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Research on the Pricing Strategy of Remanufacturing Used Cell Phones under the Carbon Emission Right Constraint

Gengjun Gao[1], Mingtao Mo[2,*]

[1]Logistics Research Center, Shanghai Maritime University, Shanghai, China

[2]Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 200120, China

Abstract

Under the carbon emission right constraint, the closed-loop supply chain model of remanufactured goods/new cell phones, including manufacturer, agent, and user, is built for the characteristics of high demand, rapid renewal, and high recycling value of cell phone products. Meanwhile, a supply chain profit maximization model is established accordingly, and factors such as optimal product pricing, recycling quality level, carbon emission price, and carbon emission reduction input are attributed to the product price impact from the rational human perspective and numerical simulation analysis is conducted to maximize profit expectation while enhancing the sustainability of cell phone market. Research shows that with the rise of carbon trading price, the price of remanufactured cell phone is more advantageous, and the agent's profit is decreasing and then increasing; with the increase of emission reduction measures, the manufacturer's profit increases and then decreases, and the marginal cost advantage of low carbon emission of the remanufactured cell phone will decrease.

Keywords

Carbon Emission Rights; Recycling of Used Mobile Phones; Price; Game Theory.

1. Introduction

With the establishment of the "double carbon" target and the gradual formation of the carbon emission trading market, more and more production-oriented enterprises and users are beginning to pay attention to the energy-saving and environmental protection and sustainability of the products themselves. For electronic products such as cell phones, due to their high demand and rapid renewal, and the high pollution and high-value characteristics of used products, if they can be properly recycled, they will not only greatly save resources and reduce the impact of waste materials on the environment, but also effectively reduce the carbon emissions in the production process. Currently, the remanufactured cell phones sold in the market are remanufactured by recycling used cell phones and using their residual value to achieve resource recycling, energy-saving, and emission reduction[1]. Usually, for the two types of cell phone products, new products and remanufactured products, due to their different costs and pricing, the profit level will also be different, and enterprises as rational people will arrange the production of both types of cell phones in the case of profit maximization. And under the carbon emission right constraint, the remanufactured product cell phone has the obvious advantage of low carbon and low manufacturing cost, which is important to enhance the overall sustainability of the cell phone product industry. For this reason, it is necessary to combine relevant elements and analyze the relevant influencing factors of the two types of products in the new environment from the perspective of rational people in an integrated manner, to help all supply chain participants to maximize their benefits in green and low-carbon.

In studies on recycling of used electronics, scholars have considered more the government's incentive behavior for recycling of used electronics rather than entirely from a pure market perspective. Zuoan Togo et al[2] constructed a dynamic and static game model of government, producers, and consumers in the closed-loop supply chain of electronic products based on the extended producer responsibility system, and proved that government decisions affect the motivation of producers and consumers to participate in the closed-loop supply chain. Xiqiang Xia et al[3] constructed a game model of recyclers and processors under different government subsidy strategies based on two recycling models, single-channel and dual-channel, and proved that in single-channel recycling, different subsidy targets do not affect the recycling quantity. Wang Zhong[4] studied the coordination problem of a single-channel electronics supply chain based on promotional efforts and found that the coordination state can be achieved under the benefit sharing-cost sharing contract when promotional efforts and sales price affect market demand at the same time. Csheng-Kang Chen et al [5] studied that manufacturers seek profit maximization by considering the optimal behavior of agents and independent third parties and proved that under the reward and punishment mechanism, recycling used products are more effective when the manufacturer cannot offer a higher transfer price.B.C. Giri et al[6] study forward dual-channel and reverse dual-channel for manufacturers selling products to customers through traditional retail channels and Internet channels and demonstrate that the agent-led decentralization scheme is more profitable.

