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Outsourcing or Authorizing? Optimal Options for Third-Party Remanufacturing Modes with Green Consumerism

Juncheng Wu [1], Lei Zhang [2,*] and Xuan Shen [2]

[1] Industrial and Commercial Bank of China Chengdu Shahe Branch, Chengdu 610051, China; wujuncheng95@gmail.com
[2] School of Management and Economics, University of Electronic Science and Technology of China, Chengdu 611731, China; shenxuan0929@163.com
* Correspondence: mouclim@uestc.edu.cn

Abstract: In recent decades, more and more consumers are becoming concerned about the environment and increasingly tend to buy remanufactured products. However, despite the emergence of green consumerism, many original equipment manufacturers (OEMs) are unlikely to engage in remanufacturing themselves and instead prefer to contract it to third-party remanufacturers (TPRs). Although the literature has recently highlighted the difference between outsourcing and authorizing remanufacturing, it does not explore how green consumerism impacts the choice between these two remanufacturing modes. To fill this gap, in this study, we develop two theoretical models according to which the OEM can outsource or authorize its remanufacturing operations to a TPR to satisfy green consumers who prefer remanufactured products. By comparing optimal outcomes, such as quantities, profit, and environmental factors, our analysis shows that a substantial proportion of environmentally conscious consumers prefer the strategy of remanufacturing outsourcing, which provides a win–win–win strategy for the OEM, the TPR, and the environment; otherwise, the OEM chooses to authorize remanufacturing, which negatively affects the TPR and the environment. As such, we suggest that governments try to increase the proportion of the population that favors green consumerism or implement measures that encourage OEMs to adopt remanufacturing outsourcing.

Keywords: remanufacturing; green consumerism; outsourcing; authorization; sustainability

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1. Introduction

Remanufacturing involves collecting used products, restoring them to like-new quality, and selling them again [1,2]. Remanufacturing yields sustainable benefits because it can divert materials from landfills [3]. As such, governments and environmental groups spare no effort to educate consumers about the sustainable benefits of remanufacturing. For example, the EU made a reinvigorated attempt to promote green consumerism in its Waste Electrical and Electronic Equipment Directive (WEEE) [4].

The efforts of governments and environmental groups have reaped solid returns: more than three-quarters of consumers (25% totally agree and 50% tend to agree) are ready to buy environmentally friendly products even if they are more expensive than "normal" products [5]. Similarly, according to a survey by Alibaba Group, in 2017, 56% of Chinese citizens were willing to purchase green products, which is an increase of 26% from a year earlier [6].

Although green consumers' concern for the environment may even surpass their concern for a product's function [7,8], from the perspective of original equipment manufacturers (OEMs), the sale of remanufactured products would cannibalize the sales of new products [9,10]. In practice, to deal with the potential cannibalization effects on new products sales, many OEMs are unlikely to engage in remanufacturing themselves but usually contract it to third-party remanufacturers (TPRs). For instance, it is estimated that more than 96% of U.S. remanufacturers are TPRs that perform contracted remanufacturing for OEMs [11].

This contracting of remanufacturing operations provides two different options/modes for OEMs: outsourcing and authorization remanufacturing [12]. The outsourcing option is where the OEM distributes not only all new products produced by itself but also the remanufactured products offered by the TPR. This mode is quite common in developed countries, such as the U.S.A., countries in the EU, and Japan [13]. However, in developing countries, including China and India, OEMs would like to grant authorization of remanufacturing to a TPR, where the OEM only distributes new products, while all remanufactured products are made and sold by the authorized TPR.

Based on motivations from practice, the purpose of this study is to provide operational insights into how green consumerism impacts the choice between the two remanufacturing modes. More specifically, besides the strategic consumers who make a tradeoff between the remanufactured and new products, there are some green consumers who are guided by environmental considerations, tending to favor remanufactured products. Faced with green consumerism, OEMs are unlikely to engage in remanufacturing themselves but instead contract it to TPRs with two different options/modes: outsourcing and authorization remanufacturing.

Although an increasing number of researchers have recently highlighted the difference between two possible third-party remanufacturing modes, e.g., Zhou et al. [1] and Zou et al. [12], it is unclear for practitioners or managers how green consumerism impacts the choice between these two modes. To fill this gap in the literature, in this study, we develop two theoretical models that provide the OEM with the flexibility to choose to authorize or outsource its remanufacturing operations to a TPR. Specifically, we aim to address the following research questions:

- How does green consumerism affect the different options, i.e., remanufacturing outsourcing and/or authorization?
- How does green consumerism affect the economic benefits of outsourcing and authorization remanufacturing?
- How does green consumerism affect the sustainable benefits offered by outsourcing and authorization remanufacturing?

Our analysis provides suggestions for the selection of remanufacturing mode with green consumerism. Specifically, we find that based on remanufacturing outsourcing, the OEM would like to decrease the availability of its new products to distribute more remanufactured products. Moreover, this increase in quantities of remanufactured products in remanufacturing outsourcing is beneficial for the OEM, the TPR, and environment if the proportion of the population that favors green consumerism is pronounced. However, if the proportion of the population that favors green consumerism is not pronounced, the OEM should prefer remanufacturing authorization in order to distribute more new products. This aggressive strategy in new product selling negatively affects the TPR and the environment. As such, we suggest two possible options: governments and environmental organizations should try to increase the proportion of the population that favors green consumerism or encourage third-party remanufacturers to distribute more remanufactured products.

