Optimizing Circular Economy Strategies for OEMs: Impact of Patent Licensing and Customer Behaviours under Various Commission Contracts with Platforms Lotka-Volterra Model with Fear Effect and Linear Harvesting

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Abstract. Within the context of e-commerce platforms, which serve as the digital marketplace for manufacturers' new and refurbished products, a dual role in the refurbishing process has emerged. Manufacturers can utilize patent licensing to either profit from new market entrants or retain control over internal refurbishing operations. To gain a deeper understanding of this evolving landscape of business competition and collaboration, our study has developed a two-phase game-theoretic model. This analysis is centered on a market comprised of a single OEM, a platform, and a diverse consumer base with varying product valuations, divided into high-end and low-end segments. In this framework, the platform offers two distinct commission structures: a proportional fee contract and a per-unit fee contract. Simultaneously, the OEM can opt for either in-house refurbishing or authorized refurbishing. This combination results in four unique business scenarios. Importantly, our findings extend beyond previous research by revealing that the choice of refurbishing mode is not solely dictated by refurbishing costs but is also significantly influenced by market parameters, especially the commission fee. Furthermore, our study highlights the divergence in the behavior of OEMs' royalty fees and refurbishing strategies when faced with changes in commission rates under a proportional fee contract, primarily due to the platform's propensity for free-riding behavior. Ultimately, our comparative analysis of profits between the OEM and the platform under various commission contracts provides valuable insights, indicating that the proportional fee contract consistently favors the OEM, while the platform's choice of commission contract depends on refurbishing costs.

Keywords: circular economy strategies, original equipment manufacturers, lotka-volterra model

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1 Introduction

A significant transformation has been observed in the manufacturing sector, where there has been a surge in waste production due to the conventional approach to new product life cycles. In light of growing concerns about resource scarcity and environmental harm within the industry, a shift towards adopting a circular economy model has gained prominence [1], [2]. The practice of remanufacturing and refurbishing has emerged as a practical solution, involving the repair and revitalization of used goods into items that are almost as good as new. This shift effectively steers away from the linear product life cycle to embrace a circular one [3]. According to [4], this approach has garnered significant attention in the manufacturing domain, as it plays a pivotal role in reducing waste disposal, curbing the consumption of natural resources, and minimizing the accumulation of materials in landfills.

Governments and environmental groups are making considerable efforts to encourage firms to engage in refurbishing. The Waste Electrical and Electronic Equipment (WEEE) directive in the European Union is one such initiative, promoting ”extended producer responsibility.” This directive makes it mandatory for all original equipment manufacturers to take responsibility for treating and recycling their products when they are no longer desired by their owners. Refurbishing is a strategy highly favored by companies, delivering both economic and environmental benefits. It not only conserves raw materials but also preserves a significant portion of the value added during the production of new items [5, 6]. One of its noteworthy aspects is cost savings, with refurbishing leading to a 40-65 percent reduction in manufacturing expenses [7]. As a result, a growing number of prominent manufacturers, including Apple, Samsung, Lenovo, Fuji, Xerox, Kodak, IBM, HP, Bosch, Boeing, and Caterpillar, have incorporated refurbishing into their business models [8]. Furthermore, refurbishing yields substantial environmental advantages. It reduces the environmental impact associated with disposing of returned products and consumes fewer natural resources and less energy compared to manufacturing new items. In fact, refurbi-shing a product requires only about 15 percent of the energy needed to create the product from scratch [9].

The emergence of the Internet economy has given rise to major players in the online retail sector, such as Amazon, JD.com, BestBuy, Newegg, and others. Online retailers offer manufacturers a direct avenue to reach customers and enable them to conduct transactions independently, albeit for a fee associated with this service [10, 11]. The convenience and safety of online shopping have prompted a significant consumer shift from traditional offline retail, underscoring the immense potential within the online consumer market. An enlightening report from the U.S. Commerce Department reveals that in 2020, the total online consumption in the United States amounted to a staggering 861.12 billion, constituting 21.3% of the entire year's retail sales [11]. Notably, major corporations such as Apple, Nike, HP, and others have adopted e-tailers as platforms for selling their products. These statistics underscore the irresistible momentum of online shopping, and the strategic challenge faced by traditional offline businesses in addressing the rise of online sales is becoming increasingly prominent.

