eta} < 0, \frac{\partial q_r^{RD}}{\partial\eta} < 0, \frac{\partial\pi_{OEM}^{RD}}{\partial\eta} > 0 if \eta < \eta_1, \frac{\partial\pi_{IR}^{RD}}{\partial\eta} < 0;$ *b.* $p_n^{RD} < p_{no}^{RD}; p_r^{RD} > p_{ro}^{RD} if \lambda > \frac{\alpha}{2};$

From Lemma 6a, we can observe that the increase of λ will improve the retail prices, quantities and profits in Model RD. The intuition is that consumer's WTP for new and rem products increases if consumers obtain a higher WTP from consumer reviews. Not only more consumers will purchase the products, but also they are willing to pay a higher price, which leads to the increase of the profit of the firms. Moreover, there are some interesting findings on the impact of η. For example, when the royalty fee increases, the retail prices of new and rem products will increase but their quantities will decrease. The reasons are as follows: for the IR, it needs to pay a royalty fee for per unit rem product. With the increase of η, the IR will pay more fee if it does not lower the quantity of rem products. Hence, it is a better choice for the IR to lower the quantity of rem products, which decreases the pay fee. Besides, With the decreased supply of rem products, the IR will improve the price of rem products to improve its profit. But, the severely negative effect of the lower

quantity on the profit makes the profit of the IR decrease with η. For the OEM, it will obtain part revenues from the royalty fee. Facing with the decreased quantity of rem products, the OEM will lack the motivation to produce new products since the IR will remanufacture fewer end-of-use products. Thus, the quantity of new products also decreases with η. With the lower supply of new products, consumers are willing to pay a higher price. Although the royalty fee and increased price improve the profit of the OEM, a larger η will extremely lower the quantity of rem products, which hurts the profit of the OEM. Thus, the profit of the OEM will decrease with η if $\eta > \eta_1$. Lemma 6a will provide several guidelines for practitioners. Specially, if the OEM wants to obtain a higher profit, it can appropriately increase the royalty fee or improve the product quality to increase the obtained WTP from consumer reviews. Lemma 6b shows the same results with Lemma 2b. That is to say, the price of new products under the situation without consumer reviews is higher than that with consumer reviews. Besides, the price of rem products under the situation with consumer reviews is larger than that without consumer reviews of the obtained WTP is larger. Lemma 6b will help the OEM and the IR to adjust their prices for new and rem products if they change their strategy from without to with consumer reviews.

4.2.2. Model RI

In Model RI, the OEM maximizes its profit by selling new products to consumers at the retail price p_n and charging the royalty fee for per unit rem product. The IR pays a royalty fee η for per unit rem product and sells them to the reseller at the wholesale w_r. The reseller will offer rem products to consumers at the retail price p_r. The objective functions of three practitioners are:

$$\pi_{OEM}(p_1, p_n) = (p_1 - c_n)q_1 + \mu((p_n - c_n)q_n + \eta q_r)$$

$$\pi_{IR}(w_r) = \mu((w_r - c_r)q_r - \eta q_r)$$

$$\text{s.t.} q_1 > q_r$$

$$\pi_I(p_r) = \mu(p_r - w_r)q_r$$

Since it is not practical for the IR to remanufacture all end-of-use products of period 1, all optimal results should satisfy the constraint:$q_1 > q_r$. On the basis of this constraint, we obtain the necessary condition when there exist the optimal results: $c_{r1}^{RI} < c_r < c_{r2}^{RI}$. We apply backward induction to derive all optimal decisions, which is presented in the following lemma.

Lemma 7:. *In Model RI, the optimal prices, quantities and profits can be written as:*

$$p_1^{RI} = \frac{1 + c_n}{2}$$

$$p_n^{RI} = \frac{G + (2\alpha - 4)c_n - 3\eta}{5\alpha - 8}$$

$$w_r^{RI} = -\frac{H + (4 - 2\alpha)c_r + \eta(4 - \alpha)}{5\alpha - 8}$$

$$p_r^{RI} = -\frac{3H + (4 - \alpha)c_r + 2\eta(\alpha + 2)}{2(5\alpha - 8)}$$

$$q_n^{RI} = -\frac{(\alpha - 2)(G + (4 - 3\alpha)c_n) + 2\eta(\alpha - 1)}{2(5\alpha - 8)(\alpha - 1)(\beta - 1)}$$

$$q_r^{RI} = -\frac{H + (3\alpha - 4)c_r + 4\eta(\alpha - 1)}{2(5\alpha - 8)(\alpha - 1)(\beta - 1)\alpha}$$

$$\pi_{OEM}^{RI} = \left(\frac{1 - c_n}{2}\right)^2 + \mu\left(\left(-\frac{((\alpha - 2)(G + (4 - 3\alpha)c_n) + 2\eta(\alpha - 1))(G + (4 - 3\alpha)c_n - 3\eta)}{2(5\alpha - 8)^2(\alpha - 1)(\beta - 1)}\right) - \eta\frac{H + (3\alpha - 4)c_r + 4\eta(\alpha - 1)}{2(5\alpha - 8)(\alpha - 1)(\beta - 1)\alpha}\right)$$

$$\pi_{IR}^{RI} = \mu\frac{(H + (3\alpha - 4)c_r + 4\eta(\alpha - 1))^2}{2(5\alpha - 8)^2(\alpha - 1)(\beta - 1)\alpha}$$

$$\pi_I^{RI} = \mu\frac{(H + (3\alpha - 4)c_r + 4\eta(\alpha - 1))^2}{4(5\alpha - 8)^2(\alpha - 1)(\beta - 1)\alpha}$$

$$G = 3\beta\lambda\alpha - 4\alpha\beta - 3\beta\lambda + 4\alpha + 4\beta - c_r - 4; H = \alpha^2\beta\lambda + 2\alpha^2\beta - \alpha^2 c_n - 5\alpha\beta\lambda - 2\alpha^2 - 2\alpha\beta + 2\alpha c_n + 4\beta\lambda + 2\alpha;$$

Lemma 7 shows the optimal decisions in Model RI. Because the reseller is introduced to sell rem products, we find the wholesale price and the profit of the reseller are also related to $\lambda and \eta$.

Similar to Model RD, we discuss the impact of $\lambda and \eta$, and conduct the price comparison between the situations with and without

consumer reviews in Model RI. The results are shown in the following lemma

Lemma 8:. *a.* $\frac{\partial p_n^{RI}}{\partial \lambda} > 0, \partial w_r$

$$RI$$

$$\partial\lambda > 0, \frac{\partial p_r^{RI}}{\partial \lambda} > 0, \frac{\partial q_n^{RI}}{\partial \lambda} > 0, \frac{\partial q_r^{RI}}{\partial \lambda} > 0, \frac{\partial \pi_{OEM}^{RI}}{\partial \lambda} > 0, \frac{\partial \pi_{IR}^{RI}}{\partial \lambda} > 0, \frac{\partial \pi_I^{RI}}{\partial \lambda} > 0; \frac{\partial p_n^{RI}}{\partial \eta} > 0, \frac{\partial w_r^{RI}}{\partial \eta} > 0, \frac{\partial p_r^{RI}}{\partial \eta} > 0, \frac{\partial q_n^{RI}}{\partial \eta} < 0, \frac{\partial q_r^{RI}}{\partial \eta} < 0, \frac{\partial \pi_{OEM}^{RI}}{\partial \eta} > 0 if \eta < \eta_2, \frac{\partial \pi_{IR}^{RI}}{\partial \eta} < 0, \frac{\partial \pi_I^{RI}}{\partial \eta} < 0$$

