Optimal type of government subsidies in a three-echelon supply chain considering used parts' different quality

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Abstract. This paper studies the optimal decisions of manufacturers and retailers regarding production and pricing in a three-echelon supply chain. With government subsidy, consumers can choose between new products and remanufactured products. We examine which policy is better from the perspective of profit for manufacturers and retailers. The government and enterprises can get some inspiration from the research results to make better decisions. The main results and contributions are summarized as follows. First, from the perspective of manufacturers' profits, government subsidies to manufacturers have the same effect as subsidies to consumers. Second, when consumers prefer more for the remanufactured product, the manufacturer's profit increases with the quality of used cores, thus the manufacturer could buy higher quality used cores. Third, as quality of used cores increase, demand for the remanufactured product decreases.

Keywords: Green supply chain; Government subsidy; Green products.

1 Introduction

The environmental problems caused by carbon dioxide have become one of the important issues concerned by the international community (Yang et al., 2020).

To fundamentally solve this problem, recycling and remanufacturing are considered to be the most effective ways. For enterprises, recycling waste products not only reduces the consumption of raw materials, but also reduces the pollution caused by waste products to the environment (Feng et al., 2017). In 2020, The National Development and Reform Commission (NDRC) has issued a public notice on the "Interim Measures for the Administration of Automobile Parts Remanufacturing (Draft for Comments)" for public comment. It encouraged automobile production enterprises to recycle old motor vehicle parts for remanufacturing through after-sales service system and specialized recycling companies. Then, these used parts can be supplied to the remanufacturing company.

To encourage companies to engage in remanufacturing, the government chose to subsidy manufacturers directly. The government usually issues subsidies to manufac-

V. Escudero et al. (Eds.): BADS 2022, AHCS 11, pp. 947–958, 2023.
https://doi.org/10.2991/978-94-6463-102-9_98

turers based on the sales volume. In Indian, the government subsidized the manufacturer engaging in remanufacturing in 2015(Zhang et al., 2020). Subsidies to manufacturers have no effect on consumer behavior. The government adjusts consumers' propensity to buy remanufactured goods by subsidizing them. Subsidies to consumers refer to the deduction of subsidies from the price of products, which can directly reduce consumers' spending on purchasing products, guide consumers to support low-carbon products, and encourage producers to produce low-carbon products or even zero-emission products.

In order to fully analyze the impact of the government subsidy for the remanufacturing activities, this paper considers both the subsidy for the manufacturer and the consumer and compares the two subsidy policies. Interestingly, the results show that the two subsidies had almost the same effect except the effect on the remanufactured products' demand and the profit for the retailer.

2 Literature Review

We studied the literature relevant to our research. One is supply chain operations considering government subsidy and the second is remanufacturing closed-loop supply chain.

2.1 Remanufacturing Closed-loop Supply Chain

Many scholars have studied the reverse mode selection that the recycling can be carried out by a manufacturer or a retailer or a third party. Kushwaha et al. (2020) proposed an optimal combination of channels for collecting used products from several scattered geographic regions in a finite period situation. Savaska et al. (2004) solved the problem of choosing the right reverse channel structure from customers and Atasu et al. (2013) studied how the collection cost structure influence the optimal reverse channel choice of manufacturers.

Pricing is another problem after channel selection. Cao et al. (2019) studied the optimal decisions of two firms. In addition to new products, remanufactures are also sold. Mondal et al. (2019) derived the pricing and greening strategies for the channel members and the whole supply chain. Wen et al. (2020) explored manufacturer's optimal decisions in a closed-loop supply chain considering consumers with different environmental responsibility. Hosseini-Motlagh et al. (2020) investigated both traditional and centralized decision-making structures and analysed the optimal values of CLSC members' decisions.

The aforementioned studies have attributed to supply chain operations from many aspects, but few of them have explored the effects of the consumer acceptance of the remanufactured good. This work investigates the manufacturer's choice of used cores of different quality and optimal pricing decisions by taking consumers' acceptance of the remanufactured good into consideration.

2.2 Supply Chain Operations under Government Subsidy

To promote remanufacturing, the government may subsidy the manufacturer to share the extra cost or the consumer to reduce the impact of consumers' environmental externalities. In the past few decades, some scholars explored the effect of government subsidies and the optimal type of subsidy.