In the research on closed-loop supply chain game, scholars have studied recycling channels, low-carbon emission reduction, and market demand, but the combination with carbon market is missing in the research on carbon emission and emission reduction. Chen et al[7] established a closed-loop supply chain model with competitive dual-channel sales and multi-channel recycling under four reward and penalty mechanisms; and demonstrated that when the recycling price coefficient is small compared with the competition coefficient of recycling channels, manufacturers will choose a mixed recycling channel of manufacturers and third-party recyclers. Yu et al[8] analyzed the effects of carbon reduction per unit of low-carbon product, retailer sales effort, and fairness concern on manufacturers' and retailers' decisions and utilities, and found that in a manufacturer-led supply chain, manufacturers are mostly the profitable party regardless of which party has fairness concern and concern level. Qian Yutian[9] studied three models of direct recycling by manufacturers, separate recycling by retailers, and recycling by third-party recyclers, and found that the increase in the quality of recycled product and the maximum recycling price increased the price of used products, but had opposite effects on the decisions of supply chain members. Jian Li et al[10] studied a three-tier reverse supply chain consisting of recyclers, remanufacturers, and agents with complete information sharing, revealing the potential market demand for remanufactured products in the reverse supply chain and the impact of utilization of used products. Liwen Liu et al[11] studied three options for OEMs (dual recycling model of OEM and agent, dual recycling model of agent and third party, and dual recycling model of OEM and third party) and proved that the dual collection model of OEM and agent is the best choice in any case.

This paper introduces carbon trading into the cell phone supply chain from the perspective of a rational person, and constructs a closed-loop supply chain (CLSC) game model that includes manufacturers, agents, and users, and integrates purchasing, production, sales, and recycling to serve the whole life cycle of cell phone products. At the same time, this paper takes profit expectation as the goal and attributes various factors to product price, and considers the impact of carbon emission trading price, recycling quality level of used cell phones, and carbon emission reduction investment of manufacturers for the pricing and sustainability of remanufactured and new cell phone products. The aim is to improve the sustainability of products while ensuring profits. The main parameters of the model are analyzed through simulation, and recommendations for product pricing and sustainability are provided.

2. Problem Description and Conditional Assumptions

2.1. Problem Description

Generally speaking, cell phones supplied in the market can be divided into two categories: remanufactured products and new products. Due to the advantages of remanufactured products in resource recycling, energy-saving, and emission reduction, they have received more and more attention from manufacturers and users in recent years. In this model, cell phone manufacturers have the ability to produce, recycle and remanufacture at the same time, while agents are responsible for selling remanufactured and new cell phones to consumers, without considering the intervention of the government and other third parties, the model involves the subjects of cell phone manufacturers M, sales agents S and users C, as shown in Figure 1.

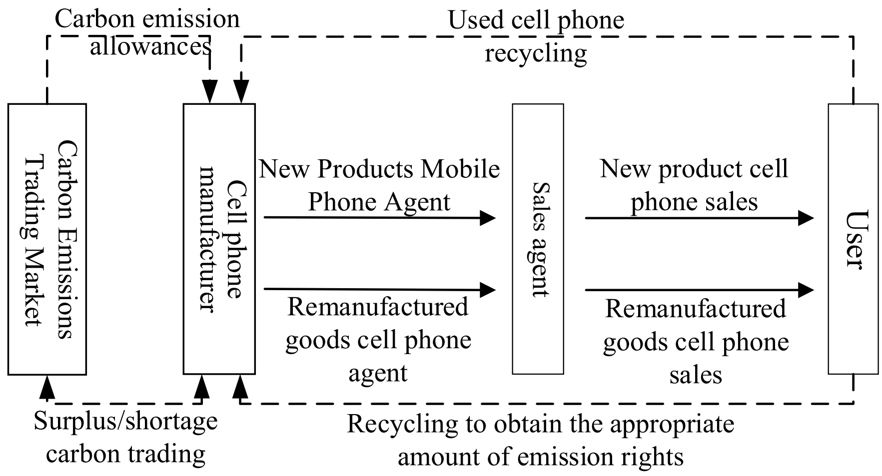

Figure 1. Supply chain process of remanufactured goods/new cell phone

The recycling of used cell phones by cell phone manufacturers is mainly based on the recycling of the whole machine, and based on which remanufactured cell phones are produced and delivered to the agents for sale. Since there is a certain residual value of used cell phones and some of their parts can be put into use directly after renewal, which makes the remanufacturing process save some processes and raw materials compared with the production of new products, so the remanufacturing cost of used cell phones is lower compared with the manufacturing cost of new cell phones, and the manufacturing carbon emission is also lower. At the same time, according to the carbon market rules such as "Carbon Emission Rights Registration Management Rules (Trial Implementation)" and "Carbon Emission Rights Trading Management Rules (Trial Implementation)", cell phone manufacturers will get a certain amount of free emission allowance, and the part of emission allowance exceeded in the manufacturing process needs to pay the corresponding emission tax, while the surplus part can be sold for profit[12]. Based on this, cell phone manufacturers and agents, as rational persons in the market, need to develop pricing strategies for remanufactured and new cell phones under the premise of maximizing their expected profits, while the price is also related to the market demand. Based on the above, from the rational person perspective, this paper attributes various factors to the product price to study the market for both remanufactured and new cell phones. The specific symbols are set as in Table 1.

