Pricing strategy on new and remanufactured products with difference of distribution channel

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Abstract

The paper studies a manufacturer who provides both new and remanufactured products, which are sold by an identical dealer (called channel I) or by two competitors (called channel II), and investigates differentiated and undifferentiated pricing strategy of channel I and Bertrand and Stackelberg competitive pricing strategy in channel II. Interestingly, we find that differentiated pricing is superior to undifferentiated pricing in Channel I; and in channel II Stackelberg competitive pricing can bring more profits to the dealer of new products than Stackelberg game, whereas there exists a threshold, which is related to the wholesale price and the substitutability of products, in the profits of the two games for the dealer of remanufactured products. And then we explore that differentiated pricing of Channel I and Bertrand competitive pricing of Channel II are more profitable to the manufacturer. The profit differences of the two dominant pricing strategies depend on the tradeoff among the production costs, the substitutability of products and the proportion of green consumers. Finally, the further analysis shows that the appropriate choice of pricing strategies and channel structures need to consider the matching between the product substitutability, the proportion of green consumers, the wholesale price or the production costs of new and remanufactured products.

Keywords: manufacturing; differentiated pricing; Bertrand and Stackelberg price competition; distribution channel

JEL Classification: M 14
1. Introduction

Early manufacturing activities, partially emphasizing on economic efficiency, are lack of awareness of environmental protection and sustainable development. Under the pressure of deteriorated environment, shortage of resources and constraints of laws and regulations, many companies are forced to pay more attention to the recycling and reuse of used products. By disassembling their components and specialized processing, remanufactured products are potential in achieving the same quality and performance as the original ones, and effective management of the product lifecycle has been put on agenda.

Today the scale of global remanufacturing industry is estimated over 100 billion USD, and the developed countries have fully recognized the value of the industry. In USA, remanufacturing has been play a crucial part in the national economy, and the output value of the industry is more than 75 billion USD with 73,000 enterprises; Japanese engineering machinery remanufacturing has reached world leading level; German automobile remanufacturing is the priority development areas. Compared to the production of new products, remanufacturing can save 60% energy, 70% materials, and reduce more than 80% emissions of air pollutants; therefore, it shows a profound practical significance in achieving the duple targets of energy conservation and carbon emission reduction.

In this context, many companies build a parallel production-distribution system of new and remanufacturing products. In order to maintain brand equity, how to determine pricing mechanism on new and remanufactured products, to maximize the profits of an enterprise, to attain the purpose of expanding market share and competitive advantage become a focal topic business and academic world.

Focusing on the substitutability of products and the proportion of green consumers, our paper provides an alternative approach which studies pricing decisions on new and remanufactured products with the differences of distribution channel. The rest of this paper is organized as follows. Section 2 firstly reviews the relevant literature and then clarifies the contribution of this paper. Section 3 describes the supply chain structure and the theoretical background related the analytical model to the consumer behavior theory. Section 4 and section 5 respectively develop models and analytical results of different pricing strategies for manufacturers and dealers. After that, section 6 is engaged to discuss the effect of substitutability of products and the proportion of green consumers on the profit of manufacturers and dealers. Finally conclusions of this research and possible directions for future research are illustrated in section 7.

2. Literature Review

Remanufacturing is environmentally efficient and plays an important role in increasing
profits, McConocha and Speh (1991) argue that remanufacturing creates important benefits:
(1) savings in labor, materials, and energy costs, (2) shorter production lead times, (3) balanced production lines, (4) new market development opportunities, and (5) a positive, socially concerned image. More comprehensive surveys are contained in overview written by Pokharel and Mutha (2009), Ilgin and Gupta (2010).

Since take-back of used products benefits to the manufacturer, it is a hot topic how the remanufacturing should be understood and improves potential profits. The use of remanufacturing as a tool to serve secondary markets can reduce the number of units procured from the advanced market for the reseller (Robotis et al., 2005). In a duopoly market where two manufacturers compete for sales of durable goods, a manufacturer can increase both profit margins and sales to the detriment of a non-interfering competitor by taking back and reselling refurbished products (Heese et al., 2005). Liang et al. (2009) study the economic incentive that attracts customers to return their used products (called cores) and the problem of pricing on a core linking with a remanufactured product. In order to investigate questions of interest to policy-makers in government and managers in industry, Webster and Mitra (2007), Mitra and Webster (2008), Aksen et al. (2009) also analyze the effects of take-back laws and government subsidies as a means of promoting remanufacturing activity.