Qiao & Su (2020) discussed how manufacturing and remanufacturing quantity and consumer surplus are affected by the government subsidy. Huang et al. (2020) focused on the impacts of different kinds of government subsidy on members' profits and the environment.

Zhang et al. (2020) analyzed the effect of government reward-penalty policies (RPPs) on the decisions of a dual-channel closed-loop supply chain (CLSC). Chen et al. (2020) studied the governments optimal subsidy level when the number of used products returning to the OEM is uncertain. Meng et al. (2020) solved whether governments subsidies consumers and the optimal subsidy value. Zhu et al. (2020) studied the influence of providing cash subsidy and imposing carbon regulation policies on the demand for remanufactured products and firm profit. Wang et al. (2019) investigated how are government subsidies distributed among the different parts in a reverse supply chain. He et al. (2019) explored channel structure and pricing decisions for the manufacturer and governments subsidy policy with competing new and remanufactured products.

Wan & Hong (2019) explored how customers are affected by subsidy policies and transfer pricing policies. Guo et al. (2019) investigated optimal recovery and production strategies for the closed-loop supply chain under the circumstances of supply disruption and government subsidy. Shu et al. (2017) examined the optimal pricing and production decision under remanufacturing subsidy and tax rebate. Wang et al. (2014) explored the impact of subsidy policies on the development of the recycling and remanufacturing industry. Li et al. (2014) analyzed the effect of carbon subsidy on remanufacturing closed-loop supply chain and explored the profits and the carbon emission quantities of three types of a supply chain.

We draw upon and extend prior research in remanufacturing to study a manufacturer's subsidy policy for different objects. Rather than assume different type policies, we consider both subsidy policy for two objects.

However, only few literatures considered supply chain members' decision is influenced by the quality difference of used parts. Ferguson et al. (2009) solved a tactical production-planning problem for remanufacturing when returns have different quality levels. Samuel et al. (2020) investigated the influences of the quality of returns on the CLSC network under different carbon related policies.

Different from the above-mentioned studies, we consider the supplier provides different quality of used cores and manufacturers need to choose from used parts of different qualities.

3 Assumptions and Models

3.1 Problem Description

The three-echelon green supply chain defined in the present research comprises a manufacturer M, a retailer R and a supplier S; the manufacturer is the leader of the supply chain and has two types of subsidy policy— subsidy for the manufacturer and subsidy for the consumer. The retailer is the follower. The supplier provides cores of different quality to the manufacturer， then the manufacturer sells the remanufactured product to the consumer directly and the new product through the retailer.

3.2 Government Subsidy Model

In this part, we discuss the scenario where the government subsidies related members to facilitate the development of remanufacturing. Regarding the supply chain members' profit, we discuss the impact of subsidies on the strategies of manufacturers and retailers. The manufacturer's two decision variables are the price for the remanufactured product and the wholesale price for the new product (p_{1r}, w_{1n}) and the retailer's only decision variable is the price for the new product (p_{1n}). Specially, we consider there are two types of government's subsidy: subsidy for the manufacturer or subsidy for the consumer. Finally, we compare the effect of different quality of the used cores on the supply chain member's profit.

Table 1. Related Parameters and Meanings

Parameters	Definition
w	Manufacturer's wholesale price
p_r / p_n	Manufacturer's/ Retailer's retail price
q_{ij}	Sales quantity (i=1: subsidy for the remanufacturer; i=2: subsidy for the retailer; j=n or r: new or remanufactured product)
τ	Collection rate
C_L	Investment cost coefficient
A	Acquisition cost
s	Government's subsidy
e_i	Product's emission intensity
E	Total emission
φ	Quality of used cores
θ	consumer's willingness-to-pay for the remanufactured product
i	i= r or m, represents the manufacturer or the retailer
Π_i	The profit of i
$E(\pi_i)$ $U(\pi_i)$	The expected profit and the utility of i

Subsidy for the Manufacturer

In this subsection, we consider the government subsidy for the manufacturer. The optimization problems of the remanufacturer and the retailer under the subsidy for the manufacturer can be formulated as follows.

