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Pricing Strategy of Dual-Channel Closed-Loop Supply Chain Considering Quality of Recycled Mobile Phone and Effort Cost

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Abstract. In the age of mobile Internet, as a kind of unique and necessary fast consumer electronic product with product volume, function attribute and value content, mobile phone's recycle and reuse have become a widely concerned social problem. Considering the influence of the quality level and effort cost of recycled mobile phones on the recycling profit, this paper constructs a decision-making model of the dual-channel mobile phone closed-loop supply chain composed of the manufacturer, distributor and the third-party online recycling platform to solve the optimization problem of the dual-channel closed-loop supply chain. This paper gains the optimal retail price and the quality level of recycled mobile phones under decentralized and centralized decision-making by applying the game theory. The results show that the total profit and mobile phone quality level of closed-loop supply chain are higher than that of decentralized decision, too much efforts cost can lead to the loss of phone quality and profits, the quality of recycled mobile phone and effort cost is the key to the profit of supply chain.

Keywords: Closed-loop supply chain, Dual-channel, Recycle quality, Effort cost.

1. Introduction

At present, mobile phone has become necessary fast-moving products for people's life, and the rate of upgrading is constantly increasing. However, due to its physical characteristics, functional attributes and defects in recycling systems, a large number of high-quality and high-residual value "abandoned mobile phones" are left unused by consumers, while the residual value loss and environmental pollution of idle mobile phones cause huge resource waste and severe environmental safety problems. The effective recycling and reuse of abandoned mobile phones has become a new social problem that needs to be solved urgently. It is also a new source of income, new sources of profit and new service challenges that mobile phone manufacturers, distributors and recyclers need to pay attention to. The rapid application of mobile Internet technology and electronic payment technology has created a new dual-channel closed-loop supply chain model of Internet plus recycling and distributors, which has break through the technical bottlenecks, information barriers and space-time constraints of product sales and recycling transactions among members, and greatly improves the performance of the whole closed-loop supply chain of mobile phone sales and recycling. However, in order to maintain the efficient and sustainable operation of the closed-loop supply chain, while maintaining the sales volume of mobile phones, ensuring the quality and quantity of recycled mobile phones becomes the key to affect the performance of the closed-loop supply chain, which inevitably leads to the problem of recycling mobile phone quality and effort cost[1]. However, the remanufactured profit is affected by the quality level indicators such as the coloration, configuration integrity, category level, service life and maintenance status of the recycled mobile phone, while the quality level of the recycled mobile phone is affected by the recycling effort cost paid by distributors and platforms. Therefore, we study the influence of recycling mobile phone quality and effort cost on dual-channel mobile phone closed-loop supply chain.

2. Literature Review

The impact of recycled product quality on the closed-loop supply chain has traditionally received widespread attention from industry and academia. Liu et al., established a two-channel price competition model considering the quality of recycled products and involved formal and informal recycling, the optimal pricing and government subsidy effects of recycled products were compared for four competition scenarios [2].Pokharel et al., studied the optimal purchase price and quantity of recycled products by establishing the quality analysis model of remanufactured products and the quality evaluation index system[3].Watanabe et al., studied the optimal recycling decision-making problem considering the quality level of recycled products based on the analysis of the relationship between the incentive policy of waste products recycling and the quality of recycled products[4]. Zhou et al., studied the closed-loop supply chain recycling channel selection considering the quality level of recycled products[5].Zou et al., discussed the pricing and coordination of closed-loop supply chains for the proportion of recycled parts that can be used and the quality differences affecting the cost of remanufactured products[1]. However, in the actual operation of the closed-loop supply chain, the cost of product sales and recycling is required, and the amount of product recycling and quality improvement require effort. Ha et al., studied the supply chain coordination mechanism whose demand is affected by retail prices and retailer sales efforts [7]. Zhao et al., studied the two-level supply chain coordination problem considering retail price and sales effort [8].