Since supply chains need to consider reverse flow of used products, there is great interest in supply chain channel design and coordination. Savaskan et al. (2004) consider product categories in which there is no distinction between a remanufactured and a manufactured product and analyze implications of different closed-loop supply chain structures on incentives to invest in used-product collection and on supply chain profits. Karakayali et al. (2007) develop models to determine the optimal acquisition price of the end-of-life products and the selling price of the remanufactured parts in centralized as well as remanufacture- and collector-driven decentralized channels. They discuss how the decentralized channels can be coordinated to attain the end-of-life product collection rate that can be achieved in the centralized channel. On the other hand, production or inventory planning and pricing in the settings of joint manufacturing and remanufacturing is also investigated by some authors in the literature (see Bayindir et al., 2007; Shi et al., 2010; Aras et al., 2010; Karakayal et al., 2010; Vadde et al., 2011).

When a firm simultaneously provide new and remanufactured product to customers, differentiation pricing naturally becomes a critical problem for segment markets. Majumder and Groenevelt (2001), Ferguson and Toktay (2006) consider the pricing and remanufacturing/collection decisions when facing a competing local remanufacturer. They derive conditions on costs, under which remanufacturing or collection is profitable for a
monopoly or under competition, in addition to strategies that deter remanufacturer entry. Ferrer and Swaminathan (2006, 2010) study a firm that makes new products in the first period and uses returned cores to make remanufactured products (along with new products) in future periods and characterize the optimal remanufacturing and pricing strategy in monopoly and duopoly environments for two-period, multi-period and infinite-horizon settings in which the firm needs to choose differentiated prices since the remanufactured product is differentiated from the new product. Atasu et al. (2008) considers the existence of green segments, original equipment manufacturer competition, and product life-cycle effects. They find that the profitability of a remanufacturing system strongly depends on these issues as well as on their interactions and remanufacturing can become an effective marketing strategy which allows the manufacturer to defend its market share via price discrimination under competition.

Compared with the relevant literatures, our research aims to understand the profit differences caused by distribution channel structures and pricing strategies of new and remanufacturing products, and explore effects of the substitutability of products and the proportion of green consumers on the profits of the firms. The main contributions and innovations are as follows.

(1) Considering the difference of distribution channel on new and remanufactured products, the paper investigates the corresponding pricing strategy and its effect on the profits of the dealer.

(2) For different pricing strategies of the dealer, we study the wholesale price decision of the manufacturer producing new and remanufactured products, as well as the effect of distribution channel and pricing strategy on the profits of the manufacturer.

(3) We discuss how the substitutability of products and the proportion of green consumers affect the profits of the manufacturers and dealer.

To the best of our knowledge, this is the first paper that studies the mixed sale of new and remanufactured products with different distribution channel and pricing strategy as well as simultaneously considers the substitutability of products and the proportion of green consumers.

3. Problem statement and theoretical background

In this paper, the following modeling assumptions are consistent with the work of Savaskan et al. (2004), but our interest is the pricing decision on new and remanufactured products under different distribution channel rather than the problem of choosing the appropriate reverse channel structure for the collection of used products from customers.

(1) The supply chain decisions are considered in a single-period setting. The products previously exist in the market and can be returned to the manufacturer for reuse.

(2) The focus of analysis is on the average profits per period when similar products are

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introduced to the market repeatedly.

(3) All supply chain members can share the market information and seek their own maximum profit.

3.1 Distribution channels and pricing strategies

We study a manufacturer that not only produces new products, but also remanufactured products by processing of used products and components. For the manufacturer, there are two kinds of distribution channel structure to choose: (I) sold by identical dealer (called Channel I as follows), i.e. sharing the channel of new products for managerial convenience; (II) respectively sold by two competing dealers (called Channel II as follows), i.e. building special channel of remanufactured products for brand equity. In the different channel, the dealer can choose various pricing strategies to maximize own profits. We consider the differential and undifferentiated pricing strategy of the dealer for Channel I and the competitive pricing strategy with Bertrand game and Stackelberg game for Channel II. The details are depicted in Figure 1.

3.2 Demand model purchasing new and remanufactured products for consumers

Since there exists the substitutability between new and remanufactured products, we use the demand function given by McGuire and Staelin (1983, 2008) for two kinds of product. Let \( q_n \) denotes the demand of new products, and \( q_r \) denotes the demand of remanufactured products. \( p_n \) and \( p_r \) respectively denote their price.

\[
q_n = (1 - \mu)\Phi\left(1 - \frac{\beta}{1 - \theta} p_n + \frac{\beta \theta}{1 - \theta} p_r \right)
\]

\[
q_r = \mu \Phi\left(1 - \frac{\beta}{1 - \theta} p_r + \frac{\beta \theta}{1 - \theta} p_n \right)
\]

Where \( 0 \leq \mu \leq 1, 0 \leq \theta < 1 \) and \( \beta \) and \( \Phi \) are positive. For remanufactured products with the same quality and performance of original new products, there are two types of consumers in the market: (1) concerning the performance of products rather than novelty, a part of consumers believe that new products have the same value of remanufactured products