Typically, platform operators employ two prevalent types of commission contracts: the proportional fee contract (similar to revenue sharing) and the per-unit fee contract [12, 13]. In the case of a proportional fee contract, the platform takes a portion of the manufacturer's sales revenue, whereas, in a per-unit fee contract, the manufacturer is obligated to pay a fixed fee to the platform for each unit of product sold. As outlined by [12], the key distinction between these two contracts lies in the fact that under a proportional fee contract, the platform can benefit from the manufacturer's production or investment earnings, securing a certain share of additional revenue. On the other hand, with a per-unit fee contract, the manufacturer does not share revenue with the platform.

In the realm of e-commerce platforms, patents often serve as a significant hurdle when it comes to engaging with the remanufacturing market. This is due to the fact that core components found in used products are typically safeguarded by patents held by the original manufacturers, and remanufacturing processes may constitute an infringement upon these patent rights [14, 15]. Broadly speaking, when a product is covered by patent protection, any remanufacturer must obtain a license from the original equipment manufacturers (OEMs), often held by the patent holders themselves [16–18]. OEMs wield the authority to restrict any unsanctioned remanufacturing activities outside their control, thereby safeguarding their unique position within the supply chain. However, they may also adopt a more cooperative approach by offering the e-commerce platform the option to pay a patent licensing fee, granting it the privilege to use brand logos and providing technical support. An illustrative example can be found in Apple, which has introduced a proprietary screen repair machine at BestBuy, enabling them to repair damaged iPhone screens while supplying spare parts and advanced diagnostic tools to enhance their refurbishment capabilities. In essence, patent licensing opens up a novel avenue for cooperation in the remanufacturing process within the confines of a closed-loop supply chain.

Researchers have acknowledged the distinction in consumers' perception re-garding the quality of new and refurbished products [19]. As a result, consumer behavior towards these products assumes a crucial role in the pricing issue, as it can impact the demand for both product types [20–22]. According to the research conducted by [23] and [8], the availability of refurbished products at dis-counted prices raises concerns about potential sales cannibalization for higher-margin new products. Consequently, many companies decide against offering refurbished products alongside new ones. However, by incorporating both refur-bished and new products into their product lineup, firms can effectively target different customer segments and capture sales from "low-end" customers who prefer refurbished options. Despite the possibility of cannibalizing some sales of new products, the overall financial benefit to the company can be significant when carefully determining the pricing and quantity of refurbished products. There are two distinct customer segments in the market: high-end and low-end. High-end customers are open to purchasing new products but may also consider refurbished alternatives. In contrast, low-end customers exclusively prefer refur-bished products. However, the firms maintain fixed and consistent prices for their new products, and the process of refurbishing typically does not impact pricing, procurement, or other decisions related to new product offerings.

This work has primary contributions encompass several key areas. Firstly, drawing from real-world industrial practices, we have formulated specific production and remanufacturing strategies tailored to both new and remanufactured products. Through this, we offer insights into the dynamics of optimal remanufacturing strategies under two distinct commission contract scenarios. Our findings underscore that the manufacturer's choice of commission contract significantly influences remanufacturing operations, including the threshold for the remanufacturing strategy. Secondly, this paper delves into the licensing strategy across various commission formats. Thirdly, it explores the ideal remanufacturing mode for original equipment manufacturers (OEMs). Lastly, we provide a thorough analytical examination of how commission contracts and customer behavior collectively impact individual profits.