3. Closed-loop Supply Chain Decision Model

3.1 Problem Description

This paper considers the closed-loop supply chain of dual-channel mobile phones consisting of a single manufacturer, distributor and third-party online recycling platform (referred to as platform) as shown in Fig. 1.During the operation of the closed-loop supply chain, The manufacturer first wholesales the phone to the distributor at a unit price of w, then the distributor sells the phone to consumers at unit price p, and the manufacturer collects the phone through the distributor and platform. We assume that the mobile phone recycling price is positively correlated with its quality level $\theta(0<\theta<1)$, and the highest unit price of the distributor and platform recycling mobile phones are r and $d\,(r,d>0)$ .Distributor and platform both can assess the quality level of the recovered mobile phone, and the cost of quality level assessment of a single mobile phone is c_1 and c_2.We assume the quality level values are θ_r and θ_d $(0<\theta_r,\theta_d<1)$, and the unit price of mobile phone recycling can be expressed as $p_r(\theta_r)=r\theta_r$ and $p_d(\theta_d)=d\theta_d$. At the same time, in order to save the cost of mobile phone inspection, manufacturers have repurchased mobile phones from distributors and platforms for uniform unit price p_m $(p_m>r,d)$, and there is no quality difference between remanufactured mobile phone products and new products.

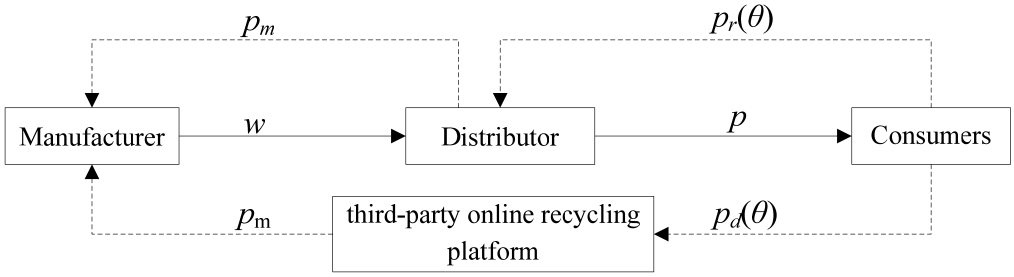

Figure. 1 Dual-channel closed-loop supply chain model

We assume that the unit production and remanufacturing costs of mobile phones are c_m and $c_s(\theta)$ $(c_m,\ c_s(\theta)>0)$, and $c_s(\theta)$ is a monotonic decreasing function for θ. According to the literature [2], $c_s(\theta)=\frac{c_n}{\theta}$, c_n is the remanufacturing cost coefficient. When $\theta=1$, the remanufacturing cost is c_n; when $\theta=0$, no remanufacturing is performed.

The mobile phone sales volume q is a linear function of the sales price p, that is, $q=\alpha-\beta p$, where α is the market's maximum demand, β is the consumer's sales price sensitivity coefficient, and the distributor and platform recycle the quality level of θ for:

$$q_r(\theta)=ap_r(\theta)-bp_d(\theta)=(ar-bd)\theta \tag{1}$$

$$q_d(\theta)=ap_d(\theta)-bp_r(\theta)=(ad-br)\theta \tag{2}$$

Among them, a is the recycling price sensitivity coefficient, and b is the competition coefficient between the distributor and the platform. In the above model, the higher the quality level of the recycled mobile phone, the greater the cost of recycling efforts. The cost of mobile phone recycling efforts for distributors and platforms is m_1 and m_2 $(m_1, m_2>0)$, and the corresponding recycling phone effort costs can be expressed as $m_r(\theta_r)=m_1\theta_r^2$ and $m_d(\theta_d)=m_2\theta_d^{\ 2}$.

3.2 Centralized Decision Model

Under the centralized decision-making, the profit of the mobile phone closed-loop supply chain is the sum of the profit of the manufacturer, distributor and platform. The manufacturer, distributor and platform all aim to maximize the overall profit of the supply chain system, so the following optimal decision-making model can be established.

$$\max_{p,\theta}\pi^C=(p-c_m)q+(c_m-c_s(\theta))(q_r(\theta)+q_d(\theta))-p_r(\theta)q_r(\theta)-p_d(\theta)q_d(\theta)-c_1q_r(\theta)-c_2q_d(\theta)-(m_1+m_2)\theta^2 \tag{3}$$