Table 1. Symbol setting table

Symbols	Meaning
D	The potential demand for cell phones in the market during a certain period.
D_1, D_2	The market demand for remanufactured and new products.
β	The coefficient of influence of the demand for a product by price fluctuations.
γ	The cross-effect coefficient of price between two mutual substitutes.
ψ	The degree of preference for low-carbon products in the market.
η_1, η_2	The profit level of manufacturers producing remanufactured and new products.
μ_1, μ_2	The profit level of agents selling remanufactured and new products.
π_t	The profit level of manufacturers selling carbon credits
c_1, c_2	The unit production cost of manufacturers producing remanufactured and new products.
θ	The level of quality of recovered used cell phones, $\theta \in (0,1)$, with a higher value indicating a lower level of wear and tear of the recovered used cell phones.
t_1, t_2	The carbon emissions per unit of production of remanufactured and new products.
q	Free carbon credits available to manufacturers
q	The unit price of carbon credits.
w_1, w_2	The wholesale price per unit for the sale of remanufactured and new products by the manufacturer.
p_1, p_2	The retail price per unit for the sale of remanufactured and new products by agents.
R	The recycling price of used cell phones.

2.2. Conditional Assumptions

To facilitate the study, the following assumptions are made.

In the market situation at a certain time, the potential demand for a brand of the cell phone in the market is D unit, which can be considered to be composed of the demand for D_1 units of new cell phones and the demand for D_2 units of remanufactured products cell phones, and the demand is affected by its price, the price of substitutes and the low carbon preference in the market, and there is a relationship of $D_1 = D - \beta P_1 + \gamma P_2 - \psi t_1$ and $D_2 = D - \beta P_2 + \gamma P_1 - \psi t_2$. Usually, the product demand is more affected by the fluctuation of its price β than by the fluctuation of the price of substitutes γ, and the demand is more affected by the price than by the user preference, i.e. $\beta > \gamma > \psi$.

In the decision of manufacturer and agent, both parties decide the profit level based on experience, and the price of two types of cell phones can be considered to be composed of expected profit level, production cost, carbon emission cost and recycling cost of used cell phones, i.e., $p_1 = \eta_1 + \mu_1 + c_1 + p_e t_1$ and $p_2 = \eta_2 + \mu_2 + c_2 + p_e t_2 + R$. Meanwhile, the relationship between the production cost c_1 of new cell phones and the remanufactured cost c_2 of remanufactured products cell phones satisfies $c_2=(1-\theta)c_1$, indicating that the higher the quality of recycled used cell phones, the remanufactured cost is lower.

In terms of carbon emissions, the unit carbon emissions of producing remanufactured and new cell phones are t_1 and t_2 respectively, while the unit carbon emissions of remanufactured cell phones are $t_2=(1-\theta)t_1$ due to saving part of the process. meanwhile, in the carbon trading market, manufacturers can get a certain amount of free carbon emission allowance T, while the trading price of each unit of carbon emission right is q. After the emission exceeds the free emission right allowance, they need to pay a certain fee The surplus emission rights can be traded in the carbon trading market for profit.

To enhance the abatement capacity, the producer invests the abatement technology enhancement cost as $c(\tau)$. According to the input-output relationship, there are $c(\tau)=\frac{h\tau^2}{2}$, τ is the abatement volume and h is the cost impact factor for emission reductions [13].

