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When 'Trade-in' and 'Trade-in' Coexist under the EPR Fund System Game Analysis of Manufacturers and Remanufacturers

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Abstract

Based on the current "recycling fund" model in the field of waste electronic products in China, this paper designs the EPR fund system with the background of the "levy-reduce-supplement" model covering the production end and the recycling end, and constructs the market. When there are two "trade-in" and "trade-in" recycling channels at the same time, the manufacturer's optimal decision and the impact on the closed-loop supply chain when these two recycling channels coexist. On this basis, based on the Stackelberg game model, Matlab software is used for numerical simulation of the obtained conclusions, and sensitivity analysis was carried out on the obtained conclusions, and finally the following conclusions were drawn: The government can increase green indicators such as eco-design or technological innovation, and encourage enterprises to adopt more green technologies in the production process to reduce pollutant emissions. Tax reductions or refunds are made according to the performance or greenness of manufacturers, to stimulate and improve manufacturers' enthusiasm to implement EPR responsibilities, reduce waste products from the source, and provide suggestions for the early realization of carbon neutrality.

Keywords

Fund EPR System; Trade-in; Game Analysis.

1. Background

This paper designs the ERP system to cover the "levy-reduce-supplement" model at the production end and the recycling end. In the first stage, manufacturers face "levy-reduce", that is, the government levies a unit product waste disposal fee (levy) on manufacturers; at the same time, in order to incentivize them to carry out ecological design, levy-reduce fees (reduce) based on the level of ecological design. "Supplement" is oriented to the recycling end of the second stage. Consumers can trade in and trade in used products with merchants, and will enjoy a government subsidy for each used part.

For products, the value of new products sold in the first stage will gradually decrease after being used by consumers, and will become old products in the second stage. Enterprises can extend the life cycle of products by recycling and remanufacturing, and realize value appreciation., so that it can be sold in the form of remanufactured products in the second stage. However, the number of new products sold and circulated in the first stage will limit the number of recycled products in the second stage, and the number of recycled products will further limit the number of remanufactured products.

2. Problem Description and Basic Assumptions

There are large differences in the production materials and processing processes of new and remanufactured products, so consumers have different willingness to pay for the two.

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Consumers currently have low awareness of remanufacturing technology and remanufactured products. Doubts about quality and reliability make them less willing to pay for remanufactured products than for new products. Consumers are willing to pay for new products in θ, and for remanufactured products in αθ (0 < α < 1). On this basis, according to the consumer utility theory, the utility of consumers purchasing new products in the first stage is U1n = θ-p1n; in the second stage, the utility of consumers "trade-in" is U2n = θ-p2n + A, the utility of "trade-in" is U2r = αθ- p2r + A + s, the utility of "direct purchase of new products" is U2fn = θ-p2n, and the utility of "direct purchase of remanufactured products" is U2fr = αθ- p2r.

In the second stage, consumers who have purchased the new products in the previous stage will face three choices: trade-in, trade-in and no-exchange, and make decisions by comparing value and utility.

1) When U2n > 0 and U2n > U2r, consumers choose the "trade-in" strategy, and the demand function of "trade-in" can be expressed as q2n = 1- (p2n - p2r - s)/(1-α)

2) When U2r > 0 and U2r > U2n, consumers choose the "trade-in" strategy, and the demand function of "trade-in" can be expressed as q2r = (p2n - p2r + s)/(1-α) - (p2r -A-s)/α respectively

3) At the same time, a new group of consumers will enter the market in the second stage, and will face two options: "direct purchase of new products" and "direct purchase of reproducts". Referring to the above analysis ideas, the demand function can be expressed as

$$q_{2fn} = 1 - \frac{p_{2n}-p_{2r}}{1-\alpha};\ q_{2fr} = \frac{p_{2n}-p_{2r}}{1-\alpha} - \frac{p_{2r}}{\alpha}$$

3. Models

The profit function of the original manufacturer in the first stage is

$$\pi_{m1} = \left(p_{1n} - c_n - (T - \beta e)\right)q_{1n} - \frac{ke^2}{2}$$

The profit function of the original manufacturer in the second stage is

$$\pi_{m2} = p_{2n}q_{2fn} + (p_{2n} - A)q_{2n} + p_{2r}q_{2fr} + (p_{2r} - A)q_{2r} + c_r(q_{2r} + q_{2fr})$$

