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DO ONLINE REVIEWS ALWAYS INCENTIVISE REMANUFACTURERS TO IMPROVE QUALITY IN A COMPETITIVE ENVIRONMENT?

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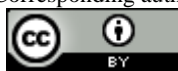
Abstract

Consumers' underestimation of the quality of remanufactured products is a barrier for remanufacturers. Online reviews provide quality signals to consumers unaware of remanufactured products. To explore whether remanufacturers produce higher quality products to improve their review ratings, considering the quality signalling effect of online reviews, a closed-loop supply chain model of the original equipment manufacturer (OEM) and independent remanufacturer (IR) was developed. The IR's two strategies, with and without online reviews, were compared to analyse the quality signalling effect of online reviews on the IR's production, pricing, and quality decisions. The results show that when the IR chooses full remanufacturing, online reviews have a quality-enhancing effect on the remanufactured product if the variable investment coefficient of the quality improvement effort is low. However, if an IR chooses partial remanufacturing, then online reviews do not have a quality-enhancing effect on the remanufactured product. In addition, if the impact of online reviews on consumers' willingness to pay for remanufactured products is negative, then the IR does not improve quality. The conclusions obtained from this study provide managerial implications for selecting quality strategies and implementing operational decisions for remanufacturers entering the e-commerce channel.

Keywords: Online reviews; remanufacturing; quality; quality signalling effect; game theory; closed-loop supply chain

JEL Classification: C70, D21, D24, D40, L11

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Introduction

Because of the green characteristics of remanufactured products, these products are attracting the interest of policymakers who need to reduce carbon emissions (Choi, Taleizadeh and Yue, 2020). The main obstacle to remanufactured products is consumer distrust of their quality (Khor and Hazen, 2017; Niu, Xu and Chen, 2022; Zhang, Gong and Hong, 2022). Online reviews can signal the quality of remanufactured products to potential consumers, thereby eliminating consumers' underestimation of the quality of remanufactured products. Crawler software was used to identify 1,488 online reviews of remanufactured products on the Chinese e-commerce platforms Jingdong and Taobao. Figure 1(a) verifies that the online reviews of remanufactured products can convey the quality signalling effect of remanufactured products. The largest word on the word cloud map represents the most frequent occurrences in the online reviews analysed in this study. A total of 89.5% of the reviews are from remanufactured printers. It is clear that consumers are most concerned with the core function of remanufactured printers-printing. Thus, the online reviews of remanufactured products convey to potential consumers the quality of those products. Furthermore, there are more positive words for remanufactured products in Figure 1(a), such as "good" and "fast". Thus, online reviews of remanufactured products can increase consumers' positive perceptions of remanufactured products. Entering the e-commerce channel and introducing online reviews are opportunities for IRs to promote those remanufactured products of which consumers lack awareness. According to Yorien de Ruijter, project manager of Reon International Exhibitions, who spoke at Rematec Asia, a growing number of remanufacturers in Europe are selling remanufactured products through e-commerce platforms, including Google, Facebook, and Amazon. Similarly, Chinese remanufacturers sell remanufactured products, such as printers and engines, on e-commerce platforms Jingdong Mall and Taobao.



Figure no. 1. Word cloud graph of the online reviews of remanufactured products

Since remanufacturers need to apply for remanufacturing licences, remanufactured products need to meet minimum quality standards (Chen, Wang and Jia, 2020; Ebrahimi Bajgani, Saberi and Toyasaki, 2023). However, remanufactured products that meet a minimum level of quality still receive negative reviews. For example, there are 96 negative reviews in 1,488 of the online reviews of remanufactured products sold on Chinese e-commerce platforms. As shown in Figure 1(b), a word cloud diagram of the negative reviews reveals that the core function – printing – is still reflected. At the same time, words such as “no”, “can’t”, and

“problem” show the dissatisfaction of consumers who gave negative reviews about the quality of remanufactured products. Thus, even if remanufactured products meet minimum quality requirements, some consumers may still be dissatisfied. Online reviews from dissatisfied consumers are detrimental to the sales of remanufactured products (Van Nguyen et al., 2020). Hence, in the online channel, remanufacturers have the incentive to offer products above a minimum level of quality to increase the number of positive reviews and reduce the number of negative reviews (Jiang and Yang, 2019). A larger number of positive reviews can contribute to an increase in the quality signalling effect of online reviews and consumers' willingness to purchase remanufactured products (Krivokapic, 2023; Zhang, Gong and Hong, 2022). However, improving the quality of remanufactured products can increase costs (Örsdemir, Kemahlioğlu-Ziya and Parlaktürk, 2014). Therefore, how remanufacturers choose between high- and low-quality strategies is a question worth exploring, taking into account the cost of quality enhancement and the quality signalling effect of online reviews. In addition, remanufacturers are divided into independent remanufacturers (IRs) and original equipment manufacturers (OEMs) engaged in remanufacturing. OEMs engaged in remanufacturing do not pay much attention to the sales of remanufactured products due to the fear of new products being cannibalised by remanufactured products (Zhang et al., 2021). Moreover, when searching for remanufactured products on websites such as Jingdong, Taobao, eBay and Amazon, it is found that the e-commerce-enabled remanufacturers are all IRs, and the remanufactured products produced by OEMs are more likely to be sold offline than online. For example, BMW sells its remanufactured parts in its shops. Therefore, a comparative discussion on the operational decision of whether or not an IR should introduce online reviews is relevant.

Consumers underestimate the actual quality of remanufactured products, and online reviews can help consumers become more aware of the actual quality of such products (Zhai, Wang and Zhao, 2024). Therefore, an IR has the incentive to introduce online reviews to influence consumer perceptions of the quality of its remanufactured products, which in turn promotes the sales of remanufactured products (Van Nguyen et al., 2020). On the one hand, the actual quality of remanufactured products is affected by the quality costs and efficiency of the IR (Yanikoğlu and Denizel, 2021). On the other hand, the actual quality of remanufactured products affects the online reviews given by reviewers, which in turn also affects the quality signals conveyed by online reviews to potential consumers (Van Nguyen et al., 2020; Zhai, Wang and Zhao, 2024; Shin, Vaccari and Zeevi, 2023). Therefore, an IR has the incentive to change its quality strategies to influence the online reviews given by reviewers, which in turn changes the quality messages conveyed by online reviews to potential consumers (Geng, Guo and Xiao, 2022; Ji et al., 2024). Changes in the quality signals conveyed by online reviews to potential consumers further affect consumers' purchase intentions for remanufactured products, which in turn affect IRs' production and pricing strategies (Qiao and Su, 2021). In monopoly markets, many studies investigated the impact of online reviews on quality decisions in terms of the different impacts of online reviews on product perceptions (Godes, 2017), pricing strategies (He and Chen, 2018; Feng, Li and Zhang, 2019), consumer quality exaggeration behaviours (Wang et al., 2019), and firm efficiency (Jiang and Yang, 2019; Zhou, Liu and Luo, 2022). In competitive markets, existing studies on the impact of online reviews on quality decisions focused on the different effects of online reviews on consumer perceptions (Kwark, Chen and Raghunathan, 2018; Lu et al., 2021; Geng, Guo and Xiao, 2022), the restrictive review strategies of platform sellers (Li et al., 2021), and the timing of software releases by competing software vendors (Wang et al., 2020). Nevertheless, the