$$\max_{p_{1r},w_{1n},\varphi} \prod_M^1 (p_{1r}, w_{1n}, \varphi) = q_{1n}(w_{1n} - c) + q_{1r}(p_{1r} - c_r\varphi_r^2 + s)$$

$$\max_{p_{1n}} \prod_R^1 (p_{1n}) = q_{1n}(p_{1n} - w_{1n})$$

We use backward induction to solve the problem and the optimal decisions are as follows:

Theorem 1. The equilibrium price for the new product is

$$p_{1n} = \frac{c - s - \varphi\theta + c_r\varphi^2 + 3}{4}$$

Theorem 2. The equilibrium wholesale price for the new product and retail price for the remanufactured product are as follows:

$$w_{1n} = \frac{c+1}{2}; \quad p_{1r} = \frac{c_r\varphi^2 + \varphi\theta - s}{2}.$$

Proposition 1. The equilibrium price for the remanufactured product increases with the quality of used cores.

Proposition 2. Consumer's willingness-to-pay for the remanufactured product has opposite effect on the optimal price for the remanufactured product and the new product.

From Proposition 2, we obtain that the manufacturer can raise the price of the remanufactured good to some extent when consumers show more preference for the remanufactured product.

Proposition 3. Both the price for the new and the remanufactured products decrease with the government's subsidies. The fall in prices for the remanufactured product is intuitive, however the new product's price is falling to cushion the impact of the remanufactured product.

Subsidy for the Retailer

This subsection analyzes the optimization problems of the remanufacturer and the retailer under the subsidy for the retailer.

$$\max_{p_{2r},w_{2n},\varphi} \prod_M^2 (p_{2r}, w_{2n}, \varphi) = q_{2n}(w_{2n} - c) + q_{2r}(p_{2r} - c_r\varphi^2)$$

$$\max_{p_{2n}} \prod_R^2 (p_{2n}) = q_{2n}(p_{2n} - w_{2n})$$

Theorem 3. The equilibrium price for the new product is

$$p_{2n} = \frac{c - s - \varphi\theta + c_r\varphi^2 + 3}{4}$$

Theorem 4. The equilibrium wholesale price for the new product and retail price for the remanufactured product are as follows:

$$w_{2n} = \frac{c + 1}{2}; \quad p_{2r} = \frac{c_r\varphi^2 + \varphi\theta + s}{2}.$$

Above, Theorems 3 and 4 show the optimal solutions when the government subsidy for the consumer. Interestingly, only the price of the remanufactured product is different with that in Theorem 2.

Proposition 4. When the government subsidy for the consumer, the optimal price of the remanufactured product is higher than the former since the manufacturer capitalize the opportunity (subsidizing consumers) to raise the price for the remanufactured product.

Proposition 5. When government subsidy for the manufacturer to promote the remanufacturing activity, there will be a lower price for the remanufactured product to achieve high sales volume. Also, the price for the new product will decrease. Since the cannibalization of the remanufactured product, total demand for the new product will decrease. Also, government subsidies have been effective in boosting the sales of remanufactured goods.

4 Numerical Illustration

In this part, several numerical illustrations are conducted to illustrate the analytical results and to explain the effect of consumer preference for the remanufactured product. The results of numerical illustration are presented in the following figures, where s = 0.05, c = c_r =0.2.

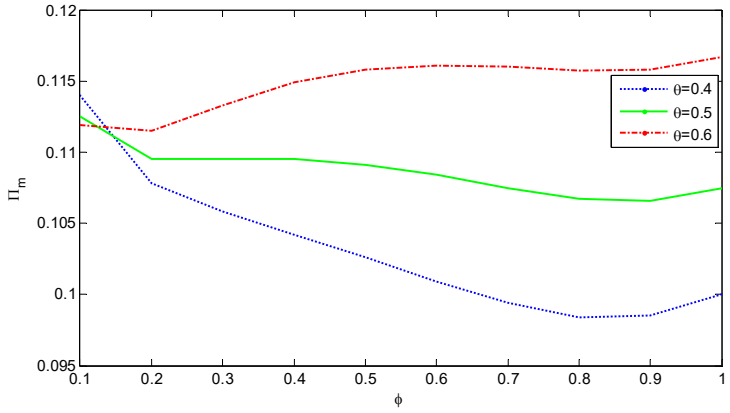

Fig. 1. The impact of the quality of the used cores on the profit of the manufacturer

Figures 1 shows that the manufacturer's profit increases with the quality of the used cores, which means that when consumers prefer more for the remanufactured product, higher quality cores generate more profit for the manufacturer. When consumers show not much interest in the remanufactured product, higher quality cores generate less profit for the manufacturer. However, when consumers take a neutral attitude, the impact of the used cores quality on manufacturers' profits is complex.