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and prefer to low-carbon and eco-friendly remanufactured products. They are known as green consumers, the ratio is indicated as \( \mu \) in the market; (2) the others prefer to new products due to pursuing fashion, highlighting personality and lacking environmental awareness and they are known as primary consumers, the ratio is described as \( 1 - \mu \) in the market. When the new and remanufactured products are sold in the same price, the proportion of demand is \( \frac{q_n}{q_r} = \frac{1 - \mu}{\mu} \). The parameter \( \theta \), the ratio of the rate of change of demand with respect to price on the other product to the rate of change of demand with respect to the price on the own product, is the description of the substitutability between new and remanufactured products. When \( \theta = 0 \), it indicates that there is no substitutability between the two products, and demand of each other is independent and not affected by price changes of the other side. If \( \theta \) is close to 1, there is the largest substitutability between the both products. The parameter \( \beta \) is denoted as the price substitutability and \( \Phi \) is the largest market share. If \( p_n = p_r = 0 \), \( q_n + q_r = \Phi \).

In order to effectively use the above demand model, we need to add some constraints to guarantee that (1) prices are not less than marginal costs, (2) demand is non-negative, and (3) demand does not increase with increase in prices for either product. McGuire and Staelin (1983, 2008) give the following equivalent constraints.

Constraint 1: \( \beta \leq \frac{1}{e} \) or \( 1 - \beta e \geq 0 \), \( e \) represents expenses of products.

Constraint 2: \( \frac{\theta}{1 + \theta} \leq \mu \leq \frac{1}{1 + \theta} \)

4. Pricing decision on new and remanufactured products for dealer

4.1 Sale of new and remanufactured products from identical dealer

Let \( w_n \) and \( w_r \) represent the wholesale price purchasing new and remanufactured products for a dealer. Facing different demand of consumers, the dealer needs to simultaneously sell new and remanufactured products. The total profits of the dealer are \( \pi_d^D = (p_n - w_n)q_n + (p_r - w_r)q_r \).

Under differentiated pricing, the profits are

\[
\pi_d^D = \Phi \left[ (1 - \mu)(p_n - w_n) \left( 1 - \frac{\beta}{1 - \theta} p_n + \frac{\beta \theta}{1 - \theta} p_r \right) + \mu (p_r - w_r) \left( 1 - \frac{\beta}{1 - \theta} p_r + \frac{\beta \theta}{1 - \theta} p_n \right) \right]
\]

Sometimes undifferentiated pricing strategy also could be employed while the dealer thinks that customers have similar acceptance of new and remanufactured products. Set \( p_n = p_r = p \) and the profits are

\[
\pi_d^N = \Phi \left( 1 - \beta p \right) \left[ p - (1 - \mu) w_n - \mu w_r \right]
\]
Lemma 1:

\[ (L1.1) \text{If } 4\mu(1-\mu) > \theta^2, \text{ in differentiated pricing strategy, the optimal price of new and remanufactured products is} \]

\[ p_{n}^{op} = \frac{4\mu(1-\mu) - \theta^2 - (1-\mu)[2\mu - \theta^2]}{\beta[4\mu(1-\mu) - \theta^2]} \]

(1)

\[ p_{r}^{op} = \frac{4\mu(1-\mu) - \theta^2 - \mu(2(1-\mu) - \theta^2)(1-\beta w_r) - \mu(1-2\mu)(1-\beta w_r)}{\beta[4\mu(1-\mu) - \theta^2]} \]

(2)

\[ (L1.2) \text{In undifferentiated pricing strategy, the optimal price of new and remanufactured products is} \]

\[ p_{n}^{op} = p_{r}^{op} = \frac{2 - (1-\mu)(1-\beta w_n) - \mu(1-\beta w_r)}{2\beta} \]

(3)

Proposition 1:

\[ (P1.1) \text{When } \theta = 0 \text{ or } \mu = \frac{1}{2}, p_{n}^{op} = \frac{1+\beta w_n}{2\beta} \text{ and } p_{r}^{op} = \frac{1+\beta w_r}{2\beta} \]

\[ (P1.2) \text{When } \frac{1-\beta w_r}{1-\beta w_n} \geq \left(\frac{\theta}{\mu} + 2\right) \left(\frac{\theta}{1-\mu} + 2\right) \leq 1 \text{ and } \frac{1-\beta w_r}{1-\beta w_n} \geq 1 \geq \left(\frac{\theta}{\mu} + 2\right) \left(\frac{\theta}{1-\mu} + 2\right) \leq 1 \text{. When differentiated pricing strategy is performed, the price of new and remanufactured products should satisfy } p_{n}^{op} \geq p_{r}^{op} \text{ and vice versa.} \]

Corollary 1: In general, \( w_r \leq w_n \), that is \( \frac{1-\beta w_r}{1-\beta w_n} \geq 1 \). According to the proposition 1: If the proportion of green consumers \( \mu \geq 1/2 \), then \( \left(\frac{\theta}{\mu} + 2\right) \left(\frac{\theta}{1-\mu} + 2\right) \leq 1 \) and \( \frac{1-\beta w_r}{1-\beta w_n} \geq 1 \geq \left(\frac{\theta}{\mu} + 2\right) \left(\frac{\theta}{1-\mu} + 2\right) \leq 1 \). When differentiated pricing strategy is performed, the price of new and remanufactured products should satisfy \( p_{n}^{op} \geq p_{r}^{op} \) in order to maximize the total profits.