literature did not examine the impact of online reviews on the quality decisions of remanufactured products from the perspective of competition between the OEM and the IR. In addition, Yan and Han (2021), Qiao and Su (2021), and Han and Yan (2022) studied the impact of online reviews of new products on remanufacturers' operational decisions. However, the impacts of the online reviews of remanufactured products on remanufacturers' quality and operational decisions remain unknown. On the one hand, based on quality signal theory, online reviews convey quality signals of remanufactured products to consumers (Jiang and Yang, 2019; Tong and Xiao, 2024). Consumers change their purchasing decisions based on the quality signals transmitted by online reviews, which, in turn, affects the production of remanufactured products. On the other hand, IRs endogenously change the quality decisions of remanufactured products because they are aware of the impact of quality signals on the production of remanufactured products (Kwark, Chen and Raghunathan, 2018; Geng, Guo and Xiao, 2022). Based on the research gap, it is necessary to explore the impact of online reviews on IR's quality decisions, the main objective of this study is to provide guidance to IRs in their decision-making on whether to enter the e-commerce channel or not, quality and operational decisions. Specifically, this study focusses on the following questions: (1) Under which conditions do online reviews enable the IR to improve the quality of remanufactured products? How do online reviews affect the size of high-quality zones? (2) How does the quality signalling effect of online reviews affect the production, price, and market entrance decisions of the IR? (3) If online reviews negatively affect the consumer utility of remanufactured products, then how do the quality decisions of the IR change?

The novel contributions of this study are as follows. First, this study is the first to consider the impact of the online reviews of remanufactured products on the quality decisions of these products under the competitive markets of the OEM and the IR, extending the previous literature on the impact of online reviews on manufacturers' quality decisions. Previous studies did not focus on remanufacturers that are limited by the amount of recyclable products they can produce. Although a small body of literature considered the impact of online reviews on manufacturers' quality decisions in a competitive market, none of the literature considered the impact of online reviews on the quality decisions of remanufactured products in a competitive market for new and remanufactured products. Second, this study expands the theoretical research on the e-commerce of remanufacturers by analysing the impact of the online reviews on remanufacturers' quality and operational decisions. The previous literature was based on the impact of the online reviews of new products on the operational decisions of remanufacturers, without considering the e-commercialisation of remanufacturers. This paper provides theoretical support for the e-commerce of remanufacturers by considering the impact of the online reviews of remanufactured products on remanufacturers' quality and operational decisions.

The remainder of this study is organised as follows. Section 2 reviews the related literature. Section 3 provides the model descriptions and the optimal solutions under both models without and with online reviews. Section 4 compares the base model and the online review model and examines changes in quality and operational decisions when online reviews negatively influence consumers' purchase intentions. Section 5 discusses the results of the model. Section 6 provides the conclusions and future research directions.

1. Literature review

Consumers' underestimation of the quality of remanufactured products is a challenge for remanufacturers. Online reviews not only help remanufacturers convey quality signals for their products, but also impact remanufacturers' quality decisions. Our study draws on the following two streams of literature: (1) the impact of online reviews on manufacturers' quality decisions and (2) the impact of online reviews on remanufacturers' operational decisions.

1.1 Impact of online reviews on manufacturers' quality decisions

As online reviews have a social interaction effect, they can help consumers learn information about product quality (Kwark, Chen and Raghunathan, 2014; Crapis et al., 2017; Feldman, Papanastasiou and Segev, 2019; Aköz, Arbatli and Celik, 2020; Shin, Vaccari and Zeevi, 2023) and in turn lead to changes in manufacturers' quality decisions (Zhao and Zhang, 2019; Wang et al., 2019; Geng, Guo and Xiao, 2022; Ji et al., 2024). In a monopolistic market, scholars investigated the impact of online reviews on quality decisions in terms of expanded awareness and familiarity effects (Godes, 2017) and on company efficiency and consumer perceptions of efficiency (Jiang and Yang, 2019). However, the impact of online reviews on quality decisions in a competitive environment was less well studied. Wang et al. (2020) studied the competitive strategies of two competing software vendors considering quality and found that they prefer early release when the quality of the software is low. Kwark, Chen and Raghunathan (2018) investigated the impact of the precision-improving and correlation-increasing effects of user-generated content on the quality decisions of competing manufacturers before product launch. Li et al. (2021) constructed a competitive market for two products containing the same brand under a model that includes a manufacturer and a platform seller and found that to prevent the platform seller from restricting the online reviews of an existing product, the manufacturer should reduce the quality of the newly launched product. Our study is similar to that of Li et al. (2021), with the difference being that this study extends the literature on online reviews and quality decisions to a closed-loop supply chain, examining the quality decisions of remanufacturers in a competitive environment of new and remanufactured products.

1.2 Remanufacturing

The literature on remanufacturing is abundant, and the lack of consumer awareness of remanufactured products has become common knowledge (Yang, Wang and Ang, 2021). Scholars considered promoting the awareness of remanufactured products in terms of blockchain (Niu, Xu and Chen, 2022), consumer education (Zhou, Xiong and Jin, 2021; Abdulla et al., 2024), warranties (Kerber, Fettermann and Bouzon, 2024), consumer preferences (Reimann, Xiong and Zhou, 2019), environmentally responsible consumers (Sheu and Choi, 2019; Wen, Xiao and Dastani, 2021), and seeding strategies (Abbey, Geismar, and Souza, 2019). With the emergence of the e-commerce trend in the remanufacturing industry (Jakowczyk et al., 2017), the impact of the quality signalling of online reviews on remanufacturers attracted increased attention. Van Nguyen et al. (2020) and Zhai, Wang and Zhao (2024) examined the factors affecting the demand for remanufactured products and found that online reviews have a positive impact on sales and that negative reviews have a more significant negative impact on sales than positive reviews. Three studies examined online reviews and the operations of remanufacturers. Yan and Han (2021) examined the entry of remanufacturers in the presence of reviews. Qiao and Su (2021) developed a two-stage game model to address the choice of distribution channel for remanufacturers. Han and

Yan (2021) examined the impact of online reviews on the entry and carbon emission reduction approaches of remanufacturers. The main difference between this study and previous studies is that this study explores the impact of online reviews on the quality strategies of remanufactured products.