; b. $p_n^{RI} < p_{no}^{RI}; p_r^{RI} > p_{ro}^{RI} if \lambda > \frac{2\alpha}{4-\alpha}; w_r^{RI} > w_{ro}^{RI} if \lambda > \frac{2\alpha}{4-\alpha};$

From lemma 8a, we firstly can observe that the prices, quantities and the profits of the IR and the OEM will increase with λ. The main reason is that a larger λ will improve consumer's WTP for the products. Moreover, the impact of the royalty fee in Model RI is similar to that in Model RD. The profit of the OEM will increase with η if $\eta < \eta_2$. For the wholesale price, we find it increases with η. It is because the decreased quantity of rem products and the increased royalty fee will spur the IR to improve the wholesale price of rem products to lower its loss. Besides, the decreased quantity of rem products will harm the profits of the IR and the reseller. Lemma 8b shows the similar results with Lemma 4b, but provides the parties in Model RI with the price adjustment guidelines when they change their strategy from without to with consumer reviews.

4.2.3. Comparison of Model RD and Model RI

In subsection 4.1.3, we provide the distribution channel choice for the IR when the OEM adopts the fixed fee licensing strategy. This part considers the setting of the royalty fee licensing strategy. Similar to 4.1.3, we compare the optimal decisions between Model RD and Model RI when the licensing strategy is the royalty fee, and obtain the following proposition. All results are derived on the basis of the condition: $\max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r2}^{RD}$.

Proposition 2:. $p_n^{RI} > p_n^{RD}, \quad p_r^{RI} > p_r^{RD}, q_n^{RI} > q_n^{RD} \quad if \quad \max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r4}, \quad q_r^{RI} < q_r^{RD} \text{if} \max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r5}, \pi_{IR}^{RD} > \pi_{IR}^{RI} if \max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r6}, \pi_{OEM}^{RI} > \pi_{OEM}^{RD}$

Proposition 2 reveals the impact of the distribution channel on all the optimal results when the licensing strategy is the royalty fee. Since the indirect distribution channel will cause a double marginalization problem, the retail price of new and rem products in Model RI is larger than that in Model RD. Compared with the Model RI, the IR in Model RD is more sensitive to the remanufacturing cost. But the IR in Model RI is less sensitive due to the double marginalization problem. Thus, the quantity of rem products in Model RD is larger than that in Model RI when the remanufacturing cost is smaller. When the remanufacturing cost increases to the certain value, the IR in Model RD will serverly weaken the motivation of remanufacturing, but the IR in Model RI still can obtain enough advantage from remanufacturing to offset the double marginalization problem. As a result, the quantity of rem products in Model RD is less than that in Model RI for a larger remanufacturing cost. For new products, the OEM will manufacture more in Model RI than Model RD if the remanufacturing cost is lower. It is because the IR in Model RI sells less rem products, which have lower cannibalization effect on new products. In other words, the quantity of new products in Model RD is larger than that in Model RI if the remanufacturing cost is enough large. Although a larger remanufacturing cost will induce a higher quantity of new products in Model RD, the larger retail price of new products in Model RI will significantly improve the profit of the OEM, which results in a higher profit of the OEM in Model RI.

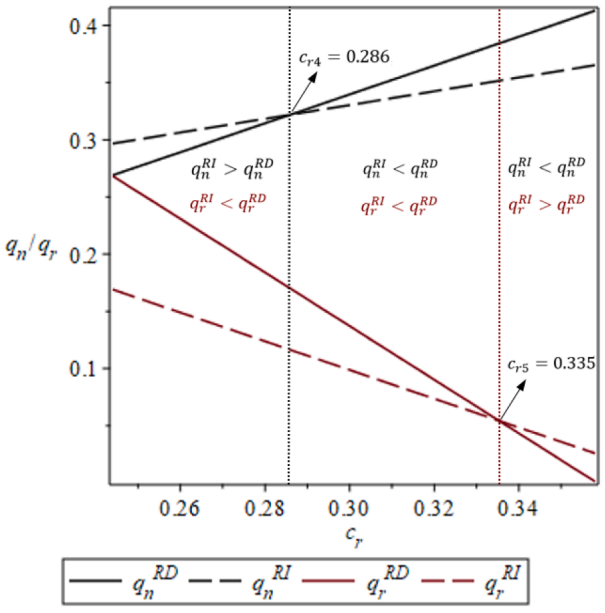


Fig. 5. The quantity of new and rem products ($\lambda = 0.4$).

For the IR, the quantity of rem products has a leading impact on its profit. If the remanufacturing cost is less, the increased profit due to the larger quantity of rem products in Model RD will make up the decreased profit due to the lower price. Thus, the profit of the IR in Model RD is larger than that in Model RI for a lower remanufacturing cost. This proposition not only can help the IR to choose the distribution channel for rem products, but also guide the OEM and the IR to adjust their optimal decisions when the IR changes the distribution channel under the royalty fee licensing strategy. For example, as is shown in Proposition 2 ($\pi_{IR}^{RD} > \pi_{IR}^{RI} if \max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r6}$), we can find that if the licensing strategy is the royalty fee, and the remanufacturing cost is less than the certain value, the IR should choose the direct distribution channel for rem products. Besides, based on the findings of Proposition 2: $p_n^{RI} > p_n^{RD}$ and $p_r^{RI} > p_r^{RD}$, we have the guideline for the parties: when the IR changes the distribution channel from the indirect to direct distribution channel under the royalty fee licensing strategy, the OEM and the IR should improve the retail prices.

Similar to Proposition 1, we also numerically shows our comparison results between Model RD and Model RI, which are shown in Figs. 5, 6 and 7. When $\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, \eta = 0.05, and \mu = 0.99$, we can observe the following results. Observing Fig. 5, we have: when $c_r < 0.286$, the quantity of new/rem products in Model RI is larger/smaller than that in Model RD. When c_r increases to the range $\{0.286, 0.335\}$, the quantities of new and rem products in Model RI are smaller than those in Model RD. If $c_r > 0.335$, the quantity of new/rem products in Model RI is smaller/larger than that in Model RD. For the profits of the OEM and IR, the observations are consistent with our proposition. In Fig. 7, we find that the profit of the OEM in Model RI is always larger than that in Model RD. However, based on Fig. 6, we know: if $c_r < 0.295$, the profit of the IR in Model RD is larger than that in Model RI; if $c_r > 0.295$, the profit of the IR in Model RD is smaller than that in Model RI. In addition, from Fig. 6, we find the size of the obtained WTP λ will have an important impact on the threshold value of c_{r6}, which will affect the distribution channel choice of the IR. For example, when $c_r = 0.292$, the IR will prefer to choose the direct distribution channel if $\lambda = 0.4$; but the IR will be willing to choose the indirect distribution channel if $\lambda = 0.3$. That is to say, a higher λ means a larger threshold value of the remanufacturing cost.