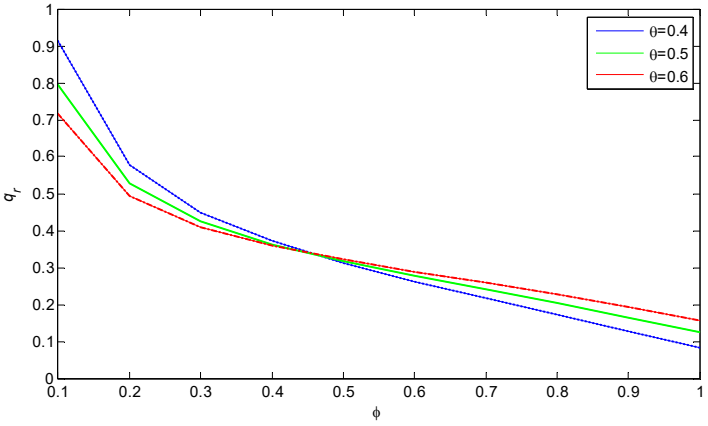

Fig. 2. The impact of the quality of the used cores on the demand for the remanufactured product

Figure 2 shows that as the quality of the used cores increases, demand for the remanufactured product decreases since the manufacturer charges a higher price for the remanufactured product which is made of higher quality of used cores. Also, there exists a threshold. When the quality of the used cores is less than the threshold, consumers'

less preference for the remanufactured product generate higher demand. When the quality of the used cores is more than the threshold, the lower the consumer preference, the lower the demand.

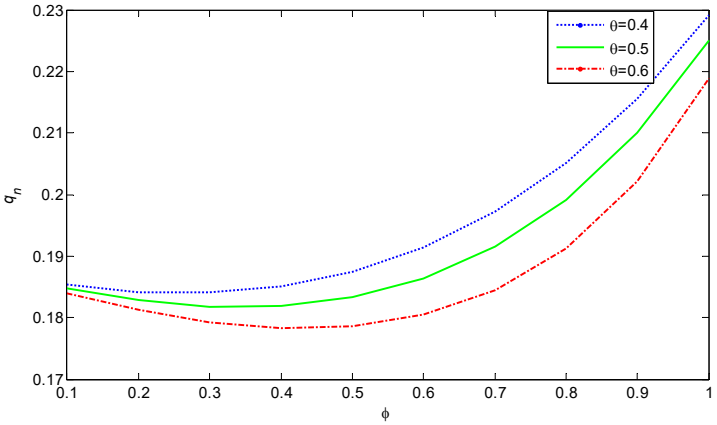

Fig. 3. The impact of the quality of the used cores on the demand for the new product

Figure 3 shows that as the quality of the used cores increase, the demand for the new product decreases first then increases. Consumers' preference and the demand for the new product are positive correlation.

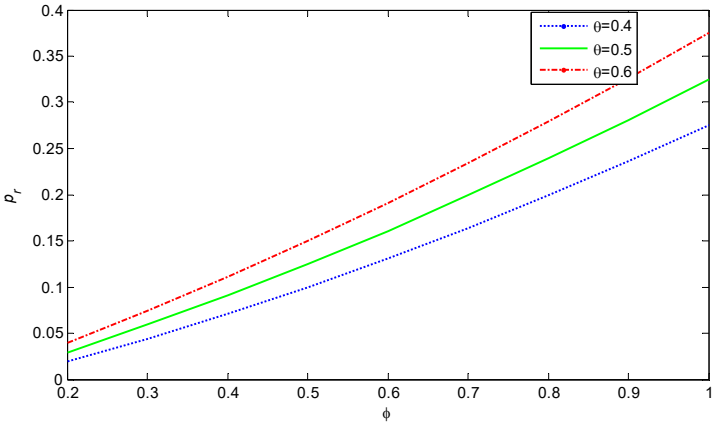

Fig. 4. The impact of the quality of the used cores on the remanufactured product's price

As the quality of used cores that the manufacturer buys from the supplier increases, the price for it increases. Intuitively, the price for the remanufactured product is high when consumers show more preference for it.