The remainder of this article is organized as follows. Section 2 contains a literature review. All the assumptions and notations are introduced in Section 3. The optimal decisions and main results are provided in Section 4. Finally, several research directions are discussed in Section 5.

2. Literature Review

This section covers two research issues involved in green consumerism and the third-party remanufacturing modes, that is, outsourcing and authorization.

Due to increasing environmental problems, green consumerism is gaining growing attention from researchers. For example, Agrawal et al. [14] adopted a life-cycle environmental impact perspective and analytically investigated whether leasing can be more profitable and have a lower total environmental impact. Gleim et al. [15] investigated individual barriers that affect consumers' evaluations of the green products found in retail outlets. Yew et al. [16], based on a conceptual model developed by integrating the theory of planned behavior and pro-environment behavior research, analyzed survey data from 208 Singapore testbed eco-town apartment precinct households. Soomro et al. [17] extended the theory of planned behavior (TBP) and utilized actual behavioral variables by considering the importance of recycling household waste. Although the above-mentioned studies provided the inspiration for us to explore sustainable consumption and changes in consumer behaviors, they do not consider how green consumerism impacts remanufacturing decisions.

Recently, more and more researchers have addressed the optimal remanufacturing decisions according to green consumer behavior. For instance, Gu et al. [18] studied a firm that had the option to design a non-remanufacturable or a remanufacturable product and to specify a corresponding quality, and they found that the design choices affect both the production costs and consumer valuations associated with the product. Nelson et al. [19] constructed an extended theory of planned behavior model to understand the relationship between a consumer's interaction with a product and the environment, their knowledge of environmental issues and attitudes toward the environment, and their willingness to purchase the product. Ogiemwonyi et al. [20] revealed that green purchase behavior was directly influenced by subjective norms, awareness of consequences, and environmental attitude, and it was indirectly influenced by environmental concern, environmental responsibility, and awareness of consequences through environmental attitudes. Marcon et al. [21] provided a comprehensive literature review for green product attributes organized based on a product life-cycle management perspective. In particular, Tan et al. [22] recently developed business models with green consumerism to highlight whether a manufacturer should outsource its remanufacturing to a third-party remanufacturer. Taken together, these studies do not pay attention to the effect of green consumerism on the different options for third-party remanufacturing modes—that is, outsourcing and authorization. We build on their work by considering how green consumerism impacts the remanufacturing outsourcing and authorization modes.

Our study also investigates third-party remanufacturing: On the one hand, many researchers have highlighted remanufacturing outsourcing. For example, Qian et al. [23] highlighted how the new product upgrading strategy affects the decision making of the downstream OEM and the supplier. Zou et al. [12] developed two models in which the OEMs outsource remanufacturing to third-party remanufacturers, which have an advantage in cost or quality. Xia et al. [24] investigated how emission reduction approaches affect outsourcing remanufacturing in relation to carbon trading. Zhang et al. [25] investigated the strategic interaction of encroachment and outsourcing strategies between a contracted third-party remanufacturer and an OEM in a sustainable supply chain. Zhou et al. [26] considered a supply chain where the OEM outsources the production of new products to an independent manufacturer and they cooperate with each other again in remanufacturing. On the other hand, there are several studies that have discussed the topic of remanufacturing authorization between OEMs and third-party remanufacturers, e.g., Lv et al. [27], Zhou et al. [28], Li et al. [29], Liu et al. [30], and Huang and Wang [31]. Although an increasing number of researchers have recently highlighted remanufacturing outsourcing or authorizing, they do not examine the choice between the two remanufacturing modes by comparing them.

Fortunately, a few studies have recently highlighted optimal options for third-party remanufacturing modes. In particular, Zhou et al. [1] examined a supply chain where the OEM outsources the production process of new products to the contracted manufacturer and enters the remanufacturing market by cooperating with the remanufacturer through outsourcing or authorization remanufacturing modes. However, Zou et al. [12] compared the remanufacturing outsourcing or authorization modes by modeling the interaction between the OEM and the third-party remanufacturer in terms of consumer surplus, social welfare, and the environment. Li et al. [32] investigated remanufacturing operational strategies under three modes, i.e., in-house, outsourcing, and authorization modes. We follow this stream of research by comparing the differences between optimal decisions, environmental, and economic performance but differ in an important way: we examine the strategic consequences of green consumerism, that is, we extend the previous researchers' results to highlight how green consumerism impacts the choice between the two remanufacturing modes.

3. Model Description and Solutions

3.1. Model Description

An OEM's business decisions and strategic choices in remanufacturing are shaped by two theoretical paradigms: (1) the OEM outsources the remanufacturing to third-party manufacturers and compensates the latter through outsourcing service fees. However, the OEM retains full responsibility for the marketing of both product categories (Model O). Alternatively, (2) OEM authorizes the TPR to handle both the remanufacturing process and the marketing of remanufacturing products, charging franchise production and distribution licensing fees, whereas the OEM concentrates on the manufacturing and marketing of new products (Model A).