4.3. The OEM's licensing strategy choice

In previous sections, we discuss the distribution channel choice for rem products, given the licensing strategy. In this subsection, we identify the OEM's optimal licensing strategy by comparing the sub-game perfect equilibrium under each licensing strategy (Hong et al., 2018; Reimann et al., 2019; and Zhou et al., 2020) . Then, we obtain the following proposition.

Proposition 3:. 1) *when* $max\{\lambda_{r1}^{FD}, \lambda_{r1}^{FI}, \lambda_{r1}^{RD}, \lambda_{r1}^{RI}\} < \lambda < min\{\lambda_{r3}, \lambda_{r6}\}$, $\pi_{OEM}^{FD} > \pi_{OEM}^{RD} if F > F_{D1}$;

2) when $\max\{\lambda_{r3}, \lambda_{r6}\} < \lambda < \min\{\lambda_{r2}^{RD}, \lambda_{r2}^{RI}, \lambda_{r2}^{FD}, \lambda_{r2}^{FI}\}$, $\pi_{OEM}^{FI} > \pi_{OEM}^{RI} if F > F_{I1}$;

3) when $\min\{\lambda_{r3}, \lambda_{r6}\} < \lambda < \max\{\lambda_{r3}, \lambda_{r6}\}$,

a. $\lambda_{r3} < \lambda < \lambda_{r6} (\alpha > \frac{32-12\sqrt{2}}{23})$, $\pi_{OEM}^{FI} > \pi_{OEM}^{RD} if F > F_{T2}$;

b. $\lambda_{r6} < \lambda < \lambda_{r3} (\alpha < \frac{32-12\sqrt{2}}{23})$, $\pi_{OEM}^{FD} > \pi_{OEM}^{RI} if F > F_{T1}$;

Proposition 3 shows the optimal licensing strategy of the OEM when the IR has chosen the optimal distribution channel for rem products. From Proposition 1 and 2, we know that the IR under the fixed (royalty) fee licensing strategy is more willing to choose the direct distribution channel for rem products when $\max\{\lambda_{r1}^{FD}, \lambda_{r1}^{FI}\} < \lambda < \lambda_{r3} (\max\{\lambda_{r1}^{RD}, \lambda_{r1}^{RI}\} < \lambda < \lambda_{r6})$ Hence, when $max\{\lambda_{r1}^{FD}, \lambda_{r1}^{FI}, \lambda_{r1}^{RD}, \lambda_{r1}^{RI}\} < \lambda < min\{\lambda_{r3}, \lambda_{r6}\}$, we compare the profits of the OEM between Model FD and RD to obtain the optimal OEM's licensing strategy. And we find that the OEM will choose Model FD if the fixed fee is larger than F_{D1}. When $\max\{\lambda_{r3}, \lambda_{r6}\} < \lambda < \min\{\lambda_{r2}^{RD}, \lambda_{r2}^{RI}, \lambda_{r2}^{FD}, \lambda_{r2}^{FI}\}$, the optimal distribution channel of the IR under the fixed and royalty fee licensing strategy is the indirect distribution channel. Thus, comparing $\pi_{OEM}^{FI} with \pi_{OEM}^{RI}$, we find that the OEM will prefer to choose Model FI if the fixed fee is larger than F_{I1}. When λ is between $\min\{\lambda_{r3}, \lambda_{r6}\}$ and

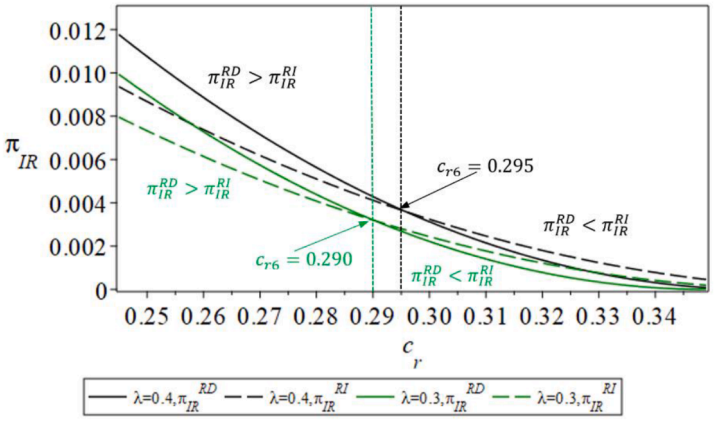


Fig. 6. The profit of the IR ($\lambda = 0.3$ or 0.4).

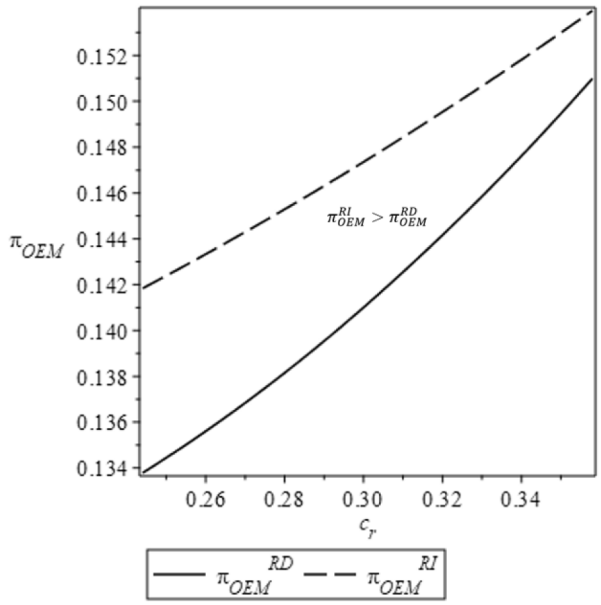


Fig. 7. The profit of the OEM ($\lambda = 0.4$).

$\max\{\lambda_{r3}, \lambda_{r6}\}$, there are two different cases: *a* and *b*. If $\alpha > \frac{32-12\sqrt{2}}{23}$, we have case *a:* $\lambda_{r3} < \lambda < \lambda_{r6}$. In case *a*, the IR under the fixed (royalty) fee licensing strategy prefers to choose the indirect (direct) distribution channel for rem products. Comparing π_{OEM}^{FI} *with* π_{OEM}^{RD}, the result indicates that the OEM prefers Model FI if the fixed fee is larger than F_{T2}. If $\alpha < \frac{32-12\sqrt{2}}{23}$, we have case *b:* $\lambda_{r6} < \lambda < \lambda_{r3}$. In this case, the IR under the fixed (royalty) fee licensing strategy chooses the direct (indirect) distribution channel for rem products. Comparing π_{OEM}^{FD} *with* π_{OEM}^{RI}, we find the OEM will prefer to choose Model FD if the fixed fee is larger than F_{T1}. In summary, we can conclude that the OEM prefers to choose the fixed fee licensing strategy if the fixed licensing fee is larger. This is because a larger fixed fee obtains a larger revenue for the OEM, compared with the royalty fee. This proposition will provide the OEM with guidelines about the licensing strategy choice.