We assume that $t_1=ar-bd$, $t_2=ad-br$. Solving (3), it can be determined that the optimal unit sales price and recovery quality level of the mobile phone are respectively $p^{C*}=\frac{\alpha+\beta c_m}{2\beta}$ and $\theta^{C*}=\frac{(c_m-c_1)t_1+(c_m-c_2)t_2}{2(rt_1+dt_2+m_1+m_2)}$. At this point, the maximum total profit of the closed-loop supply chain is:

$$\pi^{C*}=\frac{(\alpha-\beta c_m)^2}{4\beta}+\frac{((c_m-c_1)t_1+(c_m-c_2)t_2)^2}{4(rt_1+dt_2+m_1+m_2)}-c_n(t_1+t_2) \tag{4}$$

3.3 Decentralized Decision Model

Under decentralized decision-making, manufacturers, distributors and platforms compete with each other with the goal of maximizing profit, thus forming a Stackelberg game in which manufacturers lead, distributors and platforms follow. The manufacturer first determines the wholesale price w and recycling price p_m, the distributor determines the retail price p, and then the distributor and the platform determine the quality level of recycling mobile phone which are θ_r and θ_d respectively. Thus, the following optimal decision models of manufacturer, distributor and platform can be constructed respectively.

$$\max_{w}\pi_m^D=(w-c_m)q+(c_m-p_m)(q_r(\theta_r)+q_d(\theta_d))-c_s(\theta_r)q_r(\theta_r)-c_s(\theta_d)q_d(\theta_d) \tag{5}$$

$$\max_{p,\theta_r}\pi_r^D=(p-w)q+(p_m-p_r(\theta_r)-c_1)q_r(\theta_r)-m_1\theta_r^{\ 2} \tag{6}$$

$$\max_{\theta_d}\pi_d^D=(p_m-p_d(\theta_d)-c_2)q_d(\theta_d)-m_2\theta_d^{\ 2} \tag{7}$$

According to the above model, and using the inverse induction method, it can be determined that the optimal recycling mobile phone quality level of the platform and the distributor is respectively $\theta_d^{D*} = \frac{(p_m - c_2)t_2}{2(dt_2 + m_2)}$ and $\theta_r^{D*} = \frac{(p_m - c_1)t_1}{2(rt_1 + m_1)}$. The optimal sales and wholesale prices are respectively $p^{D*} = \frac{3\alpha + \beta c_m}{4\beta}$ and $\omega^{D*} = \frac{\alpha + \beta c_m}{2\beta}$.Correspondingly, we can be determined that the maximum profit of the manufacturer, distributor, and platform are

$$\pi_d^{D*} = \frac{(p_m - c_2)t_2}{4(dt_2 + m_2)} \tag{8}$$

$$\pi_r^{D*} = \frac{(\alpha - \beta c_m)^2}{16\beta} + \frac{(p_m - c_1)t_1}{4(rt_1 + m_1)} \tag{9}$$

$$\pi_m^{D*} = \frac{(\alpha\text{-}\beta c_m)^2}{8\beta} + (c_\text{m} - p_m)\left(\frac{(p_m - c_1)t_1^2}{2(rt_1 + m_1)} + \frac{(p_m - c_2)t_2^2}{2(dt_2 + m_2)}\right) - c_n(t_1 + t_2) \tag{10}$$

Proposition 1. $p^{C*} < P^{D*}, \theta^{C*} > \theta_r^{D*}, \theta^{C*} > \theta_d^{D*}$, and $\pi^{C*} > \pi^{D*} = \pi_m^{D*} + \pi_r^{D*} + \pi_d^{D*}$.

Conclusion 1 shows that under the decentralized decision-making, there is a higher retail price, a lower quality of the recovered mobile phone, and the overall profit of the supply chain is less than the total profit under the centralized decision, which has a large optimization space.

Proposition 2. When the manufacturer recycles mobile phones at:

$$\frac{(c_m + c_1)(dt_2 + m_2)t_1^2 + (c_m + c_2)(rt_1 + m_1)t_2^2}{2\left((dt_2 + m_2)t_1^2 + (rt_1 + m_1)t_2^2\right)}$$

they make the most profit.