2 Model Assumptions

We devised a game model to explore the decision-making process of Original Equipment Manufacturers (OEMs) regarding their refurbishing practices and the commission contract they enter into with a closed-loop supply chain platform. OEMs, in this scenario, join the platform by entering into a stable commission contract and proceed to sell new products on the platform. They also grant the platform the rights to refurbish their patented products (authorized refurbishing). Consequently, both new and refurbished products coexist in the market. When an OEM engages in product sales through the platform, they are required to pay a commission to the platform. This commission can take two common forms: the proportional fee, where the OEM pays a percentage of the sales price to the platform and retains the remainder, resembling a revenue-sharing model, and the per-unit fee, where the OEM pays a fixed transaction fee for each unit sold. The commission fee is considered an exogenous parameter, as platforms typically apply the same commission rate to sellers within the same product category. In this paper, we denote these two platform commission contract models as P (proportional fee) and F (per-unit fee).

The Original Equipment Manufacturer (OEM) utilizes raw materials for the production of new products, incurring a manufacturing cost denoted as c_n. In contrast, refurbished products are manufactured using used products and some new components, resulting in a refurbishing cost, denoted as c_r. It is assumed that $c_r$is less than c_n, as the core components of discarded products can be integrated into refurbished items, substantially reducing the consumption of raw materials. The costs associated with handling used products, including collection, disassembly, cleaning, and testing, are presumed to be zero, and all used products can be efficiently recycled and refurbished post-treatment. When the OEM opts to grant refurbishing rights to the platform, the platform imposes a licensing fee for each unit of refurbished product. This authorization not only grants the platform the rights for refurbishing but also provides access to the OEM's technology and equipment support.

The market consists of two distinct segments: high-end and low-end. Customers shopping in the high-end segment are more inclined to purchase new products, while those in the low-end segment predominantly opt for refurbished goods. In the absence of refurbished products, the demand for new items, often referred to as the high-end demand and denoted as q, prevails. However, in the presence of a refurbished goods market, a portion of high-end customers, indicated by $\alpha(p_r)$, will transition to buying refurbished products if they are available. Furthermore, by offering refurbished products at a price of p_r, a retailer can attract a group of price-sensitive low-end buyers, capturing a market share represented by a for refurbished products, with l denoting their price sensitivity. These factors collectively determine the number of customers purchasing new and refurbished products.

$$q_n = q - \alpha(p_r) \tag{1}$$

$$q_r = a - lp_r + \alpha(p_r) \tag{2}$$

where q_n and q_r are the production quantity of new and refurbished products We assume that cannibalization mimics a general linear switching function, thatis,

$$\alpha(p_r) = b(p_n - p_r), \tag{3}$$

for some coefficient cannibalization b, wherep_n is the new product price. In our model, we examine a scenario where there are no constraints on the supply of refurbished products throughout the entire product life cycle. The potential pool of used products available for collection is substantial, and our study operates under the assumption that there exists no maximum limit on the total quantity available for refurbishing.

3 Model Formulation and Solution

In this section, two different models are discussed to explore the interrelationship between the platform commission contract and licensing. Section 3.1 discusses the refurbishing model when adopting proportional fee contract. Similarly, Section 3.2. discusses the refurbishing model when adopting per-unit fee contract.

3.1 Model*P (Commission Contract- Proportional Fee)*

In the P model, the OEM sells only new products and we assume that the OEM adopts the proportional fee contract. The platform appreciates a portion θ of sales commission. The platform is licensed with a licence fee θ for refurbishing. The price of new products is p_n, and the refurbished products are provided at a price of p_r. The profit expressions of both parties are as follows:

$$\max_{p_n^A} \Pi_M^P = \left((1-\theta)p_n^P - c_n\right) q_n^P + f q_r^P \tag{4}$$

$$\max_{p_r^A} \Pi_E^P = \theta p_n^P q_n^P + (p_r - c_r - f) q_r^P \tag{5}$$

The first part of the manufacturer profit expression represents the sales profit of new product, and the second part represents the total royalty fee obtained from the platform. The first part of the platform profit expression represents the sales profit of new product, and the second part represents the sales profit of refurbished product.