In both models, green consumers are $b \in [0,1]$, and hence, the proportion of the strategic consumers in the market is $1-b$. We assume the strategic consumers in the market who express a willingness to pay (WTP) for new products is θ and which are considered uniformly distributed in the interval $[0,1]$ [10]. On the other hand, we introduce a coefficient $\delta \in (0,1)$ representing the discount ratio of WTP for remanufacturing products compared to WTP for new products from the perspective of strategic consumers [3,10]. Then, the net utility of new and remanufacturing products for strategic consumers can be given as $U_n^c = \theta - P_n$ and $U_r^c = \delta\theta - P_r$. We determine that the prices for new products and remanufacturing products are P_n and P_r, respectively. Then, like Zhang et al. [3] and Zhou et al. [10], we can derive the demand functions of strategic consumers as follows.

$$\begin{aligned} q_n^c &= (1-b)\left(\tfrac{1-(P_n-P_r)}{1-\delta}\right) \\ q_r^c &= (1-b)\left(\tfrac{\delta P_n - P_r}{\delta(1-\delta)}\right) \end{aligned} \tag{1}$$

Like Wang et al. [8] and Zhou et al. [10], we assume that green consumers who are guided by environmental considerations tend to favor the remanufacturing of products. Then, the demand for remanufacturing products from green consumers is given as follows.

$$q_r^g = b\left(\frac{\delta P_n - P_r}{\delta(1-\delta)}\right) \tag{2}$$

Thus, based on the previously derived demand functions, we can further deduce the total demand for new products and remanufacturing products as follows.

$$\begin{aligned} q_n &= q_n^c = (1-b)\left(\tfrac{1-(P_n-P_r)}{1-\delta}\right) \\ q_r &= q_r^c + q_r^g = (1-b)\left(\tfrac{\delta P_n - P_r}{\delta(1-\delta)}\right) + b\left(\tfrac{\delta P_n - P_r}{\delta(1-\delta)}\right) \end{aligned} \tag{3}$$

We also denote the manufacturing costs of new products and remanufacturing products as $c_n > c_r > 0$. Like Zhang et al. [3], Zhou et al. [10], and Yan et al. [33], we assume that all new products are remanufacturable once at the end of their life cycle and all decisions are made in one period setting.

3.2. Model Solution

3.2.1. Model O (Outsourcing Remanufacturing Model)

In the outsourcing remanufacturing model, OEM handles the marketing of both new and remanufacturing products, and it delegates the remanufacturing production process to third-party manufacturers by paying outsourcing fees p_o.

Since the OEM sells both new and remanufactured products, the problem of the OEM and TPR can be given as follows.

$$\begin{aligned}&\max_{q_n^O, q_r^O} \pi_m^O = p_n q_n - c_n q_n + p_r q_r - p_o q_r\\&\max_{p_o} \pi_r^O = p_o q_r - c_r q_r\end{aligned} \tag{4}$$

To determine the subgame perfect outcomes, we adopt backward induction in Model O. That is, maximizing the OEM's profits with q_n and q_r, we can establish that $q_n^{O*} = \frac{(1-b)[2c_n b + b\delta - 2b - p_o b - 2\delta + 2 - 2c_n + 2p_o]}{(4-4b-4\delta+4b\delta-b^2\delta)}$, $q_r^{O*} = \frac{(1-b)(\delta c_n b - b\delta - 2\delta c_n + 2p_o)}{2\delta(4b-4+4\delta-4b\delta+b^2\delta)}$. Then, substituting them into π_r^O and maximizing them with p_o, we can establish that $p_o^* = \frac{\delta b(1-c_n)+2\delta c_n+2c_r}{4}$. Finally, substituting p_o^* into q_n, q_r, π_m^O, and π_r^O, we can obtain all optimal decisions in the following results.

Lemma 1. *In Model O, the equilibrium decisions and profits are*

$$\begin{aligned}
p_o^* &= \frac{\delta b(1-c_n)+2\delta c_n+2c_r}{4}\\
q_n^{O*} &= \frac{(1-b)\begin{bmatrix} b^2\delta c_n - b^2\delta + 8bc_n + 6b\delta - 4b\delta c_n - 8b \\ -2bc_r + 8 + 4\delta c_n - 8\delta - 8c_n + 4c_r \end{bmatrix}}{4(4-4b-4\delta+4b\delta-b^2\delta)}\\
q_r^{O*} &= \frac{(1-b)(\delta b - \delta b c_n + 2\delta c_n - 2c_r)}{2\delta(4b-4+4\delta-4b\delta+b^2\delta)}\\
\pi_m^{O*} &= \frac{(1-b)\begin{bmatrix} 3b^2\delta^2 c_n^2 - 6b^2\delta^2 c_n + 3b^2\delta^2 + 28b\delta^2 c_n - 16b\delta^2 - 12b\delta^2 c_n^2 \\ +16\delta b + 4\delta b c_r - 32\delta b c_n + 16\delta b c_n^2 - 4\delta b c_r c_n - 32\delta^2 c_n \\ +16\delta^2 + 12\delta^2 c_n^2 - 16\delta + 32\delta c_n + 8\delta c_r c_n - 16\delta c_n^2 - 4c_r^2 \end{bmatrix}}{16(-4+4b+4\delta-4\delta b+\delta b^2)}\\
\pi_r^{O*} &= \frac{(1-b)(\delta b c_n - \delta b - 2\delta c_n + 2c_r)^2}{8\delta(4-4b-4\delta+4\delta b-\delta b^2)}.
\end{aligned}$$

3.2.2. Model A (Authorization Remanufacturing Model)

In Model A, the OEM responds to the manufacturing and marketing processes of new products while granting authorization of the remanufacturing operations and the sales processes of remanufacturing products to the TPR by charging licensing fees p_s. As a consequence, the problems of both participants are as follows.

$$\begin{aligned}&\max_{q_n, p_s} \pi_m^A = p_n q_n - c_n q_n + p_s q_r\\&\max_{q_r} \pi_r^A = p_r q_r - c_r q_r - p_s q_r\end{aligned} \tag{5}$$