Proposition 2: For the given \( w_n \) and \( w_r \), the total profits \( \pi_d^{op} \) for differentiated pricing are not less than \( \pi_d^{op} \) for undifferentiated pricing. If and only if \( \frac{1-\beta w_r}{1-\beta w_n} = \frac{(2\mu + \theta)(1-\mu)}{(2(1-\mu) + \theta)\mu} \),

\[ \pi_d^{op} = \pi_d^{op} \]

Figure 2: Total profits of dealer for differential and undifferentiated pricing
From Proposition 2 and figure 2, we find that it is not able to achieve the maximum profits if the dealer ignores the difference of consumers demand and try to employ the same price, when new and remanufactured products sold by identical dealer.

**Corollary 2:** When \( w_r \leq w_n \), if \( \mu \leq \frac{1}{2} \), then \( 1 - \beta w_r \leq 1 - \beta w_n \), so \( \pi^N_s \) and \( \pi^N_r \) may be equal. Otherwise, if \( \mu > \frac{1}{2} \), then \( \left( 1 - \beta w_r, 1 - \beta w_n \right) \neq \left( 1 - \beta w_r, 1 - \beta w_n \right) \), thus \( \pi^N_s \) and \( \pi^N_r \) can not be equal. In this situation, differentiated pricing will bring more profits than undifferentiated pricing and it’s the best pricing strategy for the dealer.

**4.2 Sale of new and remanufactured products from different dealer**

If new and manufactured products are respectively sold from different dealer, the dealer will launch price competition between new and remanufactured products in order to attract customers and maximize own profits. Here we consider two types of competitive strategy: Bertrand game and Stackelberg game.

In Bertrand game, the dealer can not observe the price of each other when making pricing decision and the optimal price of either dealer is a function of the other. The pricing strategy \(( p^B_n, p^B_r )\) is a Nash equilibrium means that

\[
p^B_n \in \arg\max \pi^B_n = (1 - \mu)\Phi(p_n - w_n) \left( 1 - \frac{\beta}{1 - \theta} p_n + \frac{\beta \theta}{1 - \theta} p_r \right) \]

\[
p^B_r \in \arg\max \pi^B_r = \mu \Phi(p_r - w_r) \left( 1 - \frac{\beta}{1 - \theta} p_r + \frac{\beta \theta}{1 - \theta} p_n \right) \]

**Lemma2:** The Nash equilibrium of the price on new and remanufactured products in Bertrand game is determined by the following expressions.

\[
p^B_n = \frac{4 - \theta^2 - 2(1 - \beta w_n) - \theta(1 - \beta w_r)}{\beta (4 - \theta^2)}
\]
\( p_r^{s*} = \frac{4 - \theta^2 - 2(1 - \beta w_r) - \theta(1 - \beta w_n)}{\beta(4 - \theta^2)} \)

\( \phi = 0, \quad \psi = 0 \).

The above conclusions can be easily obtained by the simultaneous first-order condition

\[ \frac{\partial \pi_d^{R}}{\partial p_n} = 0, \quad \frac{\partial \pi_d^{S}}{\partial p_r} = 0. \]

In the coexisting market of new and remanufactured products, new products take the lead in consumer demand. So the dealer of new products often make pricing decision as a leader and the dealer of remanufactured products as a follower observing the price of new products. Thus the price of remanufactured products is a function of the price of new products, that is

\[ p_r^{s*} = f(p_n^{s*}) \].

The pricing strategy \( (p_n^{s*}, p_r^{s*}) \) is a Nash equilibrium means that:

\[ p_n^{s*} = \arg \max \pi_d^{s*} = (1 - \mu) \Phi(p_n - w_n) \left( 1 - \frac{\beta}{1 - \theta} p_n + \frac{\beta \theta}{1 - \theta} f(p_n^{s*}) \right) \]

\[ p_r^{s*} = \arg \max \pi_d^{s*} = \mu \Phi(p_r - w_r) \left( 1 - \frac{\beta}{1 - \theta} p_r + \frac{\beta \theta}{1 - \theta} p_n \right) \]

**Lemma 3:** The Nash equilibrium of the price on new and remanufactured products in Stackelberg game is determined by the following expressions.

\[ p_n^{s*} = \frac{4 - 2\theta^2 - (2 - \theta^2)(1 - \beta w_n) - \theta(1 - \beta w_n)}{\beta(4 - 2\theta^2)} \]

\[ p_r^{s*} = \frac{2(4 - 2\theta^2) - (4 - \theta^2)(1 - \beta w_r) - \theta(2 - \theta^2)(1 - \beta w_n)}{2\beta(4 - 2\theta^2)} \]

The above results are easily solved by backward induction.