3. Model Building and Analysis

3.1. Modeling

Based on the above model and assumptions, the profit expectation of the cell phone manufacturer consists of the profit expectation of producing remanufactured and new products, the profit from carbon trading, and the technical input, then the profit expectation $E(M)$ of the manufacturer is.

$$E(M)=E(\eta_1)+E(\eta_2)+E(\pi_t)-C(\tau) \tag{1}$$

Among them, the profit expectation $E(\eta_1)$ for producing new cell phones is:

$$E(\eta_1)=\eta_1(D-\beta(\eta_1+\mu_1+c_1+p_et_1)+\gamma(\eta_2+\mu_2+c_2+p_et_2+R)-\psi t_1) \tag{2}$$

The profit expectation $E(\eta_2)$ for the production of remanufactured goods cell phones is

$$E(\eta_2)=\eta_2(D-\beta(\eta_2+\mu_2+c_2+p_et_2+R)+\gamma(\eta_1+\mu_1+c_1+p_et_1)-\psi t_2) \tag{3}$$

The profit $E(\pi_t)$ from the sale of carbon credits is

$$E(\pi_t)=q(T-D_1t_1-D_2t_2+\tau) \tag{4}$$

Similarly, agents determine the retail profit levels μ_1 and μ_2 for remanufactured and new products based on the manufacturer's decision, and the profit expectation $E(S)$ for selling the two types of cell phones is

$$\begin{aligned}E(S)&=E(\mu_1)+E(\mu_2)\\&=\mu_1[D-\beta(\eta_1+\mu_1+c_1+p_et_1)+r(\eta_2+\mu_2+c_2+p_et_2+R)-\psi t_1]\\&\quad+\mu_2[D-\beta(\eta_2+\mu_2+c_2+p_et_2+R)+\gamma(\eta_1+\mu_1+c_1+p_et_1)-\psi t_2]\end{aligned} \tag{5}$$

3.2. Model Analysis

In the model, since the cell phone agents set the retail price based on the manufacturer's wholesale price, it can be considered that the cell phone manufacturer is the dominant player and the agents are the followers in the whole game process, which constitutes the Stackelberg game model [14]. In the model, the cell phone producer determines the profit level η_1 for the production of new cell phones, the profit level η_2 for the production of remanufactured machines, and the recycling price R for used cell phones according to experience and market forecasts, with the goal of profit maximization. subsequently, the agent sets the profit level μ_1 for the sale of new cell phones and the profit level μ_2 for the sale of remanufactured cell phones on this basis.

Using the inverse induction method, the Hessian matrix [15] of the agent's expected profit $E(S)$ can be obtained from equation (5) as:

$$H_{E(S)} = \begin{bmatrix} \frac{\partial^2 E(S)}{\partial \mu_1^2} & \frac{\partial^2 E(S)}{\partial \mu_1 \partial \mu_2} \\ \frac{\partial^2 E(S)}{\partial \mu_2 \partial \mu_1} & \frac{\partial^2 E(S)}{\partial \mu_2^2} \end{bmatrix} = \begin{bmatrix} -2\beta & 2\gamma \\ 2\gamma & -2\beta \end{bmatrix} \tag{6}$$

The sensitivity coefficient changes from $\beta > 0$, $\frac{\partial^2 E(S)}{\partial \mu_1^2} < 0$, and $\frac{\partial^2 E(S)}{\partial \mu_1^2} < 0$, $|H_{E(S)}| > 0$, so the Hessian matrix of the agent's expected profit $E(S)$ is negative definite, i.e., μ_1 and μ_2 have the only optimal solution that maximizes the agent's expected profit.

Letting the first order derivatives of $E(S)$ with respect to μ_1 and μ_2 be zero, it follows that:

$$\begin{cases} \mu_1^* = \frac{\beta\psi t_1 + \gamma\psi t_2}{2(\gamma^2 - \beta^2)} - \frac{D}{2(\gamma - \beta)} - \frac{\eta_1 + c_1 + p_e t_1}{2} \\ \mu_2^* = \frac{\gamma\psi t_1 + \beta\psi t_2}{2(\gamma^2 - \beta^2)} - \frac{D}{2(\gamma - \beta)} - \frac{\eta_2 + c_2 + p_e t_2 + R}{2} \end{cases} \tag{7}$$

Substituting equation (7) into equation (1) and calculating the first-order partial derivative of $E(M)$ concerning η_1, η_2 and making it equal to zero, we obtain the optimal profit level for producers to produce two types of cell phones.