We adopt backward induction in Model O again. That is, maximizing the OEM's profits with q_n while maximizing the TPR's profits with q_r, we can establish that $q_n^{A*} = \frac{(1-b)(2-\delta+c_r+p_s-2c_n)}{(4-\delta)}$, $q_r^{A*} = \frac{\delta-2c_r-2p_s+\delta c_n}{\delta(4-\delta)}$. Then, substituting them into π_m^A and maximizing them with p_s, we can establish that $p_s^* = \frac{(2b-c_n-3)\delta^2+2\delta(2c_r+4-2b+2bc_n-bc_r)-8c_r}{16+2\delta(b-3)}$. Finally, substituting p_s^* into q_n, q_r, π_m^A, and π_r^A, we can obtain all optimal decisions in the following results.

Lemma 2. *In Model A, the equilibrium outcomes and profits are*

$$p_s^* = \frac{(2b-c_n-3)\delta^2+2\delta(2c_r+4-2b+2bc_n-bc_r)-8c_r}{16+2\delta(b-3)}$$
$$q_n^{A*} = \frac{(1-b)(\delta c_n-3\delta+2c_r-8c_n+8)}{2(8-3\delta+\delta b)}$$
$$q_r^{A*} = \frac{2\delta c_n+b\delta-\delta bc_n-2c_r}{\delta(8-3\delta+\delta b)}$$
$$\pi_m^{A*} = \frac{\begin{bmatrix} 4b\delta^2c_n-4b\delta^2-4b\delta c_n^2+4\delta bc_r+8b\delta+8b\delta c_n^2-16b\delta c_n \\ -6\delta c_n^2-\delta^2c_n^2-8\delta c_n^2-4c_r^2-8\delta+3\delta^2+8\delta c_nc_r+16\delta c_n \end{bmatrix}}{4\delta(3\delta-\delta b-8)}$$
$$\pi_r^{A*} = \frac{(\delta bc_n-\delta b-2\delta c_n+2c_r)^2}{\delta(8-3\delta+\delta b)^2}.$$

To ensure that the outcomes in Lemmas 1 and 2 are not negative, we need to $\frac{(3\delta-3b\delta-\delta c_n+\delta c_nb+12c_n-10c_nb-8+10b)\delta}{2(\delta-b\delta+2)} = \underline{c}_r < c_r < \overline{c}_r = \frac{b\delta-\delta c_nb+2\delta c_n}{2}$

4. Analysis and Insights

In this section, based on Lemma 1 and Lemma 2, we provide several useful insights through comparing the equilibrium decisions and profits of the two models.

Based on the proof in Appendix A, we first focus on how green consumerism affects the different options, i.e., remanufacturing outsourcing and/or authorization. In particular,

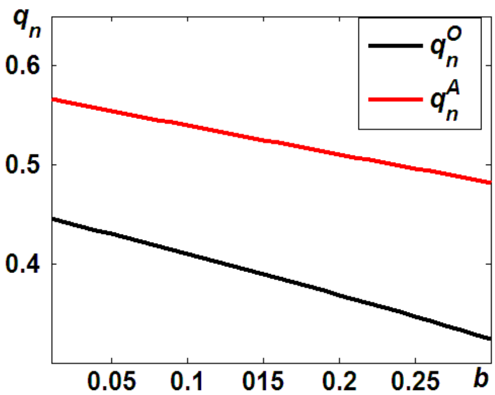
Proposition 1. *The optimal quantity of remanufactured (new) products in Model O is higher (lower) than that of Model A, i.e.,* $q_r^O > q_r^A (q_n^O < q_n^A)$.

It is worth noting that in Model O, both new and remanufactured products are distributed by the OEM; however, in Model A, the new (remanufactured) products are distributed by the OEM (TPR). Then, in Model O, the OEM can directly benefit from the sale of remanufactured products; however, in Model A, the OEM would indirectly benefit from the licensing fees p_s set to the TPR. Furthermore, green consumers tend to favor remanufactured products, which are associated with a lower remanufacturing cost, i.e., $c_r < c_n$. Additionally, since all remanufactured products are distributed by the TPR in Model A, to deal with the cannibalization effects of remanufactured products, the OEM would like to strategically establish licensing fees to exert further control over the quantity of remanufacturing products. As such, as Proposition 1 shows, to maximize the profits, the OEM would like to provide more units of remanufactured products in Model O, i.e., $q_r^O > q_r^A$.

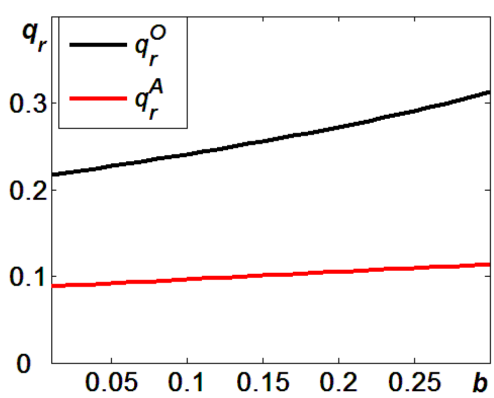
On the other hand, there are two main reasons for the OEM to limit the availability of new products in Model O. First, the lower the quantities of new products sold in the market, the higher the prices for both products. That is, the lower quantities of new products enable the OEM to earn higher marginal revenue from both products. Second, the lower the quantities of new products sold in the market, the higher the market share left to the remanufactured products. That is, the lower quantities of new products enable the OEM to influence demand for remanufactured products, $q_n^O < q_n^A$.