**Proposition 3:** If \( \frac{1 - \beta w_r}{1 - \beta w_n} \leq \frac{2 - \theta^2}{\theta} \), the Nash equilibrium of the price on new and remanufactured satisfy the following relationship in two games: \( p_n^{s*} \geq p_n^{R*} \) and \( p_r^{s*} \geq p_r^{R*} \), vice versa.

**Proposition 4:** In the two competitive pricing strategies, new products’ profits \( \pi_d^{s*} \) of the Nash equilibrium in Stackelberg game are not less than \( \pi_d^{R*} \) in Bertrand game, that is \( \pi_d^{s*} \geq \pi_d^{R*} \). If and only if \( \theta = 0 \) or \( \frac{1 - \beta w_n}{1 - \beta w_n} = \frac{2 - \theta^2}{\theta} \), the both are equal.

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Proposition 5: For remanufactured products, if \( \frac{\theta(2 - \theta^2)}{4 - 3\theta^2} \leq \frac{1 - \beta w_n}{1 - \beta w_n} \leq \frac{2 - \theta^2}{\theta} \), then \( \pi_{d(n)}^{s_n} \geq \pi_{d(n)}^{r_n} \), and if \( \frac{1 - \beta w_n}{1 - \beta w_n} > \frac{2 - \theta^2}{\theta} \) or \( \frac{1 - \beta w_n}{1 - \beta w_n} < \frac{\theta(2 - \theta^2)}{4 - 3\theta^2} \), then \( \pi_{d(n)}^{s_n} < \pi_{d(n)}^{r_n} \).

Figure 3: Profits of Nash equilibrium on new and remanufactured products in Channel II

Form proposition 4 and 5, we have the managerial implications as below.

The dealer of new products should accelerate the products into the market, increase the efforts to promote new products, enhance the pricing priority of new products. Thus it always can bring more profits. For the dealer of remanufactured products, the choice of competitive pricing strategy depends on the tradeoff between the wholesale price and substitutability.

5. Pricing decision on new and remanufactured products for manufacturer

The manufacturer produces new and remanufactured products and sells them to the dealer at wholesale price, while the dealer is responsible for selling products to consumers. Assumed that the market demand information can be shared, the critical problem facing for the manufacturer is how to determine the wholesale price and to ensure their own reasonable profits. Let \( c_n \) and \( c_r \) each represent the production costs of new and remanufactured products, so the problem of the manufacturer is

\[
\max \quad \pi_m = (1 - \mu) \Phi(w_n - c_n) \left(1 - \frac{\beta}{1 - \theta} p_n + \frac{\beta \theta}{1 - \theta} p_r \right)
+ \mu \Phi(w_r - c_r) \left(1 - \frac{\beta}{1 - \theta} p_r + \frac{\beta \theta}{1 - \theta} p_n \right)
\]

For the given wholesale price \( w_n \) and \( w_r \), the pricing decision on the dealer can be written to the following general form according to the expression (1)-(7). Let \( p_n \) and \( p_r \) be
\[ p_n = \frac{1}{\beta} \left[ 1 - \lambda_n (1 - \beta w_n) - \lambda_r (1 - \beta w_r) \right], \quad p_r = \frac{1}{\beta} \left[ 1 - \xi_n (1 - \beta w_n) - \xi_r (1 - \beta w_r) \right]. \]

**Lemma**: When \(4\mu(1-\mu)(\lambda_n - \beta\lambda_n)(\xi_n - \beta\xi_n) > [1 - \mu](\lambda_n - \beta\lambda_n) + \mu(\xi_n - \beta\xi_n)]^2\), the profit function \(\pi_m\) for the manufacturer is concave with respect to \(w_n\) and \(w_r\).