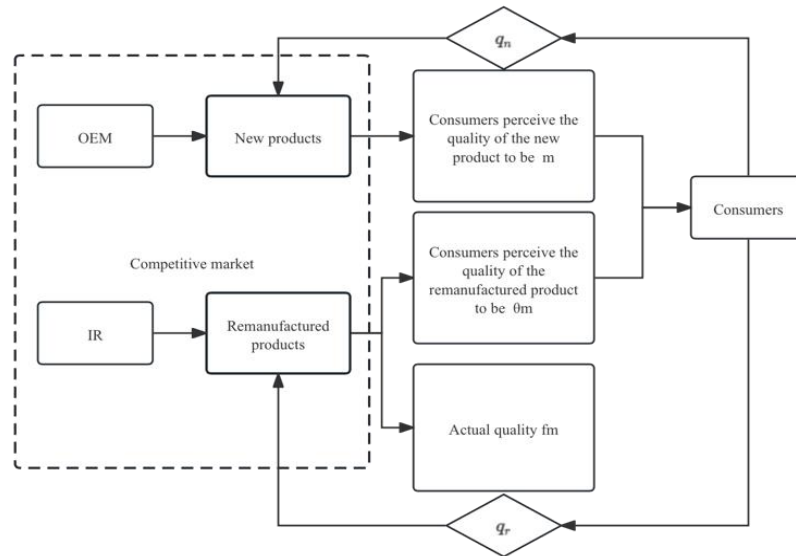
1.3 Research gaps

In summary, the number of studies on the effect of online reviews on manufacturers' quality strategy was large; however, studies on the effect of online reviews on remanufacturers' quality and operation strategies were rare. The contributions of this study are as follows. First, there were few studies on the effects of online reviews on product quality decisions in competitive markets, and the literature did not discuss closed-loop supply chains and remanufacturers. This study extends the study of the effect of online reviews on manufacturers' quality decisions from the perspective of competition between new and remanufactured products. Second, studies on the impact of online reviews on the operational decisions of remanufacturers were carried out from the perspective of the online reviews of new products, while the impact of online reviews due to the e-commerce of remanufactured products was ignored. Furthermore, the literature on the effects of online reviews on remanufacturers' operational strategies considered only channel selection and market entry strategies, while quality strategies were less explored. This study explores the impact of the online reviews of remanufactured products on the quality decisions of the IR and complements those studies on the impact of online reviews on the operational decisions of the IR.

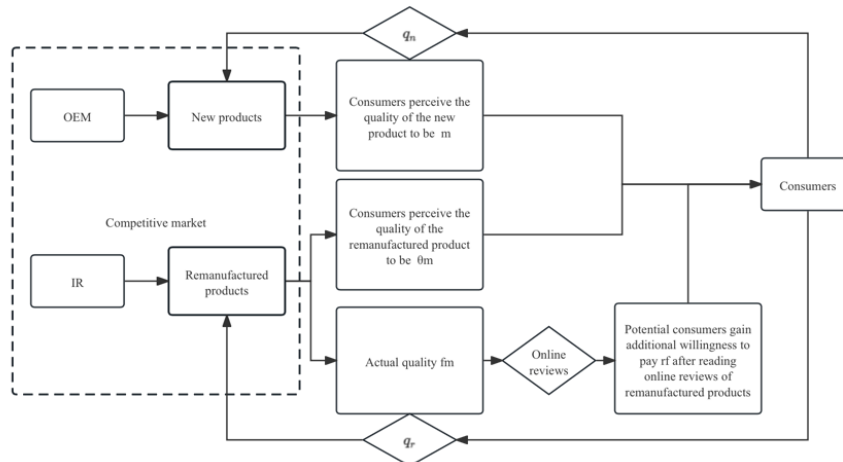
2. Modelling

2.1 Model descriptions and notations

The impact of online reviews on remanufactured products in a closed supply chain that includes an OEM and an IR was explored. The former produces and sells new products, and the latter collects used products to produce and sells the remanufactured products (Ray et al., 2021). As shown in Figure 2, since consumers tend to underestimate the actual quality of remanufactured products, based on social learning theory (Feldman, Papanastasiou and Segev, 2019; Li, Du and Wei, 2023), when the IR introduces online reviews, these online reviews influence consumers' perceptions of the quality of remanufactured products (Zhai, Wang and Zhao, 2024). Furthermore, based on quality signalling theory (Jiang and Yang, 2019; Tong and Xiao, 2024), since the IR realises that online reviews can convey the quality signals of remanufactured products, the IR has the incentive to endogenously change consumers' quality decisions and thus change the quality signals conveyed to consumers by online reviews (Kwark, Chen and Raghunathan, 2018; Li et al., 2021). Furthermore, changes in the quality signals conveyed to consumers by online reviews can affect potential consumers' willingness to pay for remanufactured products, which can change the operational decisions of the IR (Qiao and Su, 2021).



(a) Model B



(b) Model O

Figure no. 2. Model construction

With and without online reviews. The IR can decide whether or not to introduce online reviews based on whether or not they enter the online channel. Since this study focusses on the quality signalling effect of online reviews on IR quality decisions, it does not consider the impact of factors other than online reviews on IR under different channels. To investigate the impact of online reviews on remanufactured products, as shown in Figure 2, two models were proposed. The first is Model B, where the IR sells the remanufactured products through retail channels; therefore, potential consumers do not have access to the quality evaluations of consumers who have already used remanufactured products. The second model is Model O, where the IR sells the product through an online channel and receives online reviews; the

online reviews of remanufactured products have a quality signalling effect on potential consumers (Zhai, Wang and Zhao, 2024).

Consumer utility without online reviews. According to Chen et al. (2020), the quality of a new product is m , and consumers trust this quality information. Although the quality of remanufactured products is theoretically equal to that of new products, consumers do not believe this to be true (Zhou, Xiong and Jin, 2021). Due to consumers' distrust of remanufactured products (Kleber et al., 2018; Zhou, Xiong and Jin, 2021), consumers perceive the quality of remanufactured products to be θm , where θ denotes consumer trust in remanufactured products, and $0 < \theta < 1$ (Agrawal, Atasu and Van Ittersum, 2015; Kleber, Quariguasi Frota Neto and Reimann, 2020; Mazahir et al., 2019). Consumers' willingness to pay for a product of unit quality is v , and thus, consumers obtain utility mv for a new product and θmv for a remanufactured product (Zhao et al., 2021).

Quality decisions of the IR. The IR influences the actual quality of remanufactured products through factors such as the degree of reprocessing, recycled raw materials, and the stringency of quality control (Rizova, Wong and Ijomah, 2020; Örsdemir, Kemahlioğlu-Ziya and Parlaktürk, 2014). The decision variable f represents the quality effort of the IR. The actual quality of the remanufactured product is fm . Quality effort f affects the quality of remanufactured products fm , which in turn affects the quality signal conveyed by online reviews (Godes, 2017; Joshi and Musalem, 2021). A higher f value leads to a greater quality cost for the IR, which is required to establish quality standards and production specifications for remanufactured products (Abbey et al., 2015); thus, it is assumed that the quality threshold for remanufactured products is m_0 . As such, $m_0 \leq fm$ holds.