We now provide numerical examples to compare the two models' outcomes. We first make a detailed explanation of the data collection for all parameters. It is important to note that in both models, we normalize the potential market size to 1. Like Zhang et al. [3] and Esenduran et al. [34], we select 17-inch LCD monitors as a representative product in which the ratios of the manufacturing costs range between 0.2 and 0.6. Without loss of generality, we pick $c_n = 0.4$. In accordance with the fact that remanufacturing will cost less than manufacturing, like Zhou et al. [10], Zou et al. [12], and Zhang et al. [35], we pick $c_r = 0.1 < c_n$. In practice, there is a proportion of strategic consumers whose value discount for the remanufactured products can vary from 45% to 85% [35,36]. As such, we select the discount ratio of $\delta = 0.7$.

Based on Figure 1a, we find that, as Proposition 1 shows, the OEM always provides lower quantities of new products in Model O than in Model A, that is, $q_n^O < q_n^A$. However, Figure 1 further illustrates that as the proportion of green consumers of b increases, the quantities of new (remanufactured) products in both Model O and Model A decrease (increase). This is because an increase in the proportion of green consumers benefits the remanufacturing but may cannibalize the market share for new products. We can also observe from Figure 1 that as the proportion of green consumers of b increases, the difference in new (remanufactured) products enlarges. It is important to recall that both new and remanufactured products are distributed by the OEM; however, in Model A, the new (remanufactured) products are distributed by the OEM (TPR). Thus, the increase in the proportion of green consumers could generate an even more competitive relationship in Model O than in Model A.



(**a**)



(**b**)

Figure 1. Comparing the differences in q_n and q_r (with $c_n = 0.4$, $c_r = 0.1$, and $\delta = 0.7$). (**a**) q_n^O vs. q_n^A, (**b**) q_r^O vs. q_r^A.

We now try to address how green consumerism affects the economic benefits of outsourcing and authorization remanufacturing. That is, we answer the above question from the TPR's perspective as follows (the proof is provided in Appendix B).

Proposition 2. *The equilibrium profit of the TPR is higher in Model O than in Model A, that is,* $\pi_r^O > \pi_r^A$.

Proposition 2 reveals that when remanufacturing operations are authorized for the TPR, its situation is always inferior. This can be interpreted as follows. On the one hand, although the TPR can benefit directly from the selling of remanufactured products in Model A, the OEM would like to strategically establish licensing fees to exert control over the quantity of remanufacturing products. As such, the lower quantities of remanufactured products in Model A would lead to lower profits of the TPR in Model A. On the other hand, as mentioned earlier, in Model O, to maximize profits, the OEM would like to provide more units of remanufactured products in Model O, i.e., $q_r^O > q_r^A$. Then, this higher quantity of remanufactured products can result in higher profits for the TPR. Furthermore, in Model O, the OEM would like to limit the availability of new products, i.e., $q_n^O < q_n^A$. Moreover, this lower quantity of new products enables the OEM to earn higher marginal revenue from remanufactured products. Hence, although the TPR indirectly benefits from the selling of remanufactured products in Model O, as Proposition 2 shows, both the volume and price premium for the remanufactured products is beneficial for the TPR.

In addition to confirming Proposition 2, our numerical study in Figure 2 further reveals that as the proportion of green consumers of b increases, the profits in both Model O and Model A increase. That is, whether in Model O or Model A, the increase in the proportion of green consumers of b would benefit the remanufacturing business. Moreover, the increase in the proportion of green consumers enlarges the difference between π_r^O and π_r^A.

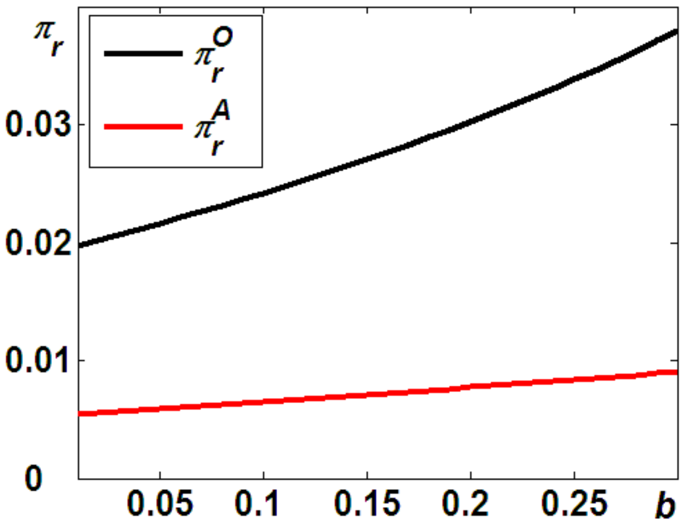


Figure 2. Comparing the differences in π_r (with $c_n = 0.4$, $c_r = 0.1$, and $\delta = 0.7$).