**(L.4.1)** In Channel I, whether the dealer performs differentiated pricing or not, the wholesale price of new and remanufactured products for the manufacturer is
\[ w_n = \frac{1 + \beta c_n}{2\beta}, \]
\[ w_r = \frac{1 + \beta c_r}{2\beta}. \]

**(L.4.2)** In Channel II, the wholesale price of new and remanufactured products under Bertrand game equilibrium is
\[ w^*_n = \frac{4\mu(1-\mu)(2-\theta^2) - \theta^2 - (1-\mu)[2\mu(2-\theta^2)^2 - \theta^2](1-\beta c_n) - \mu(2-\theta^2)\theta[1-2\mu](1-\beta c_n)}{\beta[4\mu(1-\mu)(2-\theta^2)^2 - \theta^2]}, \]
\[ w^*_r = \frac{4\mu(1-\mu)(2-\theta^2) - \theta^2 - \mu(2(1-\mu)(2-\theta^2)^2 - \theta^2)(1-\beta c_r) - \mu(2-\theta^2)(1-2(1-\mu))(1-\beta c_r)}{\beta[4\mu(1-\mu)(2-\theta^2)^2 - \theta^2]} \]
and the wholesale price of new and remanufactured products under Stackelberg game equilibrium is
\[ w^*_n = \frac{4\mu(1-\mu)(4-3\theta^2) - \theta^2 - (1-\mu)[2\mu(4-3\theta^2)^2 - \theta^2](1-\beta c_n) - \mu(4-3\theta^2)(1-2\mu)(1-\beta c_n)}{\beta[4\mu(1-\mu)(4-3\theta^2)^2 - \theta^2]}, \]
\[ w^*_r = \frac{4\mu(1-\mu)(4-3\theta^2) - \theta^2 - \mu(2(1-\mu)(4-3\theta^2)^2 - \theta^2)(1-\beta c_r) - \mu(2-\theta^2)(1-2(1-\mu))(1-\beta c_r)}{\beta[4\mu(1-\mu)(4-3\theta^2)^2 - \theta^2]} \]

From Lemma 4 the following managerial implications can be obtained.

When new and remanufactured products are simultaneously sold by identical dealer, the wholesale price is independent to the pricing strategies of the dealer and only depend on their own production costs. On the contrary, when they are respectively sold by different dealer under the competitive environment, the wholesale price depends on not only their own production costs, but also on the production costs of the other.

Besides the wholesale price, the effect of the pricing strategies on profits of manufacturers is an important issue to concern.

**Proposition 6**: For the manufacturer, the profits \(\pi_m^{D^*}\) under differentiated pricing are
not less than and \( \pi^N_m \) under undifferentiated pricing in Channel I, that is \( \pi^{D^r}_m \geq \pi^N_m \). If and only if 
\[
\frac{1 - \beta c_n}{1 - \beta c_m} = \frac{(2\mu + \theta)(1 - \mu)}{(2(1 - \mu) + \theta)\mu}, \quad \pi^{D^r}_m = \pi^N_m.
\]

Figure 4: Profits of manufacturer for differential and undifferentiated pricing in Channel I

**Proposition 7:** In Channel II, the total profits of the manufacturer under Bertrand game equilibrium \( \pi^{B^r}_m \) are always greater than \( \pi^{S^r}_m \) under Stackelberg game equilibrium, that is \( \pi^{B^r}_m > \pi^{S^r}_m \).

Figure 5: Profits of manufacture for Bertrand and Stackelberg game Equilibrium in Channel II

From proposition 6 and 7, figure 4 and 5, we can get the managerial implications as below.

In Channel I, though the wholesale price is independent to the pricing strategies of the dealer, differentiated pricing is a dominant strategy on the profits of the manufacturer. Bertrand competitive pricing strategy is a dominant strategy for the manufacturer in Channel II while the dealer fails to observe the price information of each other.
Next we need to further investigate the profit differences under the above two dominant strategies for the manufacturer.

**Proposition 8:** There are the following relationships on between the profits \( \pi_m^{D} \) of the manufacture under differentiated pricing and \( \pi_m^{B} \) under Bertrand competitive pricing.

Set \( A = \theta^2 \mu \left[ 3 - 2\theta^2 - 4\mu(1-\mu)(2-\theta^2) \right] \)

\[ B = \theta \left[ 4 \mu(1-\mu)\left( \frac{\theta}{\theta} - \frac{2}{\theta} \right) \right] \]

\[ C = \theta^2 (1-\mu) \left[ 3 - 2\theta^2 - 4\mu(1-\mu)(2-\theta^2) \right] \]

(P8.1) If \( B^2 - 4AC > 0 \),

when \[ \frac{1-\beta_c}{1-\beta_c} < \frac{-B - \sqrt{B^2 - 4AC}}{2A} \] or \[ \frac{1-\beta_c}{1-\beta_c} > \frac{-B + \sqrt{B^2 - 4AC}}{2A} \], then \( \pi_m^{D} > \pi_m^{B} \).

when \[ \frac{-B - \sqrt{B^2 - 4AC}}{2A} < \frac{1-\beta_c}{1-\beta_c} < \frac{-B + \sqrt{B^2 - 4AC}}{2A} \], then \( \pi_m^{D} < \pi_m^{B} \).

(P8.2) If \( B^2 - 4AC < 0 \), then \( \pi_m^{D} > \pi_m^{B} \).