The constraint is:

① the recyclable quantity should be greater than or equal to the actual recycled quantity: $eq_{1n} \geq q_{2n} + q_{2r}$

②the actual amount recovered should be greater than or equal to the total amount of remanufacturing: $q_{2n} + q_{2r} \geq q_{2r} + q_{2fr}$

Among them, the first item of the manufacturer's second-stage profit function represents the profit of "direct purchase of new products", the second item represents the profit of "trade-in", the third item represents the profit of "direct purchase of remanufactured products", and the fourth item represents the profit of "trade-in", and the fifth item represents the profit saved by recycling and remanufacturing.

The profit function π_{m2} of the original manufacturer in the second stage is a concave function about $p2n$ and $p2r$, and the Lagrangian function is constructed by introducing the Lagrangian multiplier μ

$$\frac{4p_{2r} - 4p_{2n} - s - 2c_r}{1-\alpha} + 2 = 0$$

$$\frac{4p_{2n} - 4p_{2r} + s + 2c_r}{1-\alpha} + \frac{2c_r - 4p_{2r} + s}{\alpha} - \frac{\mu}{\alpha} = 0$$

$$\mu\left(1 - \frac{s}{1-\alpha} + \frac{p_{2r}}{\alpha}\right) = 0$$

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1. When all the recycled waste products are used for remanufacturing, the optimal price of the products is

$$p_{2n}{}' = -\frac{6\alpha^2 - 2\alpha c_r + 5\alpha s - 8\alpha + 2c_r - s + 2}{4(\alpha - 1)}; p_{2r}{}' = -\frac{\alpha(\alpha + s - 1)}{\alpha - 1}$$

The optimal sales at this time are:

$$q'_{2n} = \frac{2\alpha + 2c_r + 3s - 2}{4(\alpha - 1)};\ q'_{2r} = \frac{6\alpha^2 + (4A - 2c_r + 5s - 6)\alpha - 4A - 4s}{4\alpha(\alpha - 1)};$$

$$q'_{2fn} = \frac{2\alpha + 2c_r - s - 2}{4(\alpha - 1)};\ q'_{2fr} = \frac{6\alpha - 2c_r + 5s - 6}{4\alpha(\alpha - 1)};$$

The optimal profit value for the second stage of the original manufacturer is

$$\pi_{m2} = \frac{K_1 + K_2 + K_3}{8\alpha(\alpha - 1)^2}$$

$$K_1 = (-36\alpha^4 + (-24A - 60s + 24c_r + 76)\alpha^3$$

$$K_2 = (-8A^2 + (-24s + 8c_r + 48)A - 4c_r{}^2 + (20s - 48)c_r - 25s^2 + 72s - 44)\alpha^2$$

$$K_3 = 16A^2 + (32s - 16c_r - 24)A + 4c_r{}^2 + (-28s + 24)c_r + 9\left(s - \frac{2}{3}\right)^2)\alpha - 8(A - c_r)(A + s))$$

2. According to the first-order condition of optimality, not all the recycled waste products in the following three cases are used for remanufacturing.

1) When α > 1/3 and s > s ', and A > A ', that is, when the consumer's acceptance of the reproduce is greater than 1/3, and the subsidy that the consumer can get from the government is greater than s ', and when the discounted price of the consumer's used product is higher than A ', at this time, the consumer is more inclined to trade in the old product due to the higher discounted price of the old product, so in this case, the recycled waste products are not all used for remanufacturing.

2) When α > 1/3, s < s ', cr > cr ' and A > A', that is, when the consumer's acceptance of reproductions is greater than 1/3, consumers can get from the government When the subsidy is less than s ', and the consumer's discounted price of used products is higher than A', at this time, consumers have less return due to old product subsidies and discounts, so the demand for reproductions is lower. Therefore, in this case, the recycled waste products are not all used for remanufacturing.

3) When α < 1/3, cr > cr 'and A > A ', that is, when the consumer acceptance of reproductions is low and the manufacturer's remanufacturing cost is high, in this case Not all recycled waste products are used for remanufacturing.