Impact of online reviews on consumer utility. Online reviews increase consumers' awareness of remanufactured products (Kwark, Chen and Raghunathan, 2014; Wang et al., 2019). After reading online reviews, it is assumed that potential consumers obtain information about quality efforts f . Similar to Qiao and Su (2021), consumers gain additional willingness to pay rf after reading online reviews. r represents the effect of quality signalling conveyed by online reviews on consumers' willingness to pay for remanufactured products, where $-1 < r < 1$ (Jiang and Yang, 2019; Qiao and Su, 2021). The higher r is, the more consumers can be persuaded by the quality signalling reflected in online reviews. When r is greater than 0, consumers can increase their willingness to pay for remanufactured products after reading online reviews. If r is less than 0, then consumers are less willing to pay for remanufactured products after reading online reviews. The decrease in consumers' willingness to pay is due to the fact that positive and negative reviews together affect consumers' willingness to pay after they read online reviews, and the negative impact of negative reviews on consumers is much greater than is the positive impact of positive reviews; therefore, a high percentage of negative reviews decreases consumers' willingness to pay for remanufactured products after they read online reviews. Figure 3 represents how the quality information disseminated by online reviews affects consumer utility and purchase decisions. First, the IR chooses whether or not to enter the online channel. If the IR does not enter the online channel, then the remanufactured product does not have online reviews given by previous consumers, and potential consumers do not have access to the quality signalling of the remanufactured product. If the IR enters the e-commerce channel, then potential consumers can obtain the quality signals of the remanufactured product through online reviews. Then, the IR considers the quality signalling effect of online reviews and determines the quality of the remanufactured product. Third, consumers who purchase remanufactured products through

online channels form reviews to transmit quality signals. Fourth, potential consumers read the reviews and choose to increase their purchase intentions for the remanufactured product and decide whether to purchase new or remanufactured products.

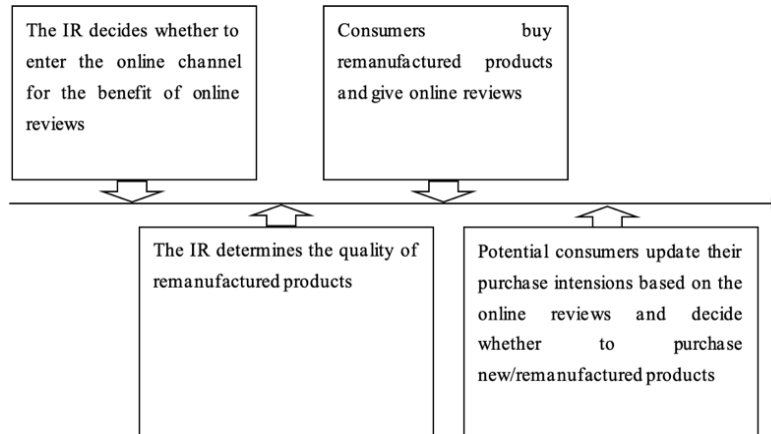


Figure no. 3. Impact of online reviews on consumer purchase decisions

Quality improvement and production costs. The cost of quality improvement $kfq_r + \frac{1}{2}lf^2$ is divided into variable and constant costs (Godes, 2017). The variable cost kfq_r is related to the production quantity of the remanufactured product (Wang et al., 2019), and the fixed cost $\frac{1}{2}lf^2$ is not associated with the output (Yoo and Cheong, 2018). It is assumed that the production costs of new and remanufactured products are Δ and 0, respectively (Han and Yan, 2021); this setting is intended to simplify the model and highlight the cost of quality.

Consumer and demand functions. In Model B, similar to Zhou, Xiong and Jin (2021), consumers make the following three decisions: buy new products, buy remanufactured products, and buy nothing. Consumers' utility from purchasing a new product is given by $u_n = mv - p_n^{Bj}$. In addition, consumers gain utility $u_r = \theta mv - p_r^{Bj}$ by purchasing a remanufactured product. The utility of the consumer purchasing nothing is 0. When consumers have the same utility in purchasing new products and purchasing remanufactured products, $mv - p_n^{Bj} = \theta mv - p_r^{Bj}$; then, $v_{nr} = \frac{p_n^{Bj} - p_r^{Bj}}{(1-\theta)m}$. When the consumer's utility from purchasing a remanufactured product is the same as that from not purchasing any product at all, $\theta mv - p_r^{Bj} = 0$; then, $v_{nr} = \frac{p_r^{Bj}}{\theta m}$. Similar to Alegoz, Kaya and Bayindir (2021), it is assumed that the market volume is 1. Based on the above derivation, the demand functions for new and remanufactured products are obtained as $q_n^{Bj} = 1 - \frac{p_n^{Bj} - p_r^{Bj}}{(1-\theta)m}$ and

$q_r^{Bj} = \frac{p_n^{Bj} - p_r^{Bj}}{(1-\theta)m} - \frac{p_r^{Bj}}{\theta m}$, respectively. The inverse demand functions are $p_n^{Bj} = \theta m(1 - q_n^{Bj} - q_r^{Bj})$ and $p_r^{Bj} = m(1 - q_n^{Bj} - \theta q_r^{Bj})$. In Model O, when consumers buy remanufactured products via the online channel and learn quality information from online reviews, consumers' utility is $u_r = \theta m v + r f^{Oj} - p_r^{Oj}$. Similarly, the inverse demand functions for new and remanufactured products are obtained as $p_n^{Oj} = m(1 - q_n^{Oj} - \theta q_r^{Oj})$ and $p_r^{Oj} = m\theta(1 - q_n^{Oj} - q_r^{Oj}) + r f^{Oj}$, respectively.

The symbols and their explanations are listed in Table 1.

Table no. 1. Summary of variables

Decision variables	Description
$\pi_{OEM}^{ij} / \pi_{IR}^{ij}$	Profit of the OEM/IR, where $i=B, O$ represent the base and online review models, respectively; $j=1, 2, 3, 4$ represent the four scenarios of no remanufacturing, partial remanufacturing and low-quality level, full remanufacturing and low-quality level, and full remanufacturing and high-quality level
p_n^{ij} / p_r^{ij}	Price of new/remanufactured products
q_n^{ij} / q_r^{ij}	Production of new/remanufactured products
f^{ij}	Efforts to improve the quality of remanufactured products
Parameters	Description
$m / \theta m$	Consumers' perceptions of the quality of new/remanufactured products before reading online reviews, $0 < \theta < 1$
v	Consumers' willingness to pay for a unit of product quality
Δ / O	Production cost of new/remanufactured products
l	Fixed investment coefficient of the quality improvement effort
k	Variable investment coefficient of the quality improvement effort
m_0	Quality thresholds of remanufactured products
r	Influence coefficients of online reviews on the perceived quality of remanufactured products, $-1 < r < 1$

2.2 Model B

In Model B, the IR does not enter the online channel, and potential consumers cannot receive quality signals of the remanufactured product from online reviews. The quality of remanufactured products must be higher than the quality threshold. As remanufactured products require recycled products as raw materials, the output of remanufactured products is less than that of new products (Zhou, Xiong and Jin, 2021). The profit function and constraints are as follows:

$$\max \pi_{OEM}^{Bj} (q_n^{Bj}) = (p_n^{Bj} - \Delta) q_n^{Bj}, \quad (1)$$

$$\max \pi_{IR}^B(q_r^{Bj}, f^{Bj}) = (p_r^{Bj} - kf^{Bj})q_r^{Bj} - \frac{1}{2}lf^{Bj2}, \quad (2)$$

$$s.t. q_n^{Bj} \geq q_r^{Bj} > 0, \quad (3)$$

$$s.t. f^{Bj}m \geq m_0. \quad (4)$$

Based on the above equations, the equilibrium solutions in Proposition 1 were derived. The proof is given in the Appendix. The OEM and IR jointly determine the quality of the remanufactured products and the production of new and remanufactured products.