(P8.3) If \( B^2 - 4AC = 0 \), then \( \pi_m^{D} \geq \pi_m^{B} \). If and only if \[ \frac{1-\beta_c}{1-\beta_c} = \frac{-B}{2A} \], \( \pi_m^{D} = \pi_m^{B} \).

Figure 6: Profits of manufacturer under differentiated pricing and Bertrand competitive pricing

6. Effect of substitutability and proportion of green consumers on profits for dealer and manufacturer

6.1 Effect on profits of dealer

Considering different pricing strategies and channel structures, we analyze the effect of
the substitutability and the proportion of green consumers on the profit differences \( \left( \pi_d^{\text{NR}} - \pi_d^{\text{BR}} \right) \) of the dealer in Channel I as well as \( \left( \pi_{d(n)}^{\text{BR}} - \pi_{d(n)}^{\text{NR}} \right) \) and \( \left( \pi_{d(r)}^{\text{BR}} - \pi_{d(r)}^{\text{NR}} \right) \) in Channel II.

**Proposition 9:** Within the feasible region of \( \mu \) and \( \theta \), if \( w_n = w_r \), then \( \left( \pi_d^{\text{NR}} - \pi_d^{\text{BR}} \right) \) is the convex function with respect to \( \mu \) (\( \mu^* = 0.5 \), \( \left( \pi_d^{\text{BR}} - \pi_d^{\text{NR}} \right) = 0 \)) and the monotonically increasing function with respect to \( \theta \); \( \left( \pi_{d(n)}^{\text{BR}} - \pi_{d(n)}^{\text{NR}} \right) \) is the monotonically increasing function with respect to \( \mu \) and the concave function with respect to \( \theta \) \( (\theta^* \approx 0.871 \), reaching the maximization); \( \left( \pi_{d(r)}^{\text{BR}} - \pi_{d(r)}^{\text{NR}} \right) \) is the monotonically decreasing function with respect to \( \mu \) and the concave function of \( \theta \) \( (\theta^* = 0.803 \) reaching the maximization). In addition, \( \left( \pi_d^{\text{BR}} - \pi_d^{\text{NR}} \right), \left( \pi_{d(n)}^{\text{BR}} - \pi_{d(n)}^{\text{NR}} \right) \) and \( \left( \pi_{d(r)}^{\text{BR}} - \pi_{d(r)}^{\text{NR}} \right) \) are non-negative.

**Corollary 3:** When \( w_n > w_r \), if and only if

\[
\theta_0 = -\frac{(1 - \beta w_n)/(1 - \beta w_r) + \sqrt{(1 - \beta w_r)^2/(1 - \beta w_n)^2 + 8}}{2}, \quad \pi_{d(n)}^{\text{BR}} - \pi_{d(n)}^{\text{NR}} = 0.
\]

On the other hand, if \( \theta > \theta_0 \), then \( \left( \pi_{d(r)}^{\text{BR}} - \pi_{d(r)}^{\text{NR}} \right) < 0 \).

When \( w_n = w_r \) and \( w_n > w_r \), the profit differences of the dealer are shown in the figure 7 and figure 8 below under different pricing strategies and channel structures.

**Figure 7:** Effect of \( \mu \) and \( \theta \) on profits of dealer where \( w_n = w_r = 8 \)

**Figure 8:** Effect of \( \mu \) and \( \theta \) on profits of dealer where \( w_n = w_r = 10 \)

From proposition 9, corollary 3, figure 7 and 8, some managerial implications are shown as follow.
(1) When \( w_n = w_r \), differentiated pricing strategy has more advantages on profits than undifferentiated pricing strategy for larger product substitutability (\( \theta \rightarrow 1 \)) and more distinct product preference (\( \mu \rightarrow 1 \) or \( \mu \rightarrow 0 \)) in Channel I and there is a optimal product substitutability \( \theta^* \) to maximize the profit differences \( (\pi^{S*}_{d(n)} - \pi^{R*}_{d(n)}) \) and \( (\pi^{S*}_{d(r)} - \pi^{R*}_{d(r)}) \) for different proportion of green consumers in Channel II.

(2) When \( w_n > w_r \), differentiated pricing still has obvious advantages where \( \mu > 0.5 \), \( \theta > 0.5 \), but the advantage is weakened under the other cases in Channel I. In addition, Stackelberg game pricing strategy similarly has advantages and there exists a threshold \( \theta_0 \) to ensure \( (\pi^{S*}_{d(n)} - \pi^{R*}_{d(n)}) = 0 \) for new products. Meanwhile, when the product substitutability \( \theta > \theta_0 \), Bertrand game pricing strategy is profitable for remanufactured products in Channel II.

6.2 Effect on profits of manufacturer

In order to further discuss the effect of the product substitutability and the proportion of green consumers on the profits of the manufacturer under different pricing strategies and channel structures, we analyze the profit differences \( (\pi^{D'}_{m} - \pi^{N'}_{m}) \) of Channel I, \( (\pi^{B'}_{m} - \pi^{S'}_{m}) \) of Channel II.