We solve the problems by using backward induction to determine the subgame perfect equilibrium. Once the manufacturer's maximization problem is solved with respect to $\mathbf{p_n^p}$, the platform can maximize its profit by choosing $\mathbf{p_r^p}$. The following proposition summarizes both parties' optimal decisions.

Theorem 1. *Let d=b+l, In Model P the equilibrium prices and quantities can be summarized as follows:*

$$
\begin{aligned}
p_n^{P*} &= \frac{b(b+2l-b\theta)c_n-(-1+\theta)\left(ab+2d(bf+q)+bdc_r\right)}{2b(-2l+b(-1+\theta))(-1+\theta)}\\
p_r^{P*} &= \frac{a+fd+dc_r}{2d}+\\
q_n^{P*} &= \frac{\frac{b(b+2l-b\theta)c_n+(-1+\theta)(ab+2dq+bdc_r)}{2d}}{4d(-1+\theta)}\\
q_r^{P*} &= \frac{(a(-4l+3b(-1+\theta))+2d(2fl+q(-1+\theta))}{-8l+4b(-1+\theta)}+\\
&\quad \frac{b(-2l+b(-1+\theta)c_n-d(-4l+b(-1+\theta))c_r)}{-8l+4b(-1+\theta)}
\end{aligned}
$$

3.2 Model F (Commission Contract- Per-Unit Fee)

In the F model, we assume that the platform adopts the per-unit fee contract and the new products are sold through the platform to customers. The OEM pays the per-unit fee for online channel service. The platform is licensed to remanufacture with a royalty fee f in the second period. The profit of both parties can be expressed as follows.

$$\max_{p_n^F}\Pi_M^F=\left(p_n^F-c_n-r\right)q_n^F+fq_r^F \tag{4}$$

$$\max_{p}{}^{F}_{p}\Pi_E^F=rq_n^F+\left(p_r-c_r-f\right)q_r^F. \tag{5}$$

We solve the problems by using backward induction to determine the subgame perfect equilibrium. Once the manufacturer's maximization problem is solved with respect to p_n^F, the platform can maximize its profit by choosing p_r^F. The following proposition summarizes both parties' optimal decisions.

Theorem 2. Let $d=b+l$, In Model F the equilibrium prices and quantities can be summarized as follows:

$$
\begin{aligned}
p_n^{F*} &= \frac{ab+2d(q+b(f+r))+b(b+2l)c_n+bdc_r}{2b(b+2l)}\\
p_r^{F*} &= \frac{a+fd+br+dc_r+\frac{ab+2d(q+b(f+r))+b(b+2l)c_n+bdc_r}{2(b+2l)}}{2d}\\
q_n^{F*} &= \frac{ab+2dq-2blr-b(b+2l)c_n+bdc_r}{4d}\\
q_r^{F*} &= \frac{a(3b+4l)-2d(2fl-q)-2blr+b(b+2l)c_n-d(b+4l)c_r}{4(b+2l)}
\end{aligned}
$$

4 Model Analysis

In this part, we look at the differences between the two models.

Proposition 1. *The manufacturer is more likely to set a lower price of new products and refurbished products in Model P than in Model F, i.e.,* $p_n^{P^*} < p_n^{F^*}$ and $p_r^{P^*}$ ¡$p_r^{F^*}$.