So far, our analysis has highlighted that compared to Model A, the TPR would always benefit more in Model O. Based on the proof in Appendix C, we can now answer the above question from the OEM's perspective, that is,

Proposition 3. *There exists a threshold of* b_Δ,*above which the OEM benefits more in Model O, that is,* $\pi_m^O > \pi_m^A$*; otherwise, the opposite holds true.*

Figure 3 shows that when the proportion of green consumers passes a critical threshold, i.e., b_Δ, the OEM will prefer the strategy of remanufacturing outsourcing. This result is quite intuitive: In both models, we assume that green consumers, who are guided by environmental considerations, tend to favor remanufacturing products. Then, if there is a substantial proportion of the market consisting of environmentally conscious consumers inclined toward remanufacturing products, distributing the remanufactured products is a profitable business. As Proposition 1 shows, the OEM would like to provide greater quantities of remanufactured products in Model O, which results in the total revenue directly obtained from the sale of remanufactured products being superior to the revenue indirectly generated from remanufacturing licensing fees. However, when the proportion of green consumers is not pronounced, i.e., $b < b_\Delta$, the marginal revenue from the sale of remanufactured products is limited. Furthermore, the more units of remanufactured products there are sold in the market, the fiercer the cannibalization effects of the new products sales. Then, when the proportion of green consumers is not pronounced, i.e., $b < b_\Delta$, the profits obtained from the sale of remanufactured products are not sufficient to "compensate" for the loss in the sales of new products that are cannibalized by the remanufactured products.

Remanufacturing yields sustainable benefits because it can divert materials from landfills [3]. Thus, as in [3,10], we calculate the environmental impacts from a resource-wasting perspective. That is, we focus on the environmental impacts caused by waste disposal and let e denote the per-unit impact due to disposal at the end of use. Thus, we can compare the environmental impacts of both models as follows (the proof is provided in Appendix D).

Proposition 4. *The environmental impact of Model O is always lower than that of Model A, i.e.,* $E^O < E^A$.

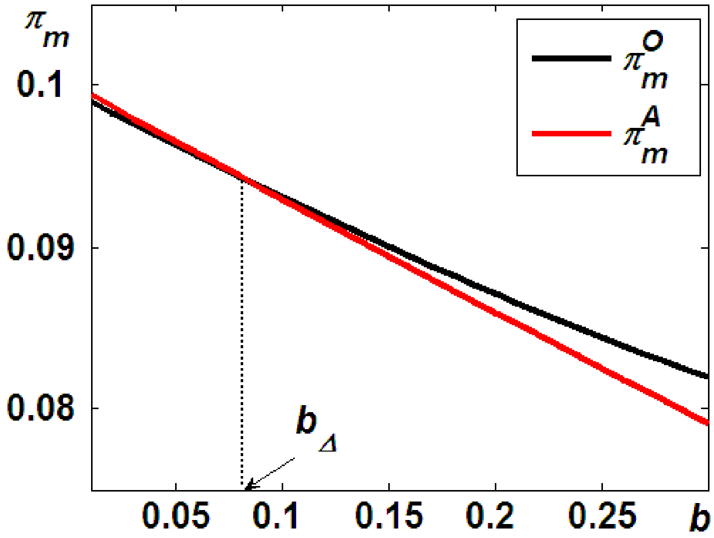


Figure 3. Comparing the difference in π_m (with $c_n = 0.4$, $c_r = 0.1$, and $\delta = 0.7$).

Proposition 4 suggests that Model O is greener than Model A. This is because the OEM would like to provide greater quantities of remanufactured products, reducing the potential resource wasting that is caused by disposal at the end of use. Furthermore, as Proposition 1 shows, the OEM would like to decrease the availability of new products, $q_n^O < q_n^A$. This reduction in the quantity of new products would decrease the total environmental impact.

Comparing the E^O and E^A in Figure 4 with $e = 1$, we observe that, as Proposition 4 shows, the environmental impact of Model O is always lower than that of Model A, i.e., $E^O < E^A$. Thus, we can conclude that Model O is greener than Model A. Moreover, Figure 4 shows that as the proportion of green consumers of b increases, the environmental impact of both Model O and Model A decreases. That is, consistent with conventional wisdom, we find that whether in Model O or Model A, an increase in the proportion of green consumers of b would result in higher environment sustainability. As such, our analysis suggests that it is very worthwhile for governments and environmental groups to educate consumers about the sustainable benefits of remanufacturing. In addition, we observe that the increase in the proportion of green consumers enlarges the difference between E^O and E^A.

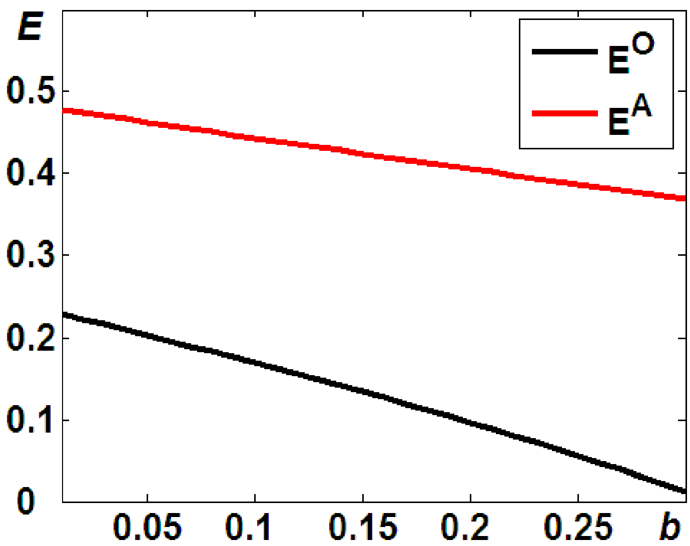


Figure 4. Comparing the difference in E.

Based on propositions 2, 3 and 4, we can provide the following corollary without proof, which helps to understand the cutoff value b^{Δ}.