In above Proposition 3, we discuss the optimal licensing strategy choice of the OEM. Besides, the OEM may meet with the following reality: The authourized IR has chosen the distribution channel, but the OEM needs to change its licensing strategy to cope with the

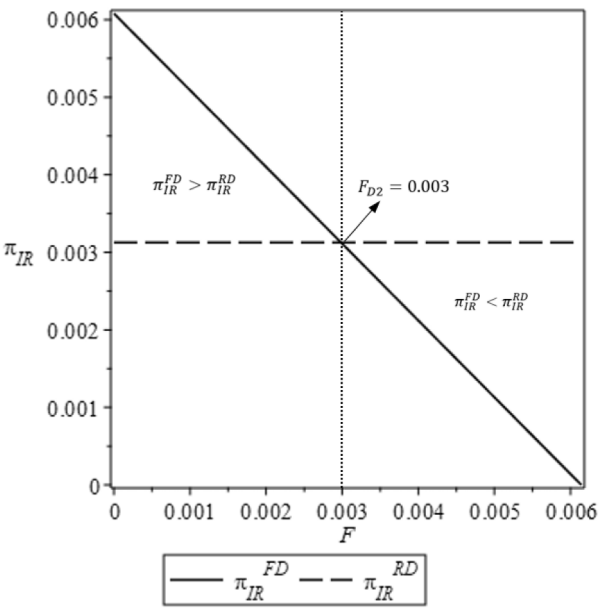


Fig. 8. The comparison of the profits of the IR ($\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, c_r = 0.3, \eta = 0.05, a$ and $= 0.99$).

change of market environment. A new problem occurs: how can the OEM and the IR adjust its optimal decisions in this situation? To address this problem, we respectively compare the optimal results between Model FD and RD, when the IR has chosen the direct distribution channel, and Model FI and Model RI, when the IR sells rem products by the indirect distribution channel. The condition with regard to c_r should satisfy: $c_{r1}^{FD} < c_r < c_{r2}^{RD}$ when comparing Model FD and Model RD. When comparing Model FI and Model RI, all results satisfy the condition:$c_{r1}^{FI} < c_r < c_{r2}^{RI}$. Besides, we also compare the total environment impact between Model RD and FD, and between Model RI and FI, to discuss the impact of the licensing strategy on environment. All findings are shown in the following propositions:

Proposition 4: $p_n^{RD} > p_n^{FD}, p_r^{RD} > p_r^{FD}$, $q_n^{RD} < q_n^{FD}, q_r^{RD} < q_r^{FD}$, $TE^{RD} < TE^{FD}$, $\pi_{IR}^{FD} > \pi_{IR}^{RD} if F < F_{D2}$.

Proposition 4 shows the comparison results between Model RD and Model FD to provide the licensing strategy choice and the decision adjustment strategy for the practitioners when the IR sells rem products by the direct distribution channel. The results indicate that the retail prices of new and rem products in Model RD are larger than those in Model FD, while the quantities of new and rem products in Model RD is smaller than those in Model FD. It is because the IR needs to pay the royalty fee for per unit rem product when the licensing strategy is the royalty fee. To pay less fee for the OEM, the IR will lower the quantity of rem products. The OEM will obtain some revenues from rem products. If the quantity of rem products decreases, it will decrease the quantity of new products. The decreased quantities of new and rem products will make the practitioners improve their retail prices to lower the demands. In addition, it is obvious that the total environment impact in Model FD is larger than that in Model RD since there are more quantities of new and rem products in Model FD. Moreover, we find the IR will agree with the contract of the fixed fee if the fixed fee is sufficiently small. This is because a larger fixed fee will cause a serious loss on the IR. This proposition provides some guidelines for the OEM on the decision adjustment when the IR sells rem products by the direct distribution channel but it changes the licensing strategy. For example, if the OEM has a goal of environment protection, it should choose Model RD.

Fig. 8 numerically shows the impact of the licensing strategy on the IR when $\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, c_r = 0.3, \eta = 0.05,$ $and \mu = 0.99$. From Fig. 8, we can see that when $F < 0.003$, the IR will agree with the fixed fee licensing strategy. Otherwise, the IR will accept the royalty fee licensing strategy.

Proposition 5: $p_n^{RI} > p_n^{FI}, p_r^{RI} > p_r^{FI}$, $q_n^{RI} < q_n^{FI}, w_r^{RI} < w_r^{FI}, q_r^{RI} < q_r^{FI}$, $TE^{RI} < TE^{FI}$, $\pi_{IR}^{FI} > \pi_{IR}^{RI} if F < F_{I2}$.

Proposition 5 compares all optimal results between Model FI and Model RI when rem products are sold by the indirect distribution channel but the licensing strategy is different. The results still demonstrate that the quantities of new and rem products, and the total environment impact are larger but their retail prices are lower in Model FI when the licensing strategy is the fixed fee. Furthermore, we find that the wholesale price in Model FI is larger than that in Model RI. On the one hand, the reseller is willing to pay a higher wholesale for rem products due to the higher retail price when the licensing strategy is the fixed fee. On the other hand, the IR will improve the wholesale price to offset the loss of the decreased demand for rem products in Model FI. And the total environment impact under Model RI is always lower than that under Model FI, which indicates the royalty fee licensing strategy benefits environment when the IR sells rem products by the indirect distribution channel. Finally, the comparison results of profits indicate that the IR will agree with the fixed fee licensing strategy when the fixed fee is smaller. These results are similar to Proposition 3. This proposition will help the practitioners to adjust the optimal decisions when rem products are sold by the indirect distribution channel but the OEM changes its licensing strategy.

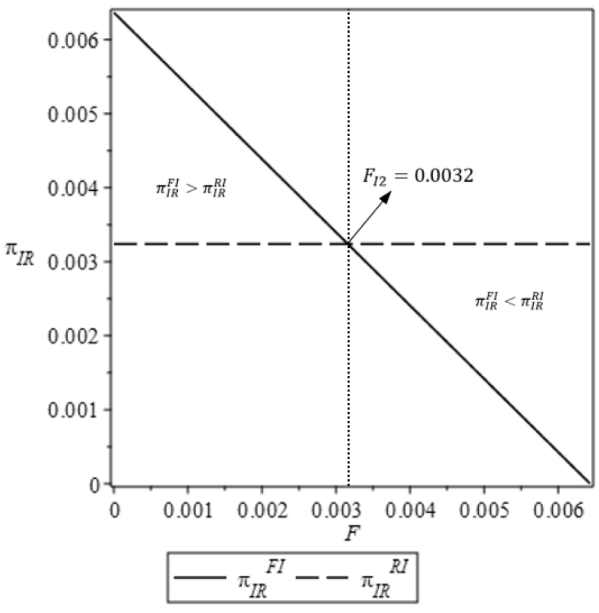


Fig. 9. The comparison of the profits of the IR ($\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, c_r = 0.3, \eta = 0.05,$ and $\mu = 0.99$).

Next, we numerically compare the profits of the IR to illustrate the impact of the OEM's licensing strategy choice when $\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, c_r = 0.3, \eta = 0.05, and \mu = 0.99$. In Fig. 9, the finding indicates that when $F < 0.0032$, the IR accepts the fixed fee licensing strategy. Whilst, if $F > 0.0032$, the IR will prefer the royalty fee licensing strategy.

4.4. Comparison of four models

In this section, we compare four models to simultaneously consider the impact of the licensing strategy and the distribution channel on the OEM. Since the conditions of the optimal results in four models are different, the comparison in this subsection should satisfy $\max\{c_{r1}^{RD}, c_{r1}^{RI}, c_{r1}^{FD}, c_{r1}^{FI}\} < c_r < \min\{c_{r2}^{RD}, c_{r2}^{RI}, c_{r2}^{FD}\}$. The results are shown in Table 4. Besides, we assume $\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, c_r = 0.3, and \mu = 0.99$ to clearly show the optimal model for the OEM, which is depicted in Fig. 10.