$$\begin{cases} \eta_1^* = \frac{\psi t_1 \beta + \psi t_2 \gamma}{2(\gamma^2 - \beta^2)} - \frac{D}{2(\gamma - \beta)} - \frac{c_1 + (p_e - q) t_1}{2} \\ \eta_2^* = \frac{\psi t_1 \gamma + \psi t_2 \beta}{2(\gamma^2 - \beta^2)} - \frac{D}{2(\gamma - \beta)} - \frac{c_2 + R + (p_e - q) t_2}{2} \end{cases} \tag{8}$$

Bringing equation (8) into equation (7) yields the optimal profit level for agents selling two types of cell phones.

$$\begin{cases} \mu_1^* = \frac{\beta\psi t_1 + \gamma\psi t_2}{4(\gamma^2 - \beta^2)} - \frac{D}{4(\gamma - \beta)} - \frac{c_1 + (p_e + q) t_1}{4} \\ \mu_2^* = \frac{\gamma\psi t_1 + \beta\psi t_2}{4(\gamma^2 - \beta^2)} - \frac{D}{4(\gamma - \beta)} - \frac{R + c_2 + (p_e + q) t_2}{4} \end{cases} \tag{9}$$

At the optimal profit level, the optimal pricing for the two types of phones is:

$$\begin{cases} p_1^* = \frac{3\left(\beta\psi t_1+\gamma\psi t_2\right)}{4(\gamma^2-\beta^2)} - \frac{3D}{4(\gamma-\beta)} + \frac{c_1+(p_e+q)t_1}{4} \\ p_2^* = \frac{\gamma\psi t_1+\beta\psi t_2}{4(\gamma^2-\beta^2)} - \frac{D}{4(\gamma-\beta)} + \frac{c_2+R+(p_e+q)t_2}{4} \end{cases} \tag{10}$$

The optimal recycling price for used cell phones is:

$$R^* = \frac{D+c_1\left(\gamma-\beta(1-\theta)\right)+t_1\left(\gamma\left(p_e+q\right)-\beta\left(P_e+q\right)(1-\theta)-2\psi(1-\theta)\right)}{\beta} \tag{11}$$

Corollary 1: In carbon trading, as the carbon trading price q becomes larger, the optimal price of both remanufactured and new products increases, but due to the difference in carbon emission costs, the price increase of new products cell phones is larger than that of remanufactured products cell phones. Meanwhile, to maintain the market demand, the profit expectation level of agents rises less, and the profit expectation of agents decreases and then increases with the change of carbon trading price q.

Proof: From the derivative relations $\frac{\partial P_1^*}{\partial q}>0$, $\frac{\partial P_2^*}{\partial q}>0$ and $\frac{\partial P_1^*}{\partial q}>\frac{\partial P_2^*}{\partial q}$ it is known that with the increase of carbon emission trading price, the optimal pricing of both remanufactured and new products rises, and the growth rate of the optimal price of new cell phones is higher than the growth rate of the optimal price of remanufactured products, which is due to the greater carbon emission in the production process of new cell phones, and with the increase of carbon emission trading price, the production cost rises accordingly. At the same time, from $\frac{\partial \eta_1^*}{\partial q}>\frac{\partial \eta_1^*}{\partial q}>0$, $\frac{\partial \mu_1^*}{\partial q}<\frac{\partial \mu_2^*}{\partial q}<0$, it is known that the profit expectation of the producer to produce two types of cell phones is positively related to the carbon emission price, while the profit expectation of the agent to sell two types of cell phones is inversely related to it, and in the agent profit expectation function $E(S)$ about the carbon emission price q, $E''(S)=\frac{4t_1^2\beta+\left(t_1^2-t_2^2\right)\beta-t_1t_2\gamma}{8}>0$, the function is concave, it is known that the agent expectation profit decreases with the increase of carbon emission tax, but starts to grow after reaching a limit.

Corollary 2: In the recycling of used cell phones, the higher the quality θ of used cell phones, the greater the recycling price R of used cell phones, the demand for remanufactured products D_2 increases, and the profit expectation $E(M)$, $E(S)$ of manufacturers and agents are increased, but the profit expectation of agents selling remanufactured products cell phones decreases.