Proposition 1. The optimal solutions of the OEM and IR are as follows:

- (i) No remanufacturing. When $k_2 < k < \sqrt{2lm\theta}$, $q_n^{B1} = \frac{m-\Delta}{2m}$, and $q_r^{B1} = 0$.
- (ii) Partial remanufacturing and low-quality level. When $k_1 < k < k_2$, $f^{B2} = \frac{m_0}{m}$, $q_n^{B2} = \frac{-km_0 + 2m\Delta + m^2(-2+\theta)}{m^2(-4+\theta)}$, and $q_r^{B2} = \frac{2km_0 - m(m+\Delta)\theta}{m^2(-4+\theta)\theta}$.
- (iii) Full remanufacturing and low-quality level. When $0 < k < k_1$, $f^{B3} = \frac{m_0}{m}$, and $q_r^{B3} = q_n^{B3} = \frac{m-\Delta}{m(2+\theta)}$,
 where $k_1 = \frac{m(3\Delta + m(-1+\theta))\theta}{m_0(2+\theta)}$, and $k_2 = \frac{m(m+\Delta)\theta}{2m_0}$.

There are the following three equilibrium solutions for the IR: no remanufacturing, partial remanufacturing and low-quality, and full remanufacturing and low-quality solutions. The equilibrium solutions in the partial remanufacturing and high-quality scenario and full remanufacturing and high-quality scenario were discarded, as shown in the Appendix.

The IR does not have an incentive to improve the quality of remanufactured products. Due to the absence of online reviews, actual quality does not influence potential consumers' willingness to pay for remanufactured products. In addition, as the variable investment coefficient of the quality improvement effort k decreases, the IR is more likely to enter the remanufacturing market and recover all recyclable products for remanufacturing.

2.3 Model O

In Model O, the IR sells the remanufactured product in the online channel, and online reviews are generated by consumers who have purchased remanufactured products. As such, the quality signal of the remanufactured product is available to potential consumers. Therefore, the profit functions of the members of the closed-loop supply chain are as follows:

$$\max p_{OEM}^{Oj}(q_n^{Oj}) = (p_n^{Oj} - D)q_n^{Oj}, \quad (5)$$

$$p_{IR}^{Oj}(q_r^{Oj}, f^{Oj}) = (p_r^{Oj} - kf^{Oj})q_r^{Oj} - \frac{1}{2}l(f^{Oj})^2, \quad (6)$$

$$s.t. q_n^{Oj} \geq q_r^{Oj} > 0, \quad (7)$$

$$s.t. f^{Oj}m \geq m_0 \quad (8)$$

Similar to 4.1, Proposition 2 was obtained.

Proposition 2. The optimal solutions are as follows:

- (i) No remanufacturing. When $k_2 + r < k < r + \sqrt{2lm\theta}$, $q_n^{O1} = \frac{m-\Delta}{2m}$, $q_r^{O1} = 0$.
- (ii) Partial remanufacturing and low-quality level. When $k_1 + r < k < k_2 + r$, $q_n^{O2} = \frac{km_0 + m^2(2-\theta) - 2m\Delta - m_0r}{m^2(4-\theta)}$, $q_r^{O2} = \frac{-2km_0 + m^2\theta + m\Delta\theta + 2m_0r}{m^2(4-\theta)\theta}$, and $f^{O2} = \frac{m_0}{m}$.
- (iii) Full remanufacturing and low-quality level. When $k_3 < k < k_1 + r$, $q_n^{O3} = q_r^{O3} = \frac{m-\Delta}{2m+m\theta}$, and $f^{O3} = \frac{m_0}{m}$.
- (iv) Full remanufacturing and high-quality level. When $0 < k < k_3$, $q_n^{O4} = q_r^{O4} = \frac{m-\Delta}{2m+m\theta}$, and $f^{O4} = \frac{(m-\Delta)(r-k)}{lm(2+\theta)}$,

$$\text{where } k_3 = r - \frac{lm_0(2+\theta)}{m-\Delta}.$$

Lemma 1. In Model O, when $0 < k < k_3$, the IR produces high-quality remanufactured products. When $k_3 < k < k_2 + r$, the IR chooses the low-quality strategy.

In Model O, that is, when online reviews provide the quality signal of the remanufactured product, the IR tends to improve the quality of the remanufactured product when the variable investment coefficient of the quality improvement effort k is low. A lower k value means that the quality enhancement techniques used are more efficient and can enhance quality at a lower cost.

In addition, the result shows that only in the full remanufacturing scenario does the IR choose a high-quality strategy. In the partial remanufacturing scenario, the IR chooses only the low-quality strategy. This finding suggests that the quality-enhancing effect of online reviews can be realised if the production level of remanufactured products is maximised. In the partial remanufacturing scenario, k is higher and the quality cost to achieve the minimum quality level is higher. If the IR further improves quality, then the high cost per unit of the remanufactured product increases the price of the remanufactured product and reduces the demand for the remanufactured product, thus weakening the competitive advantage of the IR. Therefore, the IR does not improve quality in the partial remanufacturing scenario.

Lemma 2. (i) $\frac{\partial p_r^{02}}{\partial r}, \frac{\partial p_r^{03}}{\partial r}, \frac{\partial p_r^{04}}{\partial r} > 0, \frac{\partial p_n^{02}}{\partial r} < 0, \frac{\partial p_n^{03}}{\partial r}, \frac{\partial p_n^{04}}{\partial r} = 0$. (ii) $\frac{\partial f^{02}}{\partial r}, \frac{\partial f^{03}}{\partial r} = 0$.
 $\frac{\partial f^{04}}{\partial r} > 0$. (iii) $\frac{\partial q_r^{02}}{\partial r} > 0, \frac{\partial q_n^{02}}{\partial r} < 0, \frac{\partial q_n^{03}}{\partial r}, \frac{\partial q_n^{04}}{\partial r}, \frac{\partial q_r^{03}}{\partial r}, \frac{\partial q_r^{04}}{\partial r} = 0$. (iv)
 $\frac{\partial \pi_{IR}^{02}}{\partial r}, \frac{\partial \pi_{IR}^{03}}{\partial r}, \frac{\partial \pi_{IR}^{04}}{\partial r} > 0$.

r represents the impact of online reviews on potential consumers' willingness to pay for remanufactured products. The price difference between new and remanufactured products decreases as r increases. In the partial remanufacturing scenario, an increase in r makes remanufactured products more substitutable for the new product, thus increasing the demand for remanufactured products. However, in the full remanufacturing scenario, an increase in r does not affect the demand for remanufactured products but favours the quality of remanufactured products. In summary, the effect of increasing r on price, output, and quality results in a more competitive position for remanufactured products, and thus, it is beneficial for the IR to increase r .