Corollary 1. *If $b > b^{\Delta}$, remanufacturing outsourcing would be a win–win–win strategy for both parties and the environment. Otherwise, remanufacturing outsourcing would be beneficial for the OEM but would negatively affect the TPR and the environment.*

Corollary 1 suggests that if there is a substantial proportion of the market that consists of environmentally conscious consumers inclined toward remanufacturing products, as the Stackelberg leader, it would prefer the strategy of remanufacturing outsourcing, because remanufacturing outsourcing would be a win–win–win strategy for both parties and the environment. This may be consistent with the fact that the outsourcing remanufacturing mode is quite common in developed countries, such as the U.S.A., EU countries, and Japan [13].

In practice, in developing countries, including China and India, OEMs would like to grant the authorization of remanufacturing to a TPR [13]. However, Corollary 1 shows that if the proportion of green consumers in the market is not pronounced, i.e., $b < b^{\Delta}$, an OEM would choose the strategy of authorization remanufacturing, which would be beneficial for the OEM but negatively affect the TPR and the environment. Thus, based on Corollary 1, we call for governments and environmental groups in developing countries to take steps to correct or modify the situation. First, they can try to increase the proportion of green consumers in the market so that the OEM would prefer the strategy of remanufacturing outsourcing that creates a win–win–win strategy for both parties and the environment. Second, governments and environmental groups could implement measures, such as subsidy policy, to make up for the loss in profitability and lead OEMs to adopt remanufacturing outsourcing.

5. Conclusions

Governments and environmental groups spare no effort to educate consumers about the sustainable benefits of remanufacturing. Accordingly, more than three-quarters of consumers are prepared to buy environmentally friendly products even if they are more expensive than "normal" products [5]. However, despite the fact that green consumers' concern for the environment may even surpass their concern for a product's function, many OEMs are less likely to engage in remanufacturing themselves and usually contract it to third-party remanufacturers. This contract of remanufacturing operations involves two different options/modes of remanufacturing: outsourcing and authorization.

Based on motivations from practice, the purpose of this study is to provide operational insights into how green consumerism impacts the choice between the two remanufacturing modes. More specifically, from the demand side, we divide the market into two parts: one is strategic consumers who make a tradeoff between remanufactured and new products; the other is green consumers who, guided by environmental considerations, tend to favor remanufactured products. On the other hand, from the supplier side, we provide OEMs with the flexibility to contract their remanufacturing to TPRs with two different options/modes, that is, outsourcing and authorization. In summary, this study explores the optimal remanufacturing mode by establishing and comparing decision modes for two models considering profit, quantity, and environmental factors.

The overall contribution of this study is as follows. Although an increasing number of researchers have recently highlighted the differences between the two possible third-party remanufacturing modes, it is unclear from their research how green consumerism impacts the choice between these modes. To fill this gap in the literature, in this study, we develop two models to highlight the different options for an OEM so that it can decide whether to authorize or outsource its remanufacturing operations to a TPR.

The results can provide operational insights into the third-party remanufacturing modes for the OEM. In particular, we find that under remanufacturing outsourcing, to distribute more remanufactured products, the OEM would like to decrease the availability of its new products. Moreover, our analysis reveals that if the proportion of the population with green consumerism is pronounced, the OEM would prefer the strategy of remanufacturing outsourcing that can lead to a win–win–win strategy for the OEM, the TPR and environment. This may be consistent with the fact that the outsourcing remanufacturing mode is quite common in developed countries, such as the U.S.A., the EU, and Japan [13]. However, if the proportion of the population with green consumerism is not pronounced, the OEM should prefer remanufacturing authorizing with distributing more new products. This aggressive strategy in new product selling hurts the TPR and the environment. As such, we suggest two possible options for the governments and environmental entities in the developing countries to take steps to correct or modify the situation: They should make efforts to increase the proportion of the population with green consumerism or implement some measures that can cover up to the loss in profitability and lead the OEM to adopt the remanufacturing outsourcing.

Our analysis has four limitations that can be addressed by future research. First, our analysis demonstrates that a substantial proportion of environmentally conscious consumers favor the strategy of remanufacturing outsourcing, which provides a win–win–win strategy for the OEM, the TPR, and the environment; otherwise, the OEM chooses to authorize remanufacturing, which negatively affects the TPR and the environment. To avoid dependence on a single analysis, we encourage future researchers to provide empirical support for this theoretical result. Second, we examined a supply chain where the OEM would choose remanufacturing outsourcing or authorization; however, in practice, some OEMs, such as Xerox and Cannon, choose to engage in remanufacturing themselves [32,37]. Future researchers can therefore address the possibility of OEMs engaging in remanufacturing themselves. Third, in both of our models, we ignored the possibility of competition in the new and remanufacturing markets. However, it is estimated that more than 96% of U.S. remanufacturers are TPRs who compete with each other in the remanufacturing industry. Thus, our models' limitation in this respect requires future research to address the potential impact of competition in the new and/or remanufacturing market. Fourth, future research should extend our model to allow for uncertainty in the quality of remanufactured products, incomplete contracting between the OEM and TPR, and (cooperative) sales efforts in the remanufacturing market that might provide more useful managerial insights for practitioners or managers in the remanufacturing industry.