Proof: There are derivative relations $\frac{\partial R^*}{\partial \theta}>0$, $\frac{\partial D_2}{\partial \theta}>0$, $\frac{\partial E(M)}{\partial \theta}>0$, $\frac{\partial E(S)}{\partial \theta}>0$, $\frac{\partial \eta_2^*}{\partial \theta}<0$, $\frac{\partial \mu_2^*}{\partial \theta}<0$. As the recycling quality of used cell phones increases, the recycling price, the sales of remanufactured products, the profit expectation of producers, and the profit expectation of agents all rise, while the profit level per unit of producing and selling remanufactured cell phones decreases.

Corollary 3: The profitability of the manufacturer is affected by the carbon emission reduction input $C(\tau)$. The profit expectation will increase and then decrease with the input of emission reduction measures. And when the product price is affected by the input cost, the marginal cost advantage of low carbon emission of remanufactured cell phones will be reduced, while the profit advantage of new cell phones will be relatively higher, i.e., the price of remanufactured products is more affected by the fluctuation of emission reduction inputs.

Proof: The second-order derivative $E(M)'' < 0$ of the producer's profit expectation $E(M)$ with respect to the emission reduction τ. This indicates that the producer's profit expectation $E(M)$ function is a convex function with respect to the emission reduction τ. The profit expectation increases and then decreases with the increase of the emission reduction and emission reduction input, and there is a relationship of $\frac{\partial P_2}{\partial \tau} > \frac{\partial P_1}{\partial \tau}$.

4. Example Analysis

In order to further verify the validity and rationality of the model, numerical calculations are used for analysis. Taking a brand of the cell phone as an example, the parameters are set based on the logical relationship between parameters mainly considered to meet the assumptions, and the specific values of relevant parameters in the supply chain are set as follows: $D = 500$, $\beta = 0.5$, $\psi = 0.2$, $\gamma = 0.3$, $c_1 = 100$, $t_1 = 10$, $T = 3000$,and the analysis is carried out around the impact of carbon emission price q, the quality level of recycling of used cell phone θ, and carbon emission reduction input $C(\tau)$.

4.1. Impact of Carbon Trading Price *q*

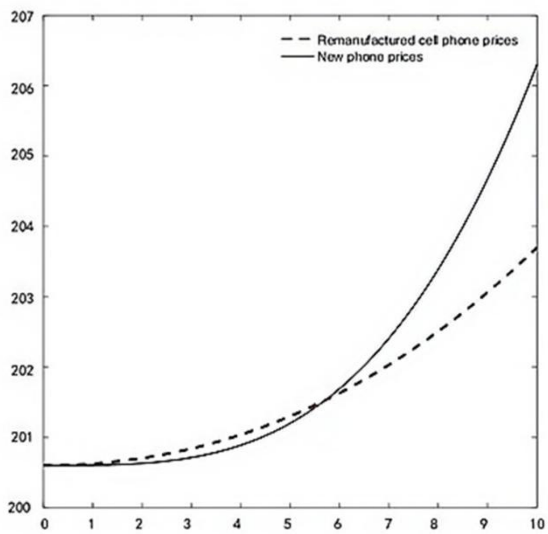

Figure 2. Relationship between the price of carbon credits and the price of two types of cell phone products

To analyze the impact of carbon trading price q, set a brand of the same series of used cell phone recycling quality level $\theta = 0.5$ constant, the value is substituted into the model, set the carbon trading price in the $q \in (0,10)$ interval, the corresponding function change relationship can be obtained. As can be seen from Figure 2, the impact of carbon trading price on the remanufactured/new product price of a brand of cell phone are positive, with the rise of carbon trading price, the new cell phone no longer has the price advantage due to higher carbon emission in the production process, and the gap has a continuous trend to expand, and when the carbon trading price is in the range of $p \in (0,6)$, the remanufactured product cell phone does not have the price advantage, which is due to the carbon emission cost at this time The price of remanufactured cell phones is slightly higher than that of new cell phones because of the higher recycling cost.

Meanwhile, it can be seen from Figure 3 that the expected profit level of agents selling remanufactured cell phones decreases and then increases with the change of carbon trading price q. At this time, although the price of cell phones increases and the total profit grows, the marginal profit decreases, which indicates that agents adopt the strategy of selling more at a lower profit to maintain the total profit level in order to maintain the total equilibrium.