From Table 4, we can find that although the relationship of the profits of the OEM in four models depends on the fixed fee, the OEM prefers the model where rem products are sold by the indirect distribution channel. The optimal model of the OEM is either Model FI or Model RI. That is to say, the double marginalization problem of the indirect distribution channel will further strengthen the advantages of the OEM's competition. This proposition will help the OEM to choose the appropriate remanufacturing cooperator. The OEM can learn about the IR's distribution channel for rem products before selecting the authorized IR, and choose the IR who sells rem products by the indirect distribution channel. For example, Apple's authorized IR, Gazelle, sells rem products by eBay, Amazon or the authorized distributors (Atasu et al., 2008; Ferguson and Souza, 2010; Souza, 2013; and Qiao and Su 2020a). Besides, in Fig. 10, we can see that if $F < F_{l1}$, the optimal model of the OEM is Model RI. When $F > F_{l1}$, Model FI is the optimal choice. It is consistent with our intuitive, because a higher fixed fee will help the OEM to adopt it.

5. Extension analysis

5.1. The optimal royalty fee in Model RD and Model RI

In Model RD and RI, we assume the royalty fee is exogenous. In this subsection, we relax this assumption and respectively solve the optimal royalty fee from the perspective of the OEM or the whole supply chain. All results satisfy the condition: $\max\{c_{r1}^{RD}, c_{r1}^{RI}\} < c_r < c_{r2}^{RD}$ in this subsection.

5.1.1. From the perspective of the OEM

For the OEM, it maximizes its profits by setting the optimal royalty fee. The profit function of the OEM in Model RD is:

$$\pi_{OEM}(\eta) = \left(p_1^{RD} - c_n\right)q_1^{RD} + \mu\left(\left(p_n^{RD} - c_n\right)q_n^{RD} + \eta q_r^{RD}\right)$$

The objective function of the OEM in Model RI can be written as:

$$\pi_{OEM}(\eta) = \left(p_1^{RI} - c_n\right)q_1^{RI} + \mu\left(\left(p_n^{RI} - c_n\right)q_n^{RI} + \eta q_r^{RI}\right)$$

According to the timeline of the related decisions in section 3.3, the OEM needs to first choose the licensing strategy, and then set the optimal prices. Thus, referring to Huang and Wang (2017a), Huang and Wang (2019), and Chai et al. (2020), we use backward induction to derive the optimal royalty fee after obtaining the optimal prices. The optimal royalty fees in the two models are shown in the following lemma. Besides, we also compare the optimal royalty fees between the two models and discuss the impact of consumer online reviews.

Lemma 9:. *a. the optimal royalty fee in Model RD is* $\eta_{OEM}^{RD} = \frac{\alpha^2(1+\beta\lambda-\beta-c_n)+8(\alpha+\beta\lambda-\alpha\beta-c_r)}{2(\alpha+8)}$*; b. the optimal royalty fee in Model RI is* $\eta_{OEM}^{RI} = \frac{\alpha^2(7-\beta\lambda-7\beta+c_n)+8\alpha(\beta\lambda+2\beta-c_r-2)+16(c_r-\beta\lambda)}{2(7\alpha-16)}$*; c.* $\eta_{OEM}^{RD} < \eta_{OEM}^{RI}$*; d.* $\frac{\partial\eta_{OEM}^{RD}}{\partial\lambda} > 0; \frac{\partial\eta_{OEM}^{RI}}{\partial\lambda} > 0; \frac{\partial\eta_{OEM}^{RD}}{\partial\beta} > 0 if \lambda > \frac{\alpha(16-7\alpha)}{(\alpha-4)^2}; \frac{\partial\eta_{OEM}^{RI}}{\partial\beta} > 0 if \lambda > \frac{\alpha^2+8\alpha}{\alpha^2+8}$.

Lemma 9 presents the optimal royalty fees which maximize the profit of the OEM in Model RD and Model RI. We find that the optimal royalty fee is related to consumer purchasing behavior, the manufacturing cost and the remanufacturing cost. Besides, we find the optimal royalty fee in Model RI is larger than that in Model RD. That is to say, the indirect distribution channel for rem products spurs the OEM to set a higher royalty fee. It is because the OEM wants to weaken the negative impact of the double marginalization problem on the IR's remanufacturing. In addition, the result presents that the optimal royalty fee in Model RD and Model RI will

Table 4
Comparison of four models.

Conditions	Comparison of four models
$F_{l1} < F < F_{D1}$	$\pi_{OEM}^{FI} > \pi_{OEM}^{RI} > \pi_{OEM}^{RD} > \pi_{OEM}^{FD}$
$F_{D1} < F < F_{l1}$	$\pi_{OEM}^{RI} > \pi_{OEM}^{FI} > \pi_{OEM}^{FD} > \pi_{OEM}^{RD}$
$F_{T2} < F < min\{F_{D1}, F_{l1}\}$	$\pi_{OEM}^{RI} > \pi_{OEM}^{FI} > \pi_{OEM}^{RD} > \pi_{OEM}^{FD}$
$max\{F_{D1}, F_{l1}\} < F < F_{T1}$	$\pi_{OEM}^{FI} > \pi_{OEM}^{RI} > \pi_{OEM}^{FD} > \pi_{OEM}^{RD}$
$F < F_{T2}$	$\pi_{OEM}^{RI} > \pi_{OEM}^{RD} > \pi_{OEM}^{FI} > \pi_{OEM}^{FD}$
$F > F_{T1}$	$\pi_{OEM}^{FI} > \pi_{OEM}^{FD} > \pi_{OEM}^{RI} > \pi_{OEM}^{RD}$

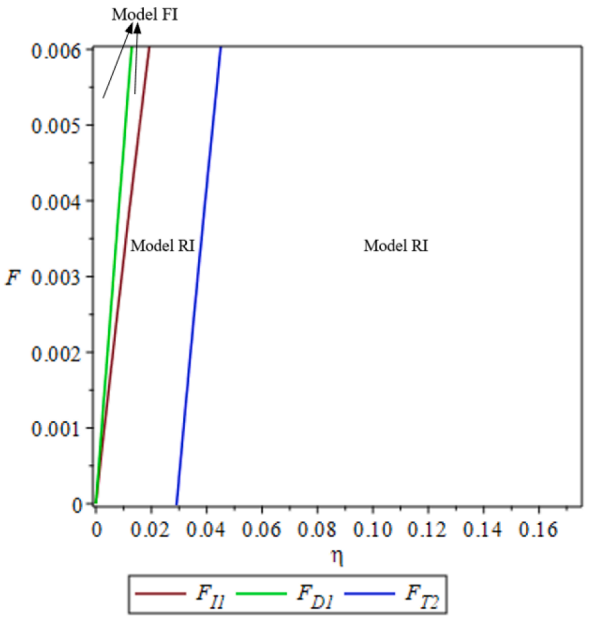


Fig. 10. The optimal model for the OEM.

increase with λ. A larger λ denotes that consumers have a higher WTP for new and rem products. To weaken the competition of rem products and obtain a higher revenue from the IR, the OEM will set a higher royalty fee. However, the impact of β on the optimal royalty fee depends on λ. Specially, if λ is larger, the optimal royalty fee increases with β. The reason is that consumers' WTP will diminish if λ is smaller but its weight is larger, which results in less demand for new and rem products. In this situation, the OEM needs to lower the optimal royalty fee to encourage the IR to remanufacture more. Only when λ is sufficiently large, will the OEM set a higher royalty fee withβ. On the one hand, this lemma will guide the OEM to set an optimal royalty fee when rem products are sold by the direct or indirect distribution channel. On the other hand, it will remind the OEM to focus on consumer reviews during the selling and guide the OEM to adjust the optimal royalty fee.