3. Comparison of the two models

In this section, the production quantity, quality, price and profits of the IR in Models B and O were compared. The optimal conditions for the IR to introduce online reviews and the impact of online reviews on price and output were obtained. In addition, the effects of the investment coefficient of the quality improvement effort and online reviews on the thresholds of the IR's production and quality decision intervals were analysed. Figure 4 compares the intervals of the different decisions of the IR under Models B and O.

Full and low (iii)	Partial and low (ii)	No (i)	
0	k_1	k_2	Model B
Full and high (iv)	Full and low (iii)	Partial and low (ii)	No (i)
0	k_3	$k_1 + r$	$k_2 + r$
			Model O

Figure no. 4. Different remanufacturing scenarios for Models B and O

Proposition 3. Compared to a retail channel without online reviews, as the IR enters the online channel and obtains online reviews, (i) the production quantity of the remanufactured products remains the same, and the quality increases if $0 < k < k_3$; (ii) the production quantity and quality of the remanufactured products are unchanged if $k_3 < k < k_1$; and (iii) the production quantity of the remanufactured products increases, and the quality remains the same if $k_1 < k < k_2$.

To visualise the impact of introducing online reviews on the production and quality of remanufactured products, Figure 5 is presented, and the notations are set as follows: $\theta = 0.3, m = 1, m_0 = 0.9, \Delta = 0.3, r = 0.02, l = 0.001$. When the variable investment coefficient of the quality improvement effort k is relatively low, online reviews help the IR improve quality and achieve complete remanufacturing. The main reason for this is that when k is low,

the quality cost to achieve the quality threshold m_0 is low. Moreover, when k is small, the IR is more likely to improve quality to promote the formation of a larger number of positive reviews, and the effect of online reviews increases. For example, Hunan Zhijian Copier Remanufacturing Co., Ltd. sells remanufactured printers on Taobao.com and improves the quality of remanufactured products to increase its percentage of positive comments.

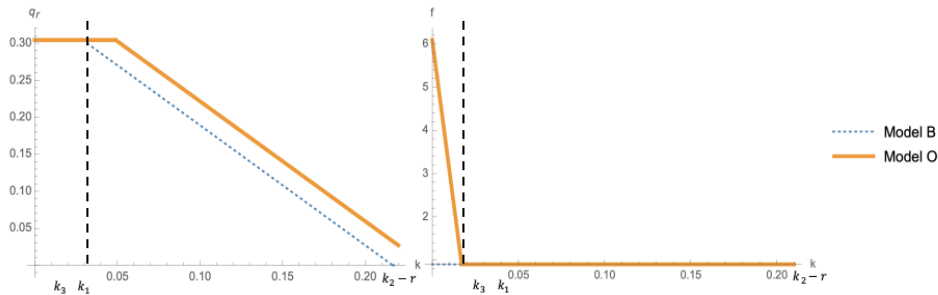


Figure no. 5. Production quantity and quality in Models B and O

Furthermore, online reviews have both a production enhancement effect and a quality enhancement effect on the IR, but production enhancement is prioritised over quality enhancement. When the recovery rate of remanufactured products is maximised, it is optimal for the IR to invest in low-marginal-cost technologies to improve quality. If the IR does not select the maximum recovery rate for partial remanufacturing, then improving quality is not a primary goal for the IR.

Proposition 4. Online reviews lead to higher prices for remanufactured products.

Online reviews can convey quality information about remanufactured products. Therefore, when potential consumers receive quality signals from online reviews, their level of uncertainty regarding the perceived quality of remanufactured products is reduced. Consumers' willingness to pay for remanufactured products increases, and thus, prices increase when the quality of such products is at a low level. In addition, if the IR improves quality to a level greater than the quality threshold m_0 , then the increase in quality costs and online review effects jointly increase the price of remanufactured products. This finding inspires the IR to increase its prices on online channels with online reviews, regardless of whether it increases the quality of remanufactured products.

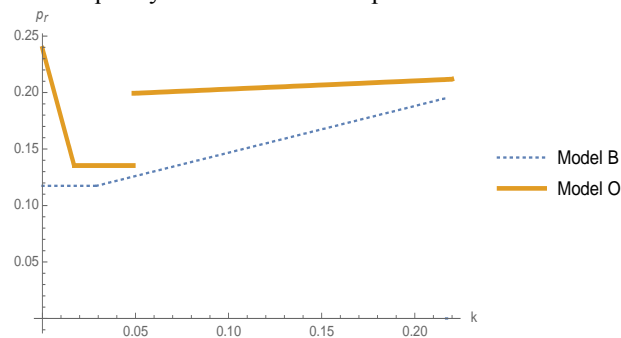


Figure no. 6. Price of the remanufactured products in Models B and O

To illustrate Proposition 4 clearly, Figure 6 was obtained, and the values are as follows: $q = 0.3, m = 1, m_0 = 0.9, D = 0.3, r = 0.02, l = 0.001$. If the IR chooses the full remanufacturing and high-quality scenario, then the pricing advantage becomes more pronounced, and the quality becomes higher as the value of the variable investment coefficient of the quality improvement effort k decreases. In the partial remanufacturing scenario, the increase in price due to online reviews is more pronounced as k decreases. In the full remanufacturing and low-quality scenario, the price increase from online reviews is smaller than those in the other scenarios. Thus, the prices of remanufactured products under a high-quality strategy are more sensitive to the low-quality strategy.

Proposition 5. (i) When $0 < k < k_3$, $\pi_{IR}^{O-4} > \pi_{IR}^{B-3}$.
 (ii) When $k_3 < k < k_1$, $\pi_{IR}^{O-3} > \pi_{IR}^{B-3}$.
 (iii) When $k_1 + r < k < k_2 + r$, $\pi_{IR}^{O-2} > \pi_{IR}^{B-2}$ and $\pi_{IR}^{O-2} > \pi_{IR}^{B-1}$.