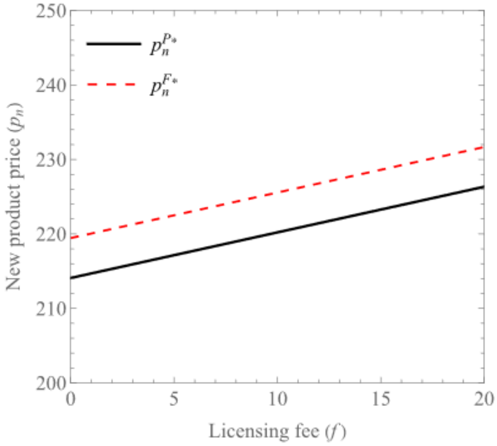

Fig. 1. Effects of licensing fee on new product price

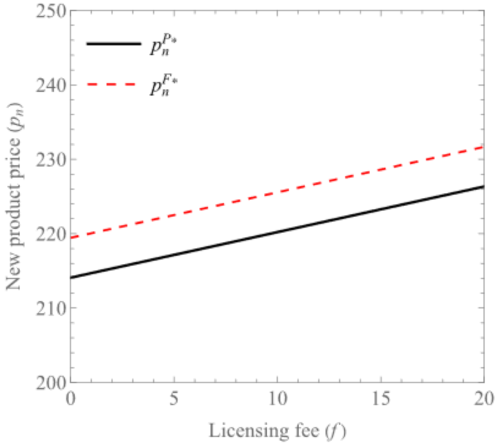

Fig. 2. . Effects of licensing fee on new refurbished product price

Proposition 1, Fig. 1 and Fig. 2 show that in the context of commission contracts, Model P (Commission Contract-Proportional Fee) is more likely to lead manufacturers to set lower prices for both new and refurbished products compared to Model F (Commission Contract-Per-Unit Fee). This difference arises from the way the commission fee is structured. In Model P, where the commission is based on a percentage of the sale price, manufacturers are incentivized to lower prices to attract more customers and increase sales, as their commission earnings directly correlate with the sale price. This competitive pricing strategy can result in lower prices for consumers. In contrast, in Model F, where the commission is a fixed amount per unit sold, manufacturers may prioritize profit margins over price reductions, leading to potentially higher prices for both new and refurbished products. Ultimately, the choice of pricing model is influenced by market dynamics, competition, and consumer expectations.

Proposition 2. *The manufacturer is more likely to set a higher quantity of new products and refurbished products in Model P than in Model F, i.e.,* $q_n^{P^*} > p_n^{F^*}$ and $p_r^{P^*} > p_r^{F^*}$

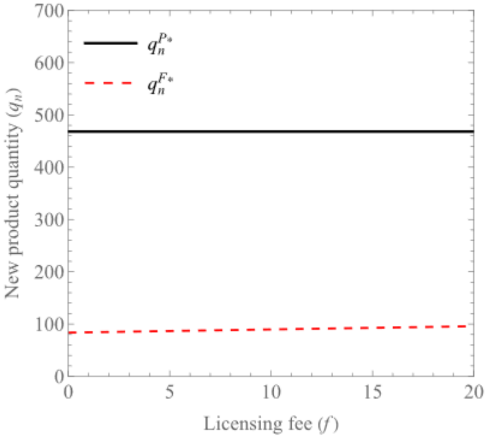

Fig. 3. . Effects of licensing fee on new product quantity

Proposition 2, Fig.3 and Fig. 4 show that in the context of commission contracts, Model P (Commission Contract-Proportional Fee) is more likely to lead manufacturers to stock higher quantities of both new and refurbished products compared to Model F (Commission Contract-Per-Unit Fee). The difference arises from the way the commission fee is structured. In Model P, where commissions are tied to the sale price as a percentage, manufacturers have a strong incentive to increase sales volume to earn higher commissions. This encourages them to stock higher quantities of products, as increased sales can lead to economies of scale and potentially improve profit margins even if prices are lower. On the other hand, in Model F, where the commission is a fixed amount per unit sold, there's less direct motivation to increase quantities, and manufacturers may opt for limited quantities at potentially higher prices to maintain per-unit profitability. The choice between these models is influenced by market dynamics, production capabilities, and the manufacturer's strategic objectives.

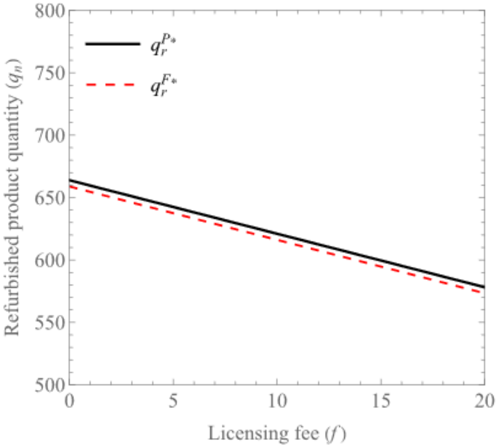

Fig. 4. . Effects of licensing fee on refurbished product quantity

Proposition 3. The manufacturer profit is more likely to be lower in Model P than in Model F, i.e., $\Pi_n^{P^*} < \Pi_n^{F^*}$.