5.1.2. From the perspective of the whole supply chain

In this part, we discuss the optimal royalty fee from the perspective of the total supply chain. The total supply chain profits in two models are respectively as follows:

$$TS^{RD}(\eta) = \pi_{OEM}^{RD} + \pi_{IR}^{RD}$$

$$TS^{RI}(\eta) = \pi_{OEM}^{RI} + \pi_{IR}^{RI} + \pi_{I}^{RI}$$

The following lemma presents the optimal royalty fees of two models:

Lemma 10:. *a. the optimal royalty fee in Model RD is* $\eta_{TS}^{RD} = \frac{\alpha(\alpha(5+\beta\lambda-5\beta-c_n))+8\lambda\beta+4(1-\beta-c_r-c_n)}{2(5\alpha+4)}$*; b. the optimal royalty fee in Model RI is* $\eta_{TS}^{RI} = \frac{\alpha^2(5-5\beta\lambda-5\beta+5c_n)+\alpha(22\beta\lambda-4\beta-10c_r-12c_n+4)+8(c_r-\beta\lambda)}{2(5\alpha+4)}$*; c.* $\eta_{TS}^{RD} > \eta_{TS}^{RI}$*; d.* $\frac{\partial\eta_{TS}^{RD}}{\partial\lambda} > 0, \frac{\partial\eta_{TS}^{RI}}{\partial\lambda} > 0; \frac{\partial\eta_{TS}^{RD}}{\partial\beta} > 0 if \lambda > \frac{5\alpha+4}{\alpha+8}, \frac{\partial\eta_{TS}^{RI}}{\partial\beta} > 0 if \lambda > \frac{5\alpha^2+4\alpha}{22\alpha-5\alpha^2-8}$.

Lemma 10 shows the optimal royalty fees which maximize the profits of the whole supply chain in Model RD and Model RI. Furthermore, the result demonstrates that the optimal royalty fee in Model RI is larger than that in Model RD when the objective function is the whole supply chain profit. Thus, if the distribution channel for rem products is changed from the direct to indirect distribution channel, the royalty fee should be decreased to maximize the whole supply chain profit. Moreover, we find that the optimal royalty fee increases with λ because there are more consumers purchasing the products. Besides, the result shows that the optimal royalty fee increases with β if λ is enough large. A larger λ significantly improves consumers' WTP for the products if its weight increases. A larger royalty fee will maximize the whole supply chain profit by improving the OEM's profit.

5.2. The impact of licensing strategy on the reseller

If the IR sells rem products by the indirect distribution channel, how the licensing strategy affects the reseller's profit. Thus, we compare the profits of the reseller between Model FI and Model RI. The following proposition shows our results. The constraint condition is $c_{r1}^{FI} < c_r < c_{r2}^{RI}$.

Proposition 6:. *when the licensing strategy is respectively the fixed fee or the royalty fee, the profits of the reseller have the relationship:*

$\pi_I^{FI} > \pi_I^{RI}$.

Proposition 6 compares the profits of the reseller in the indirect distribution channel when the licensing strategy is different. We find the if the fixed fee licensing strategy is adopted in the market, the reseller will obtain a higher profit. The reason is as follows. In model RI, the cannalizabition effect of the royalty fee on rem products in Model RI makes the quantity of rem products decrease, which leads to the quantity of rem products in Model FI being larger than that in Model RI. And the quantity of rem products will mainly affect the profit of the reseller. Thus, we have this result. This proposition can help the reseller to choose the appropriate IR. Specially, the reseller should cooperate with the IR who adopts the fixed fee licensing strategy if possible.

5.3. Social welfare

5.3.1. Consumer surplus

In order to discuss the impact of the licensing strategy and the distribution channel on consumers, we compare consumer surplus among the four models. In each model, consumer surplus can be written as:

$$CS = \int_{1-q_1}^{1} (v - p_1)dv + \int_{1-q_n}^{1} ((1-\beta)v + \beta\lambda - p_n)dv + \int_{1-q_n-q_r}^{1-q_n} ((1-\beta)\alpha v + \beta\lambda - p_r)dv$$

Considering the complexity of the expression, we numerically compare consumer surplus among four models by assuming $\alpha = 0.7$, $\beta = 0.2, \lambda = 0.4, c_n = 0.4, \eta = 0.03 or 0.05, and \mu = 0.99$. c_r should satisfy the condition: $0.254 < c_r < 0.358$. The comparison are depicted in Figs. 11 and 12. We can see the following observation by Figs. 11 and 12.

Observation 1: a. $CS^{FD} > CS^{RD} > CS^{FI} > CS^{RI} if c_r < 0.272; CS^{FD} > CS^{FI} > CS^{RD} > CS^{RI} if 0.272 < c_r$; b. $CS^{RD} and CS^{RI}$ decrease with η.

From observation 1a, we find that if the remanufacturing cost is smaller $(c_r < 0.272)$, consumer surplus of four models satisfies the following relationship: $CS^{FD} > CS^{RD} > CS^{FI} > CS^{RI}$. If remanufacturing cost is larger $(0.272 < c_r)$, the relationship of consumer surplus is $CS^{FD} > CS^{FI} > CS^{RD} > CS^{RI}$. Consumer surplus in Model FD is the largest for a smaller or larger remanufacturing cost. The results are due to the interaction between the distribution channel and the licensing strategy. Compared with the royalty fee licensing strategy, the fixed fee licensing strategy does not affect the optimal prices and quantities. Compared with the indirect distribution channel, the direct distribution channel will have lower prices for the products. These two benefits for consumers will coexist in Model FD, which leads to the largest consumer surplus. While the coexistence of the disadvantages of the royalty fee and the indirect distribution channel results in the lowest consumer surplus in Model RI. For Model RD and Model FI, their relationship depends on the size relationship between the negative effect of the royalty fee licensing strategy and the indirect distribution channel on consumer surplus. If the remanufacturing cost is lower, the indirect distribution channel will significantly diminish the quantity of rem products and improve its price, which results in a lower consumer surplus, that is, $CS^{RD} > CS^{FI}$. For a larger remanufacturing cost, the royalty fee licensing strategy will further weaken the motivation of the IR remanufacturing. The less quantity will result in a lower consumer surplus in Model RD, that is, $CS^{FI} > CS^{RD}$. Observation 1b demonstrates that consumer surplus in Model RD and Model RI decreases with the royalty fee. The reason is that a higher royalty fee means higher prices but lower quantities for new and rem products, which lowers consumer surplus. In summary, for consumers, Model FD is great.