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Appendix A

Proof for Proposition 1. Based on the outcomes in Lemmas 1 and 2, we now solve $q_n^O - q_n^A$. After simplification, we can establish that

$$q_n^O - q_n^A = \frac{(b-1)(2\delta - 3b\delta + b^2\delta + 8)(\delta c_n b - 2\delta c_n - b\delta + 2c_r)}{4(4b - 4 + 4\delta - 4b\delta + b^2\delta)(8 - 3\delta + b\delta)}.$$

Based on the above function, we find that for any $\underline{c}_r < c_r < \bar{c}_r$, $0 < b < 1$, and $0 < \delta < 1$, the function of $q_n^O - q_n^A < 0$ is always held. That is, as Proposition 1 shows, the optimal quantity of new products in Model O is lower than that of Model A, i.e., $q_n^O < q_n^A$.

Based on the outcomes in Lemmas 1 and 2, we now solve $q_r^O - q_r^A$. After simplification, we can establish that

$$q_r^O - q_r^A = \frac{(\delta c_n b - b\delta - 2\delta c_n + 2c_r)(5 - 4b + b^2)}{2(4b - 4 + 4\delta - 4b\delta + b^2\delta)(8 - 3\delta + b\delta)}.$$

Based on the above function, we find that for any $\underline{c}_r < c_r < \bar{c}_r$, $0 < b < 1$, and $0 < \delta < 1$, the function of $q_r^O - q_r^A < 0$ is always held. That is, as Proposition 1 shows, the optimal quantity of remanufactured products in Model O is higher than that of Model A, i.e., $q_r^O > q_r^A$. □

Appendix B

Proof for Proposition 2. Based on the outcomes in Lemmas 1 and 2, we now solve $\pi_r^O - \pi_r^A$. After simplification, we can establish that

$$\pi_r^O - \pi_r^A = \frac{(\delta c_n b - b\delta - 2\delta c_n + 2c_r)^2 \begin{bmatrix} 16\delta - 32 - 32b\delta - 9\delta^2 + 15b\delta^2 \\ -7b^2\delta^2 + 32b + 8b^2\delta + b^3\delta^2 \end{bmatrix}}{8\delta(4b - 4 + 4\delta - 4b\delta + b^2\delta)(8 - 3\delta + b\delta)^2}.$$

Based on the above function, we find that for any $\underline{c}_r < c_r < \bar{c}_r$, $0 < b < 1$, and $0 < \delta < 1$, the function of $\pi_r^O - \pi_r^A > 0$ is always held. That is, as Proposition 2 shows, the equilibrium profit of the TPR is higher in Model O than in Model A, that is, $\pi_r^O > \pi_r^A$. □

Appendix C

Proof for Proposition 3. Based on the outcomes in Lemmas 1 and 2, we now solve $\pi_m^O - \pi_m^A$. After simplification, we can establish that

$$\pi_m^O - \pi_m^A = \frac{(\delta c_n b - b\delta - 2\delta c_n + 2c_r)^2 (13\delta + 3b^2\delta - 12b\delta - 8 + 8b)}{16\delta(4 - 4b - 4\delta + 4b\delta - b^2\delta)(8 - 3\delta + b\delta)}.$$

Based on the above function, we find that, for any $\underline{c}_r < c_r < \bar{c}_r$ and $0 < \delta < 1$, there is a threshold of $b_\Delta = \frac{12\delta - 8 + 2\sqrt{16 - 3\delta^2 - 24\delta}}{6\delta}$, above which $\pi_m^O - \pi_m^A > 0$ is always held. Otherwise, the opposite is true. Then, as Proposition 3 shows, there is a threshold of b_Δ, above which the OEM benefits more in Model O, that is, $\pi_m^O > \pi_m^A$; otherwise, the opposite holds true. □

Appendix D

Proof for Proposition 4. Remanufacturing yields sustainable benefits because it can divert materials from landfills [3]. Thus, as in [3,10], we calculate the environmental impacts from a resource-wasting perspective. That is, we focus on the environmental impacts caused by waste disposal and let e denote the per-unit impact due to the disposal at the end of use. Then, based on the outcomes in Lemmas 1 and 2, we can establish that $E^O = e(q_n^O - q_r^O) = \frac{e(b-1)\left[\begin{array}{c} -b^2\delta^2 + b^2\delta^2 c_n + 10\delta c_n b + 6b\delta^2 - 4\delta^2 c_n b - 10b\delta \\ -2\delta c_r b + 8\delta + 4\delta^2 c_n - 8\delta^2 - 12\delta c_n + 4\delta c_r + 4c_r \end{array}\right]}{4\delta(4b-4+4\delta-4b\delta+b^2\delta)}$ and $E^A = e(q_n^A - q_r^A) = \frac{e\left[\begin{array}{c} 3b\delta^2 - 3\delta^2 + \delta^2 c_n - \delta^2 c_n b + 2\delta c_r + 4c_r \\ -2\delta c_r b - 12\delta c_n + 10\delta c_n b + 8\delta - 10b\delta \end{array}\right]}{2\delta(8-3\delta+b\delta)}$. We now solve $E^O - E^A$. After simplification, we can establish that

$$E^O - E^A = \frac{e(\delta c_n b - 2\delta c_n - b\delta + 2c_r)(5b\delta - 2\delta - 4b^2\delta + 2 + b^3\delta + 2b^2)}{4(4 - 4b - 4\delta + 4b\delta - b^2\delta)(8 - 3\delta + b\delta)}.$$

Based on the above function, we find that for any $\underline{c}_r < c_r < \bar{c}_r$, $0 < b < 1$, and $0 < \delta < 1$, the function of $E^O - E^A < 0$ is always held. That is, as Proposition 4 shows, the environmental impact of Model O is always lower than that of Model A, i.e., $E^O < E^A$. □

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