The IR can benefit from the introduction of online reviews. Thus, the IR chooses the e-commerce channel to obtain online reviews. The reasons for this result are presented below. Online reviews encourage the IR to decide on a higher production quantity and price for the remanufactured product in the low-quality and partial remanufacturing scenario (Propositions 3 and 4). In addition, in the low-quality and full remanufacturing scenario, compared to Model B, the quality and quantity of the remanufactured products remain the same in Model O, while the price of the remanufactured products increases. If the IR chooses a high-quality strategy, then greater quality leads to an increase in the positive impact of online reviews. Hence, the remanufactured products become more attractive, and the price of remanufactured products increases. As such, the profit of the IR in Model O is greater than that in Model B.

To represent the comparison of the IR's profits in Models O and B clearly, Figure 7 is presented, and the values are as follows: $q = 0.3, m = 1, m_0 = 0.9, D = 0.3, r = 0.02, l = 0.001$.

A comparison of π_{IR}^{B-2} and π_{IR}^{O-3} , not covered in Proposition 5, was obtained. The conclusion in Figure 7 is similar to Proposition 5 in that online reviews can contribute to an increase in IR's profit. As the variable investment coefficient of the quality improvement effort k decreases, the improvement effect of online reviews on the profitability of the IR becomes more pronounced. Online reviews provide the most significant boost to profits when the remanufacturer chooses a high-quality strategy.

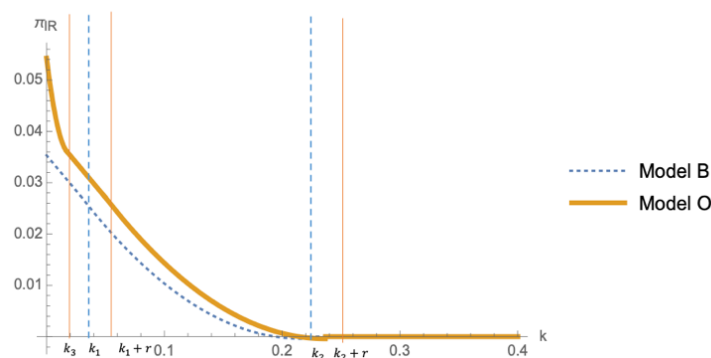


Figure no. 7. Profit of the IR in Models B and O

Proposition 6. (i) $\frac{\partial k_3}{\partial r} > 0$. (ii) $\frac{\partial k_3}{\partial l} < 0$.

Proposition 6 states that as the influence of online reviews on the perceived quality of remanufactured products r increases, the IR is more likely to produce high-quality remanufactured products. Thus, the IR should promote video-type reviews to increase the influence of online reviews on the perceived quality of remanufactured products (King, Racherla and Bush, 2014). A larger number of positive reviews encourage other consumers to comment and, thus, increase the credibility of online reviews in general (Moe and Schweidel, 2012).

In addition, the IR tends to implement a high-quality strategy if the fixed investment coefficient of the quality improvement effort l is high enough. Therefore, the IR prioritises quality enhancement techniques with higher fixed quality cost improvement factors.

Next, extended research on the optimal ORR decision of the IR when online reviews are detrimental to consumers' willingness to purchase remanufactured products was explored. Negative reviews are detrimental to consumers' purchase intentions for remanufactured products, and the negative impact of poor reviews is greater than the positive impact of positive reviews; therefore, when the rate of poor reviews is high, online reviews are detrimental to potential consumers' utility from remanufactured products. When r is less than 0, the different decision intervals for the IR under Models B and O are shown in Figure 8. Unlike in Figure 4, where $r > 0$, when $r < 0$, the threshold k_3 to enter full remanufacturing is less than 0, and thus, there is no full remanufacturing and high-quality scenario for Model O.

Full and low (iii)	Partial and low (ii)	No (i)	
0	k_1	k_2	Model B
Full and low (iii)	Partial and low (ii)	No (i)	
0	$k_1 + r$	$k_2 + r$	Model O

Figure no. 8. Different remanufacturing scenarios for Models B and O when $r < 0$

Proposition 7. In Model O, when $r < 0$, the IR does not produce high-quality remanufactured products.

From Proposition 7, if the utility of online reviews for remanufactured products rf is negative, then the high-quality and full remanufacturing scenario does not exist. Therefore, managing online reviews is an important challenge for the IR entering the e-commerce channel (Kostyra et al., 2016), and thus, the IR should focus on increasing the number of positive reviews and reducing the number of negative reviews.

Proposition 8. When $0 < k < k_1 + r$, $\pi_{IR}^{O-3} < \pi_{IR}^{B-3}$. When $k_1 < k < k_2 + r$, $\pi_{IR}^{O-2} < \pi_{IR}^{B-2}$.

To further compare the profits of the IR in the interval $k_1 + r < k < k_1$ between Models B and O, Figure 9 shows a comparison of the IR's profits in different intervals under Models O and B when $r < 0$, it is assumed that $q = 0.3, m = 1, m_0 = 0.9, D = 0.3, r = -0.02, l = 0.001$.

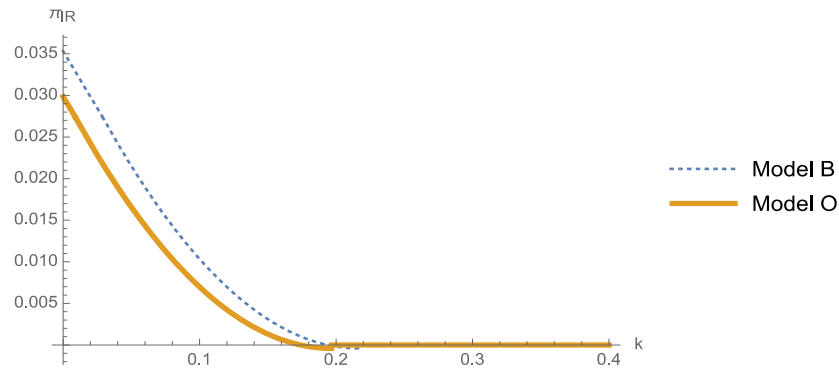


Figure no. 9. Profit of the IR in Models B and O when $r < 0$

From Proposition 8 and Figure 9, if online reviews have a negative effect on the consumer utility of remanufactured products, then the IR chooses to withdraw from online channels. Online reviews have a negative impact on consumer utility mainly because of the high percentage of poor reviews. Therefore, before entering the online channel, the IR should research consumers' perceptions of the quality efforts of remanufactured products in advance. This approach ensures that the online reviews given by consumers after entering the online channel can accurately reflect the quality efforts of the IR. This finding also explains why many e-commerce sellers choose to conduct positive feedback rebates to boost the number of positive reviews and promote the positive effect of online reviews on potential consumers (Chen et al. 2021). If the IR does not have enough positive reviews, then it should exit the online market.