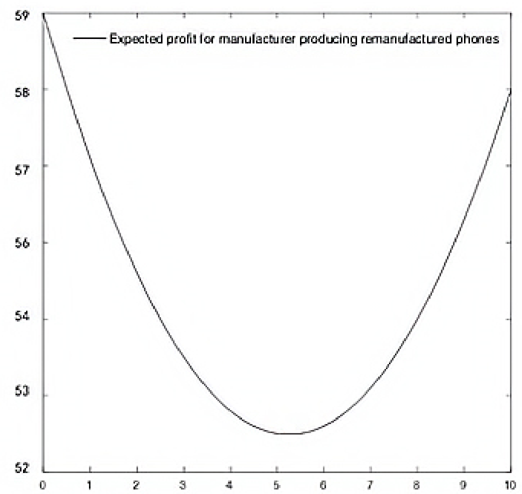

Figure 3. Relationship between the price of carbon credits and the marginal profit expectation of producers producing remanufactured goods cell phones

4.2. Impact of Quality Level θ of Recycling of Used Cell Phones

Analyzing the influence of the recycling quality θ of a brand with the same series of used cell phones, setting the other parameters constant and the recycling quality varying in the range of $\theta \in (0,1)$, the corresponding function change relationship can be obtained. As can be seen from Figure 4, the expected profit of manufacturers and agents of remanufactured cell phones increases with the improvement of recycling quality of used cell phones, which is due to the improvement of recycling quality of used cell phones and the corresponding increase of recycling price, while the recovery quantity rises with the recycling price, which drives the production quantity of remanufactured cell phones, and the carbon emission in the production process is reduced accordingly. Therefore, manufacturers should set a reasonable recycling price to benefit users and promote the development of the remanufactured cell phone market and carbon emission reduction. As can be seen from Figure 5, under the joint effect of recycling quality level and carbon trading cost, the level of producers' profit expectation grows with the growth of carbon trading price and recycling quality level, and the maximum profit expectation is obtained at point A (0.9, 10, 101620). Meanwhile, in the interval of $\theta \in (0.6,1)$, the profit in the system increases with the increase of carbon trading price, which is because the carbon emission of the remanufactured product cell phone is lower when the recycling quality level is higher, and the advantage in carbon cost is relatively obvious and can be profitable by selling carbon emission rights. Therefore, manufacturers can set corresponding recycling standards in the recycling process of used cell phones, which can enhance the ability to reduce emissions and also get a responsive profit return.

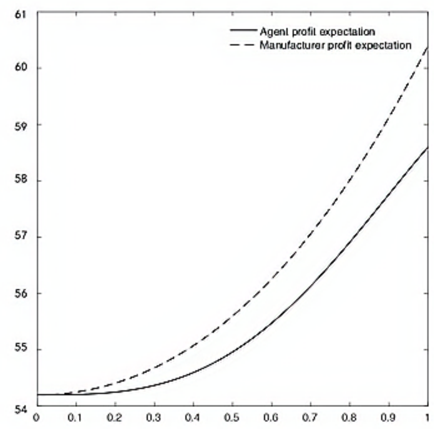

Figure 4. Relationship between recovery quality and profit expectation

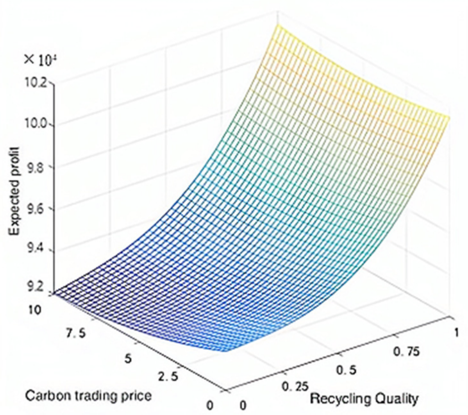

Figure 5. Relationship between recycled quality and carbon trading price and producer's expected profit