5.3.2. Social welfare

Next, we compare social welfare among the four models. Refer to Örsdemir et al. (2014) and Zou et al. (2016), social welfare is the sum of profits plus consumer surplus. Thus, we have:

$$SW = \pi_{OEM} + \pi_{IR} + \pi_I + CS$$

Similar to 5.3.1, we also numerically compare social welfare among four models by assuming $\alpha = 0.7, \beta = 0.2, \lambda = 0.4, c_n = 0.4, \eta = 0.03 or 0.05, \mu = 0.99, and F = 0.001$, which is shown in Figs. 13 and 14. The following observation presents our results.

Observation 2: a. $SW^{FD} > SW^{RD} > SW^{FI} > SW^{RI} if c_r < 0.264 or c_r > 0.326$; $SW^{FD} > SW^{FI} > SW^{RD} > SW^{RI} if 0.264 < c_r < 0.326$; b. $SW^{RD} and SW^{RI}$ decrease with η.

Observation 2a shows the relationship of social welfare among four models. For a smaller or larger remanufacturing cost $(c_r < 0.264 or c_r > 0.326)$, the relationship is $SW^{FD} > SW^{RD} > SW^{FI} > SW^{RI}$. If the remanufacturing cost is moderate $(0.264 < c_r < 0.326)$, the relationship is changed as $SW^{FD} > SW^{FI} > SW^{RD} > SW^{RI}$. That is to say, Model FD has the largest social welfare while Model RI has the lowest social welfare. It is due to the larger benefits of the direct distribution channel and the fixed fee licensing strategy for the whole industry, compared with the indirect distribution channel and the royalty fee licensing strategy. Observation 2b presents that social welfare in Model RD and Model RI will decrease with the royalty fee. That is to say, improving the royalty fee is not always beneficial for the social although it may spur the profit of the OEM to increase.

5.4. Consumers obtaining a lower WTP for remanufactured products than new products from online reviews

In our main boby, we assume consumers obtain the same WTP for new and remanufactured products. While, in reality, there exist a case where consumers have less preference for remanufactured products since they distrust remanufactured products (Atasu et al., 2013; Huang et al., 2019; and Qiao and Su, 2020b). Thus, although the quality of new and remanufactured products is the same, consumers only obtain a lower WTP for remanufactured products than new products from online reviews. In this subsection, we

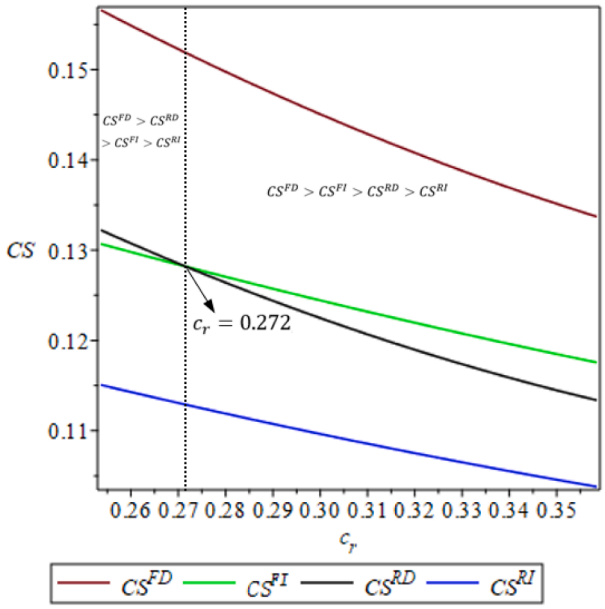


Fig. 11. Comparison of consumer surplus among the four models ($\eta = 0.05$).

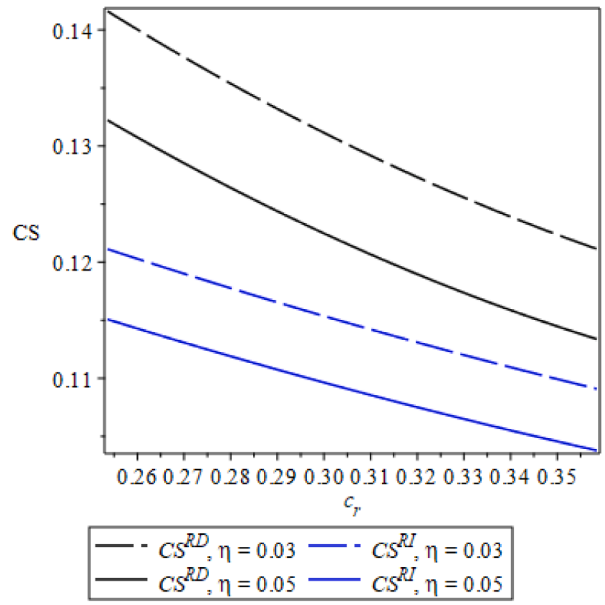


Fig. 12. Comparison of consumer surplus of Model RD or Model RI for different $\eta(\eta = 0.03$ or $0.05)$.

consider this situation, and assume consumers obtain a WTP λ for new products but a lower WTP $\alpha\lambda$ for remanufactured products from online reviews. We have the demand functions of new and remanufactured products in period 2: $q_n = 1 - \frac{p_n - p_r - (1-\alpha)\beta\lambda}{(1-\beta)(1-\alpha)}$ and $q_r = \frac{\alpha p_n - p_r}{\alpha(1-\beta)(1-\alpha)}$. Similar to the deriving process of the main body, we find the results in this case, the IR's distribution channel and the OEM's licensing strategy choice. The related results are shown in the following propositions.

Proposition 7: a. *if* $\max\{c_{r1}^{FD'}, c_{r1}^{FI'}\} < c_r < c_{r3}^{'}, \pi_{IR}^{FD} > \pi_{IR}^{FI}$; otherwise, $\pi_{IR}^{FD} < \pi_{IR}^{FI}$.

b. $\pi_{IR}^{RD} > \pi_{IR}^{RI}$ *if* $\max\{c_{r1}^{RD'}, c_{r1}^{RI'}\} < c_r < c_{r6}^{'}$; otherwise, $\pi_{IR}^{RD} < \pi_{IR}^{RI}$

Proposition 7 shows the IR's distribution channel strategy when consumers obtain a lower WTP for remanufactured products than new products from online reviews. The results indicate that if the fixed or royalty licensing strategy is adopted and the remanufacturing cost is sufficiently small, the IR prefers the direct distribution channel for remanufactured products, which is consistent with the

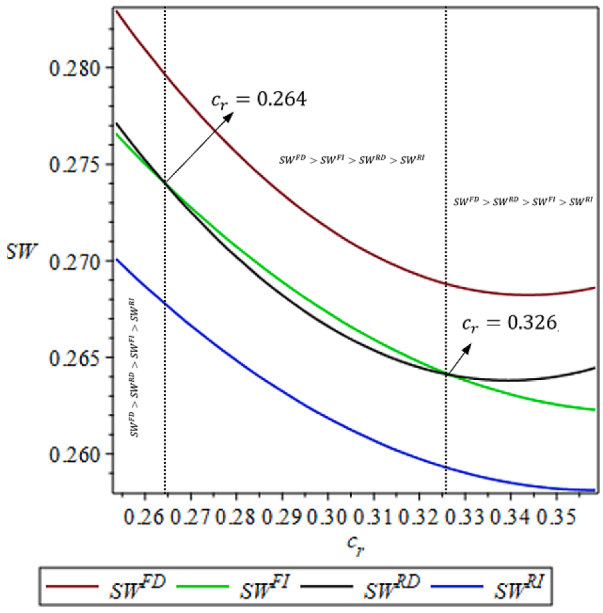


Fig. 13. Comparison of social welfare among the four models ($\eta = 0.05$).