4. Discussion

Consumers tend to underestimate the quality of remanufactured products, and the introduction of online reviews can help the IR convey quality signals about such products. In addition, the IR can change the quality of remanufactured products through changes in quality cost; thus, the IR has the incentive to influence the quality signals conveyed by online reviews by changing the quality of remanufactured products. Changes in the quality signal conveyed by online reviews affect potential consumers' purchasing decisions regarding remanufactured products, which in turn change the operational decisions of the IR. When comparing the IR's quality decisions, operational decisions, and profits under Models B and O, the changes in the IR's operational decisions under different online review strategies and changes in its decision of whether or not to introduce online reviews are revealed. The results show that the introduction of online reviews by the IR can improve the quality and profitability of remanufactured products under certain conditions. This result provides managerial insights for the IR in terms of its e-commerce and operational decisions. The specific discussion is presented below.

First, Proposition 3 and Figure 5 demonstrate that the introduction of online reviews can facilitate the shift of the IR from a low-quality strategy to a high-quality strategy under certain conditions. After the IR shifts from a low-quality strategy to a high-quality strategy for remanufactured products, the quality difference between the remanufactured and new products decreases. This result is similar to that of Kwark, Chen and Raghunathan (2018),

who report that online reviews can contribute to the reduction in the quality differences between competing products. Furthermore, after the introduction of online reviews by the IR, when the variable investment coefficient of the quality improvement effort is high, the IR chooses to increase the production quantity but keeps the low-quality strategy unchanged, and when the variable investment coefficient of the quality improvement effort is relatively low, the IR chooses to keep the maximum production unchanged but changes from the low-quality strategy to the high-quality strategy. This result supports the findings of Jiang and Yang (2019) that the lower the investment coefficient of the quality improvement effort is, the greater the likelihood of the manufacturer improving quality. When the value of the investment coefficient of the quality improvement effort is high, the IR needs to pay higher quality costs to reach the minimum quality level (Jiang and Yang, 2019), and thus, the IR prefers to keep the minimum quality level unchanged. In addition, the lower the cost of remanufactured products is, the more the IR tends to realise full remanufacturing (Kleber, Quariguasi Frota Neto and Reimann, 2020), and when the variable investment coefficient of the quality improvement effort is low, the IR needs to incur lower costs to improve quality. Therefore, when the quality of the remanufactured product is at a low level, the IR improves the quality of the remanufactured product while performing full remanufacturing.

Second, Proposition 5 and Figure 7 show that the introduction of online reviews by the IR can contribute to its profitability as long as online reviews favour an increase in consumers' willingness to purchase remanufactured products. This finding is similar to that of Yang, Wang and Ang (2021), who report that online reviews can improve manufacturers' profits. In addition, this finding is similar to Qiao and Su's (2021) conclusion that online reviews increase manufacturers' profits when the obtained willingness to pay of consumers from consumer reviews increases. Because the introduction of online reviews means that the IR has the opportunity to increase the prices of its products and favours the ability of IR to increase the quality and production of remanufactured products under certain conditions (Yang, Wang and Ang, 2021; Qiao and Su, 2021).

Third, Propositions 7 and 8 suggest that if online reviews reduce consumers' willingness to purchase remanufactured products, then the IR should not implement a high-quality strategy, but should exit the e-commerce channel to avoid the negative effects of online reviews. This conclusion is based on the fact that the negative effects of negative reviews are greater than the positive effects of positive reviews, and if there are too many negative reviews of remanufactured products, then online reviews play a negative role in the sales of remanufactured products (Van Nguyen et al., 2020). Although online reviews can convey the quality signals of remanufactured products, manufacturers benefit from online reviews only if enough positive reviews are guaranteed (Yang, Wang and Ang, 2021).

Conclusions

Main findings

When the IR introduces online reviews through the e-commerce channel, the quality signalling effect of online reviews helps potential consumers learn about the actual quality of remanufactured products. However, the IR must make decisions about whether to improve quality to further increase the quality signalling effect of online reviews. In this study, a competitive model of an OEM and an IR was developed to investigate under what conditions online reviews have a quality-enhancing effect on remanufactured products. The following

conclusions are drawn: (1) The quality of remanufactured products does not improve if the IR does not enter the e-commerce channel to introduce online reviews. In contrast, in the e-commerce channel with online reviews, the IR improves quality under certain conditions. With the introduction of online reviews, the IR does not improve quality in the partial remanufacturing scenario; however, the IR may improve quality in the full remanufacturing scenario. (2) Online reviews increase the IR's profit and the prices of remanufactured products, and a high-quality strategy can make the IR more profitable. (3) If the impact of online reviews on potential consumers' willingness to pay is negative, i.e., if the rate of negative reviews is high, then intuitively, the IR should improve quality and thus shift the effect of online reviews for consumers from negative to positive. However, the IR does not improve quality when online reviews have a negative effect and instead opts out of the online channel, thereby removing the negative impact of online reviews.

Managerial implications

The managerial insights of this study are as follows. First, after the IR introduces online reviews, it should take into account the quality signalling effect of online reviews and increase the production quantity and quality of remanufactured products under certain conditions. However, after introducing online reviews, the IR should not simultaneously increase the production and quality of remanufactured products. Specifically, the IR should increase the output of remanufactured products while maintaining a low-quality strategy and increase the quality of remanufactured products while maximising the production of remanufactured products. Second, the IR should enter the e-commerce channel to introduce online reviews as long as these online reviews have an enhancing effect on consumers' utility from remanufactured products. Furthermore, the IR should adopt strategies to increase the effect of online reviews on the perceived quality of remanufactured products, such as by promoting an increase in the amount of valid information provided by online reviews and promoting the generation of online reviews in the form of pictures and videos through the use of review rebates (Chen, Guo and Huang, 2022). Since the IR can earn higher profits under the high-quality strategy than under other strategies, it should introduce quality improvement techniques with lower variable costs to motivate itself to choose the high-quality strategy. The IR should increase the prices of remanufactured products after introducing online reviews. Third, IR should survey consumers in advance about their perceptions of the quality of remanufactured products and the ratings they can give in online reviews. In addition, if the rate of negative reviews is too high, then the IR should not enter the e-commerce channel or introduce online reviews. For remanufactured products that are already in the e-commerce channel but have a high number of negative ratings in online reviews, the IR should withdraw from the e-commerce channel to prevent these negative ratings from influencing potential consumers' willingness to purchase remanufactured products.

Limitations and future directions

This study has several limitations that require further research. First, this study constructs a single-period model to consider the effects of online reviews on the quality decisions of remanufactured products without considering the different effects of online reviews on manufacturers' quality decisions during different periods. Therefore, future studies can apply multiperiod or dynamic models. Second, this study is interested in the actual quality of remanufactured products because quality signals are conveyed to consumers through online reviews. Considering the attributes of online reviews may lead to different conclusions, e.g.

positive ratings of online reviews, proportion of text, presence or absence of images. Third, this study only considers the impact of online reviews of remanufactured products on the sales of remanufactured products, but not the impact of online reviews of remanufactured products on the sales of new products. Future research can consider that the quality signalling given in online reviews of remanufactured products is also beneficial to consumers' perceptions of the quality of new products, which can lead to further research on the operational decisions of remanufacturers.

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