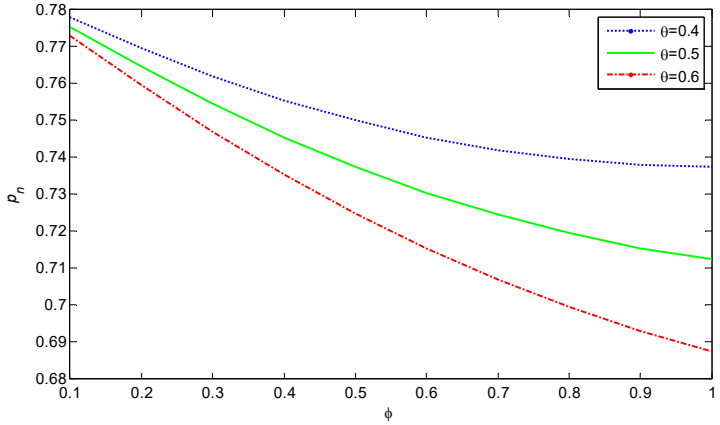

Fig. 5. The impact of the quality of the used cores on the new product's price

Contrary to the above, the price of the new product decreases with the quality of the used cores. And when consumers show more preference for the remanufactured product, the price for the new product is lower.

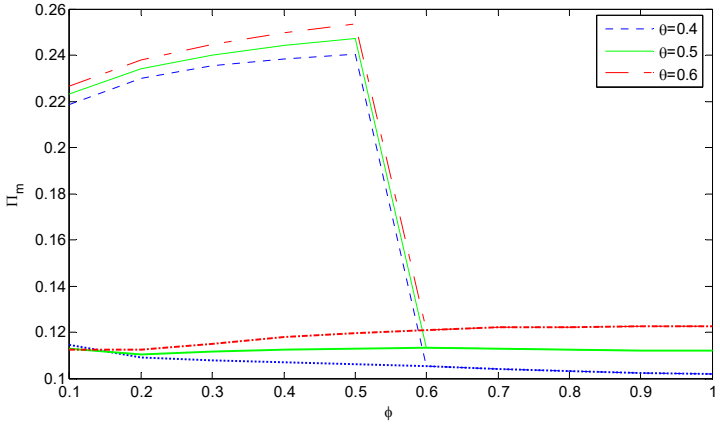

Fig. 6. The impact of the quality of the used cores on the profit of the manufacturer under two kinds of subsidy policies

Figure 6 shows the profit of the manufacturer under two subsidy policy considering when subsidy for the manufacturer there is a subsidy constraint with the maximum subsidy is 0.15. We can see that when $\varphi \geq 0.6$, the manufacturer's profit is the same in both cases since subsidy constraints do not work. If $\varphi < 0.6$, unit subsidies to manufacturers would exceed the subsidy constraint so there is a fixed subsidy for the manufacturer and the subsidy for the manufacturer is more profitable for the manufacturer.

5 Conclusions

This paper analyses the optimal decision of two members regarding production and pricing in a three-echelon supply chain under two policies (i.e., subsidy for the manufacturer and subsidy for the retailer) implemented by the government. Assume that the manufacturer could buy used cores of different quality from the supplier, the impacts of consumers' WTP for the remanufactured and product quality differences on the prices and profits of manufacturers and retailers are analyzed.

This paper draws the following management insights: (1) for manufacturers, government subsidies for manufacturers have the same effect as for consumers, which is manufacturers can benefit from government subsidy for consumers. (2) when consumers prefer more for the remanufactured product, the manufacturer's profit increases with quality of used cores thus the manufacturer could buy higher quality cores. (3) as quality of used cores increases, demand for the remanufactured product decreases since the manufacturer charges a higher price for the remanufactured product which is made of higher quality of used cores. Manufacturer should decide carefully the quality of used parts need to buy as too much quality may have the opposite effect on profit.

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