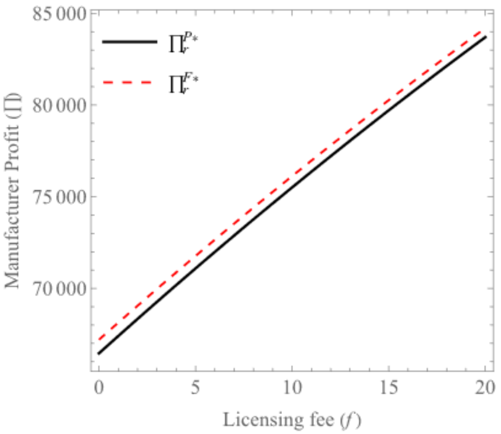

Fig. 5. Effects of licensing fee on manufacturer profit

Proposition 3 and Fig. 5 show that in the context of commission contracts, it's more likely that a manufacturer's profit will be lower in Model P (Commission Contract-Proportional Fee) compared to Model F (Commission Contract-Per-Unit Fee). This discrepancy can be attributed to the differing fee structures. In Model P, where the commission is calculated as a percentage of the sale price, manufacturers may be compelled to reduce prices to attract customers and boost sales, which, in turn, can lead to a decrease in profit margins. While higher sales volumes are achievable, the increased commission payments may outweigh the gains from larger sales. In contrast, Model F, with its fixed per-unit fee, encourages manufacturers to focus on maintaining per-unit profit margins, which may result in higher product prices. This can lead to higher profits per unit sold, even if the sales volume is lower. The choice between these models involves a trade-off between sales volume and profit margin, with Model P potentially favoring higher sales but lower per-unit profits and Model F emphasizing higher per-unit profits but potentially lower sales. Market dynamics, production costs, and consumer demand will all play a role in this decision.

5 Conclusion

In comparing Model P (Commission Contract-Proportional Fee) to Model F (Commission Contract-Per-Unit Fee), several key differences emerge that influence pricing strategies, product quantities, and manufacturer profits. Model P is more likely to result in lower prices for products as manufacturers seek to increase sales and their commission earnings directly linked to sale prices. In contrast, Model F tends to lead to higher product prices, as commission fees remain fixed per unit and, therefore, do not incentivize price reduction. Model P encourages manufacturers to stock higher quantities of products, driven by the correlation between sales volume and commission earnings, potentially resulting in economies of scale and lower per-unit production costs. On the other hand, Model F may promote limited quantities at higher prices to maintain per-unit profitability. Overall, Model P may lead to lower manufacturer profits due to lower margins despite increased sales volume, while Model F can result in higher per-unit profits at the cost of potentially lower sales. The choice between these models depends on factors such as market dynamics, production capabilities, and business objectives.

The future of commission contract models, like Model P and Model F, is expected to be marked by increased adaptability and sophistication in response to dynamic market conditions and evolving consumer behaviors. Manufacturers may explore hybrid commission models that blend proportional and per-unit fees, offering greater flexibility in pricing strategies. With the rise of data analytics and machine learning, data-driven pricing will become more prevalent, allowing manufacturers to optimize prices based on various factors. Personalized pricing and ethical considerations may play a more significant role in shaping pricing strategies, while blockchain technology and smart contracts could enhance transparency and efficiency in commission agreements. The impact of economic shocks, global events, regulatory changes, and competitive pressures will continue to drive adjustments in these models. To thrive in the evolving landscape, manufacturers will need to stay agile, data-savvy, and responsive to emerging trends and challenges.

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