**Proposition 10:** Within the feasible region of \( \mu \) and \( \theta \), if \( c_n = c_r \), then \( (\pi^{D'}_{m} - \pi^{N'}_{m}) \), \( (\pi^{B'}_{m} - \pi^{R'}_{m}) \) are the convex functions with respect to \( \mu (\mu^B = 0.5 \), reaching the maximization), \( (\pi^{D'}_{m} - \pi^{S'}_{m}) \) and \( (\pi^{B'}_{m} - \pi^{R'}_{m}) \) are the monotonically increasing functions with respect to \( \theta \), \( (\pi^{B'}_{m} - \pi^{D'}_{m}) \) is a increasing function with respect to \( \theta \) when \( \mu \) is near to 0.5. Besides all of \( (\pi^{B'}_{m} - \pi^{N'}_{m}) \), \( (\pi^{B'}_{m} - \pi^{S'}_{m}) \) and \( (\pi^{B'}_{m} - \pi^{D'}_{m}) \) are non-negative.

When \( c_n = c_r \) and \( c_n > c_r \), the changes of \( (\pi^{D'}_{m} - \pi^{N'}_{m}) \), \( (\pi^{B'}_{m} - \pi^{S'}_{m}) \) and \( (\pi^{B'}_{m} - \pi^{D'}_{m}) \) are shown in figure 9 and 10 with regard to \( \mu \) and \( \theta \).

Figure 9: Effect of \( \mu \) and \( \theta \) on profits of manufacture where \( c_n = c_r = 6 \)
Figure 10: Effect of $\mu$ and $\theta$ on profits of manufacture where $c_n = 8, c_r = 6$

From proposition 10, figure 9 and 10 the following managerial implications can be obtained.

(1) If $c_n = c_r$, for larger product substitutability and more distinct product preference ($\mu \to 0$ or $\mu \to 1$), differentiated pricing of Channel I and Bertrand game pricing of Channel II can bring more profits to the manufacturer. Whereas, especially for indistinct product preference ($\mu$ is near 0.5) and larger product substitutability, Bertrand game pricing strategy of Channel II is more profitable than differentiated pricing strategy of Channel I.

(2) On the other hand, If $c_n > c_r$, in the case of larger product substitutability smaller proportion of green consumers ($\mu \to 0$), the advantages on differentiated pricing of Channel I and Bertrand game pricing of Channel II are significantly decreased for the manufacturer. However, under larger product substitutability and proportion of green consumers ($\mu \to 1$), either of them still has obvious advantages. In addition, the profit differences $\left( \pi_m^{BP} - \pi_m^{DP} \right)$ begin to be negative.
7. Conclusions

In this paper, we explore the pricing mechanism of new and remanufactured products as a marketing strategy with a major impact on the firm’s profits in two-stage supply chain composed of the manufacturer and dealer. The distribution channel of the products adopts two kinds of structure: (1) new and remanufactured products are simultaneously sold by identical dealer (Channel I); (2) they are respectively sold by two competing dealers (Channel II). We investigate differentiated pricing and undifferentiated pricing in Channel I, as well as Bertrand and Stackelberg competitive pricing in Channel II. Our results show that the profits of the firms are affected by the factors such as the pricing strategy, the channel structure, the substitutability and the proportion of green consumers.

Pricing strategy

In Channel I, differentiated pricing is a dominant strategy compared to undifferentiated pricing for the dealer and manufacturer (see proposition 2 and proposition 6).

In Channel II, the profits of the dealer selling new products under Stackelberg game equilibrium are exceed those under Bertrand game equilibrium (see proposition 4), whereas the profit differences of the dealers selling remanufactured products under the two equilibriums depend on the tradeoff between the wholesale price and product substitutability (see proposition 5). For the manufacture, Bertrand competitive pricing can bring more profits than Stackelberg competitive pricing (see proposition 7).

Channel structure

Under differentiated pricing of Channel I and Bertrand game pricing of Channel II, the profit differences of the manufacturer depend on the tradeoff among the production costs, the product substitutability and the proportion of green consumers (see proposition 8).

Substitutability and proportion of green consumers

Profit differences caused by pricing strategies and channel structures are affected by the product substitutability and the proportion of green consumers. For the dealer and manufacturer, the appropriate choice of pricing strategies and channel structures should highlight the matching between the product substitutability and the proportion of green consumers, as well as consider the wholesale price or the production costs of new and re-manufactured products (see proposition 9 and 10).

This paper takes an important step towards understanding the mixed sale of new and remanufactured products. As this area of research expands, it is important to coordinate the conflicts causing by pricing strategies and channel structures between manufacturers and dealers. That is the topic of our future research.

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