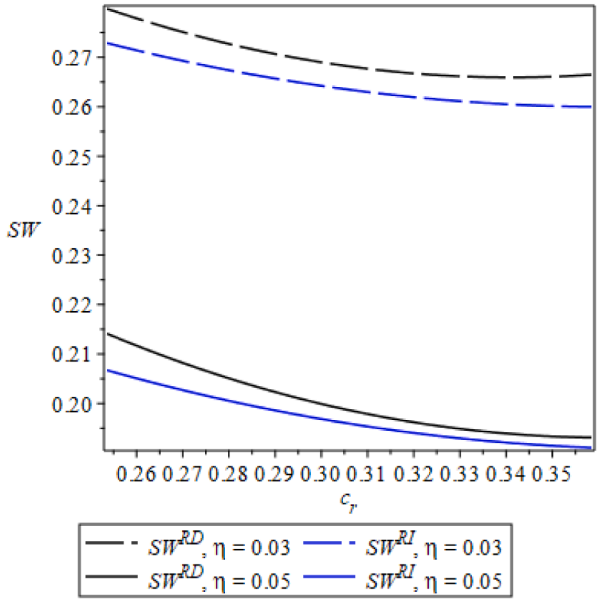


Fig. 14. comparison of social welfare of Model RD or Model RI for different $\eta(\eta = 0.03$ or $0.05)$.

distribution channel choice in section 4.

Proposition 8:. 1) *when* $\max\{\lambda_{r1}^{FD'}, \lambda_{r1}^{FI'}, \lambda_{r1}^{RD'}, \lambda_{r1}^{RI'}\} < \lambda < \min\{\lambda_{r3}', \lambda_{r6}'\}$, $\pi_{OEM}^{FD} > \pi_{OEM}^{RD} if F > F_{D1}'$;

2) when $\max\{\lambda_{r3}', \lambda_{r6}'\} < \lambda < \min\{\lambda_{r2}^{RD'}, \lambda_{r2}^{RI'}, \lambda_{r2}^{FD'}, \lambda_{r2}^{FI'}\}$, $\pi_{OEM}^{FI} > \pi_{OEM}^{RI} if F > F_{l1}'$;

3) when $\min\{\lambda_{r3}', \lambda_{r6}'\} < \lambda < \max\{\lambda_{r3}', \lambda_{r6}'\}$,

a. $\lambda_{r3}' < \lambda < \lambda_{r6}'(\alpha > \frac{32-12\sqrt{2}}{23})$, $\pi_{OEM}^{FI} > \pi_{OEM}^{RD} if F > F_{T2}'$;

b. $\lambda_{r6}' < \lambda < \lambda_{r3}'(\alpha < \frac{32-12\sqrt{2}}{23})$, $\pi_{OEM}^{FD} > \pi_{OEM}^{RI} if F > F_{T1}'$;

Proposition 8 presents the OEM's licensing strategy choice considering consumer obtaining a lower WTP for remanufactured

products than new products from online reviews. All findings indicates that the OEM's licensing strategy choice depends on the online reviews and the fixed licensing fee, which is consistent with the findings of Proposition 3.

From Proposition 7 and 8, we can know that our basic model has a stronger robustness. Even if we relax the assumption as consumer obtaining a lower WTP for remanufactured products than new products from online reviews, the main findings are still not changed.

6. Conclusions

Motivated by the practices, we build two-period game models to explore the interaction between the licensing strategy and the distribution channel in the presence of consumer online reviews in a remanufacturing area. The OEM firstly chooses the licensing strategy (the fixed or royalty fee) for the IR who remanufactures, and then the IR will choose the distribution channel (the direct or indirect distribution channel) for rem products. Faced with different choices, we apply backward induction to derive all optimal results, including the optimal prices, quantities, licensing strategy, distribution channel, and discuss the impact of consumer online reviews on the optimal results.

The interaction between the licensing strategy and the distribution channel in a remanufacturing area is evaluated. The research demonstrates that if the remanufacturing cost is lower, the IR will prefer the direct distribution channel, given the licensing strategy. Intuitively, in the direct distribution channel, the quantity of rem products will increase for a lower remanufacturing cost, which more benefits the IR. The obtained WTP will positively affect the threshold value of choosing different channels: the remanufacturing cost. Besides, we find that the profit of the OEM is higher when the IR adopts the indirect distribution channel rather than the direct distribution channel, since the higher price of new products in the indirect distribution channel offsets the loss of the lower quantity. This strengthens the profit of the OEM. Also, the results indicate that the OEM's licensing strategy choice depends on the sizes of the fixed fee and the obtained willingness-to-pay (WTP) of consumers from online reviews. For example, the OEM prefers the royalty fee licensing strategy to the IR who has chosen the direct channel, when the fixed fee and the obtained WTP are smaller. And more interestingly, we show that the OEM prefers the IR who sells rem products by the indirect distribution channel. These findings will guide different practitioners from different perspectives.

In addition, our results show that with the obtained WTP of consumers from consumer reviews, the retail prices, quantities and profits will increase due to the increased WTP of consumers. And by analyzing the impact of the royalty fee on the optimal decisions, we find that the quantities and the profit of the IR decrease, but the retail prices and the profit of the OEM increase. It is due to the lower quantity of rem products but the higher royalty fee and price of new products. Besides, compared with no consumer review, the results indicate that the price of rem products with consumer reviews is higher than that without if the obtained WTP is larger, but the price of new products in this situation is always higher than that with consumer review.

Moreover, we find the optimal royalty fees are different for two distribution channels. Interestingly, the results show that the optimal royalty fee of the direct distribution channel is smaller than that of the indirect distribution channel. This is because the double marginalization problem on the IR benefits the OEM. Finally, consumer surplus and social welfare respectively are compared among the four models numerically. The result indicates that if there are the fixed fee licensing strategy and the direct distribution channel in the market, consumer surplus and social welfare are the largest due to the advantages of the fixed fee licensing strategy and the direct distribution channel. And we relax our basic assumption about the obtained WTP to prove the robustness of our basic model.

However, there are some limitations to our research, which needs to study further in the future. Firstly, we consider the OEM selling new products by the only direct distribution channel to focus on our research problem. Therefore, the extension on the OEM selling by a dual-channel is worth studying. Besides, there is only a reseller in the indirect distribution channel for rem products. Expanding the competition resellers to sell rem products may be worthwhile research. Furthermore, we only use the obtained WTP to characterize consumer online reviews. But other factors of consumer online reviews, such as review volume, and rating credibility, also affect the firm's decisions, which is worthy of discussing. Also, the impact of consumer reviews on consumer purchasing behavior for new and rem products needs to be further tested by empirical research. Moreover, there are two licensing strategies provided in our model. If the two-part tariff licensing strategy can also be adopted by the OEM, which one among three licensing strategies is optimal?

CRediT authorship contribution statement

Haike Qiao: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Qin Su:** Conceptualization, Methodology, Validation, Writing - review & editing, Funding acquisition, Supervision.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tre.2021.102338.

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