Proof. As can be seen from $\pi_m^{D*} = \frac{(\alpha\text{-}\beta c_m)^2}{8\beta} + (c_\text{m} - p_m)\left(\frac{(p_m - c_1)t_1^2}{2(rt_1 + m_1)} + \frac{(p_m - c_2)t_2^2}{2(dt_2 + m_2)}\right) - c_\text{s}(t_1 + t_2)$, π_m^{D*} is a concave function for p_m. When $\frac{\partial \pi_m^{D*}}{\partial p_m} > 0$, the manufacturer's profit increases with the increase of p_m; when $\frac{\partial \pi_m^{D*}}{\partial p_m} < 0$, the manufacturer's profit decreases with the increase of p_m. When $\frac{\partial \pi_m^{D*}}{\partial p_m} = 0$, there is $p_m = \frac{(c_m + c_1)(dt_2 + m_2)t_1^2 + (c_m + c_2)(rt_1 + m_1)t_2^2}{2\left((dt_2 + m_2)t_1^2 + (rt_1 + m_1)t_2^2\right)}$, at which point the manufacturer is the most profitable.

According to the decision-making model, the manufacturer can only control the quality of recycled mobile phones by recycling prices. If the manufacturer's recycling prices is too high, the manufacturer's recycling cost will be too high; if the manufacturer recycling price is too low, the poor quality of recycled mobile phones will lead to excessive manufacturing remanufacturing costs. So the manufacturer's optimal recycling phone price is $\frac{(c_m + c_1)(dt_2 + m_2)t_1^2 + (c_m + c_2)(rt_1 + m_1)t_2^2}{2\left((dt_2 + m_2)t_1^2 + (rt_1 + m_1)t_2^2\right)}$.

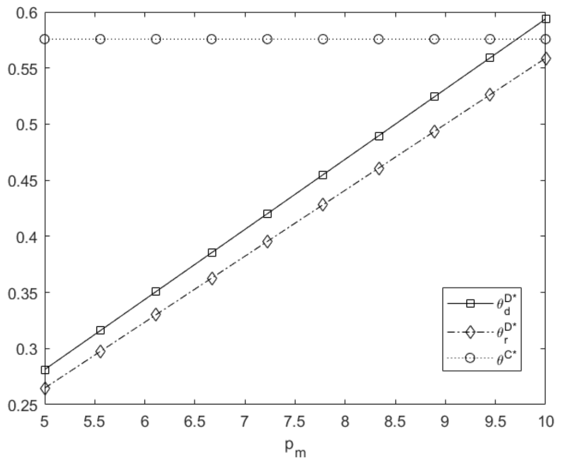

Figure. 2 Recycling mobile phone quality at different p_m

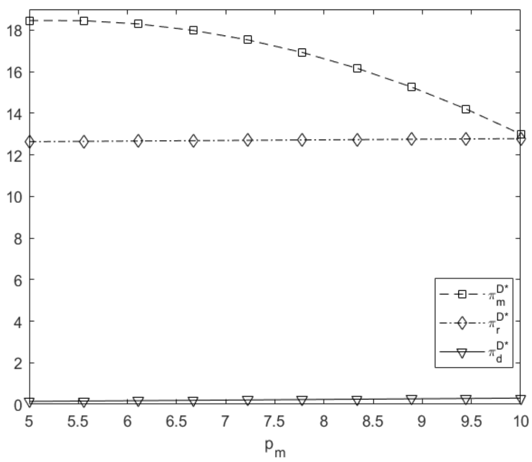

Figure. 3 Profit at different p_m

The influence of manufacturer's recycled mobile phone price on the quality and profit of recycled mobile phone is shown in figure 2 and figure 3. Figure 3 shows that under the decentralized decision, the quality level of recycled mobile phones increases with the increase of the manufacturer's recycling price, and the quality level under centralized decision-making is the highest.Figure 4 shows that manufacturer's profits rise and fall as the price of their recycled phones rises. The distributor and platform profits rise as the manufacturer's recycling price rises.

4. Conclusion

This paper constructs a closed-loop supply chain decision-making model for dual-channel mobile phones consisting of manufacturers, distributors and platforms, and considers the influence of the quality level and effort cost of recycled mobile phones on the recycling profit. The study found: (1) Under the decentralized decision-making, there is a higher mobile phone retail price, a lower quality of the recycled mobile phone, and the total profit of the closed-loop supply chain of the mobile phone is smaller than the centralized decision;(2) Manufacturers can improve the quality of recycled mobile phones by raising the recycling price, but the excessive recycling price will lead to the loss of manufacturers' profits.

Acknowledgments

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