4.3. Impact of Carbon Reduction Input $C(\tau)$

Analyzing the impact of the input of emission reduction measures for a brand design manufacturer, let $h = 0.5$, the corresponding functional change relationship can be obtained. It can be seen from Figure 6 that when the product price is influenced by the input cost, the price advantage of remanufactured products relative to the price advantage of new cell phones decreases with the increase of carbon emission input, which is due to the influence of emission reduction input, the marginal cost advantage of low carbon emission will be reduced, while the profit advantage of new cell phones will be relatively enhanced, that is, the price of remanufactured cell phones is more influenced by the fluctuation of emission reduction input. Therefore, in order to support manufacturers to invest in green product innovation, the government should also develop corresponding preferential policies to help enterprises reduce production costs, such as: providing green subsidies or tax incentives for manufacturers who invest in emission reduction. Figure 7 shows that the product price is affected by the cost of abatement inputs and the price of carbon credits, and the total profit decreases with the increase of carbon abatement inputs and the price of carbon credits, and the maximum profit expectation is obtained at the point (0.9, 10, 100170). Meanwhile, in the interval of $C(\theta) \in \left(0.7\times10^4, 1\times10^4\right)$, the profit decreases with the increase of carbon trading price, which is because the return of carbon emission reduction input is not obvious and the burden of carbon emission cost increases. At this time, in order to reduce the cost of carbon emissions, producers should increase the emission reduction investment. At the same time, producers should improve the recycling price of used cell phones, agents reduce the expected level of profit of remanufactured products cell phones, and increase the output and sales of remanufactured products cell phones to achieve thin profit.

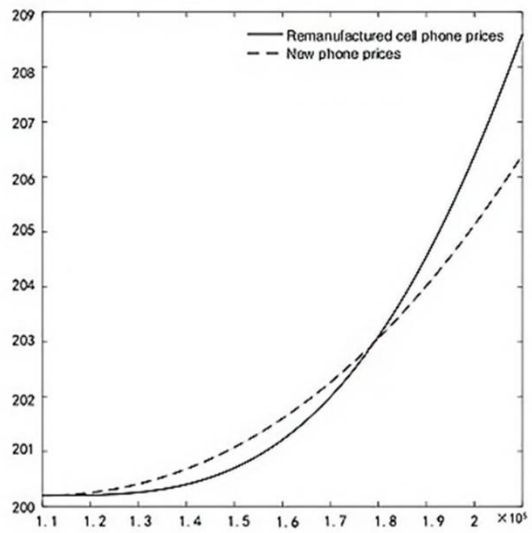

Figure 6. Relationship between carbon emission reduction inputs and prices of two types of cell phone products

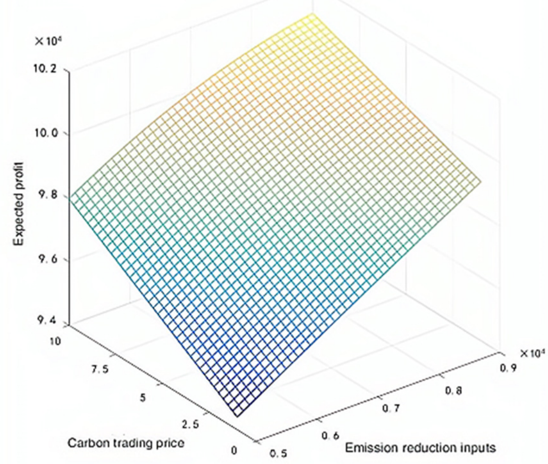

Figure 7. Impact of carbon emission reduction inputs and carbon trading price on expected profit

5. Conclusion

The paper takes carbon trading as the background to study the price impact of two types of cell phones, remanufactured products and new products; analyzes the impact of carbon trading price, recycling quality of used cell phones, carbon emission reduction input, and other factors. Compared with previous studies, this study introduces carbon trading into the cell phone supply chain, explores more the value of remanufactured cell phones, and targets profit expectations, attributes various factors to two types of product price impacts from a rational

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human perspective, and deeply analyzes the pricing and sustainability issues of two types of cell phone products: remanufactured and new products. However, at the same time, the research in this paper is limited to the market situation of producers under the condition of brand monopoly and fails to further study the condition that there are several different producers in the market, and at the same time, fails to take more into account the user satisfaction, such as the impact of users' psychological expectation value on the supply chain, and the remanufacturing of parts in the utilization of the surplus concentration of waste products. Therefore, it is also worthwhile to consider more synergy among the subjects in the related supply chain as a direction for further research afterward.

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