When the above three situations occur, when all the recycled waste products cannot be used for remanufacturing, the optimal price of the product at this time is

$$p_{2n} = \frac{A + 1}{2};\ p_{2r} = \frac{\alpha + A - c_r}{2} + \frac{s}{4}$$

The optimal sales are

$$q_{2n} = \frac{2\alpha + 2c_r + 3s - 2}{4(\alpha - 1)};\ q_{2r} = \frac{2A\alpha - 2A - 2c_r - 3s}{4\alpha(\alpha - 1)};$$

$$q_{2fn} = \frac{2\alpha + 2c_r - s - 2}{4(\alpha - 1)};\ q_{2fr} = \frac{-2A\alpha + 2A - 2c_r + s}{4\alpha(\alpha - 1)};$$

The optimal profit value for the second stage of the original manufacturer is

$$\pi_{m2} = \frac{4\alpha^2 + (-4A^2 - 4As - 4)\alpha + 4A^2 + 4As - (2c_r + s)^2}{8\alpha(\alpha - 1)}$$

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4. Analysis of Equilibrium Results

First, on the basis of the optimal equilibrium solution, the impact of the replacement recovery price A and the government's "old-for-re" subsidy s on the structure of each part of the market is analyzed.

When recycled products are not all used for remanufacturing, p2r, q2r, and q2fn are the increasing functions of the "old-for-re" government subsidy s, respectively, and q2n and q2fr are the decreasing functions of the "old-for-re" government subsidy s, respectively, p2n are not related to s;

When all recycled products are used for remanufacturing, p2r, q2fn, q2fr, p2n ($1/5 < \alpha < 1$), q2r ($0 < \alpha < 4/5$) are the increasing functions of the "old-for-re" government subsidy s, respectively, q2n, p2n ($0 < \alpha < 1/5$), q2r ($4/5 < \alpha < 1$) are the decreasing functions of the "old-for-re" government subsidy s.

It can be seen that:

(1) Under any conditions, the standard selling price for remanufactured products p2r increase with the increase in government "trade-in" subsidies.

In the case where the waste product cannot be fully remanufactured, because the subsidy target of the government subsidy s in this model is the "old-for-re" consumer, the standard selling price of the new product p2n not change with the change of the government subsidy s, and the standard selling price of the remanufactured product p2r will increase with the increase of the government "old-for-re" subsidy s. At this time, secondary consumers can choose "trade-in" or "trade-in" two replacement consumption methods. Driven by the government subsidy policy, consumers are more willing to choose "trade-in", so it appears as: the number of "trade-in" q2r increase with the increase of government subsidies, and the number of "trade-in" q2n decrease with the increase of government subsidies. At the same time, new consumers can choose "direct purchase of new products" or "direct purchase of remanufactured products", and the standard sales price of remanufactured products has p2r increased with the increase of government "trade-in" subsidies. More consumers choose the consumption method of direct purchase of new products. Therefore, the number of "direct purchase of new products" q2fn increases with the increase of government "trade-in" subsidies, and the number of "direct purchase of remanufactured products" q2fr decreases with the increase of government "trade-in" subsidies.

In the second stage, the consumer surplus of old users 21 and the consumer surplus of new users 22 increases with the increase of government subsidies, and the consumer surplus of old users in the second stage 21 and the second stage the consumer surplus of new users 22 increases with the replacement and recycling discount A of waste products.

When the recycled product cannot be fully remanufactured, the consumer surplus of the old user in the second stage can be expressed as:

$$CS_1 = \int_{\theta_2}^{\theta_1} U_{2r}\, d\theta + \int_{\theta_1}^{1} U_{2n}\, d\theta = \int_{\frac{p_{2n}-A-s}{\alpha}}^{\frac{p_{2n}-p_{2r}-s}{1-\alpha}} \alpha\theta - p_{2r} + A + s\, d\theta + \int_{\frac{p_{2n}-p_{2r}-s}{1-\alpha}}^{1} \theta - p_{2n} + A\, d\theta$$

$$CS_1 = \frac{(8A+4)\alpha^2 + (4A^2 - 4 + (12s - 8c_r - 8)A)\alpha - 4(A + \frac{3}{2}s - c_r)^2}{32\alpha(\alpha-1)}$$

① $\frac{\partial CS_1}{\partial s} = \frac{6A\alpha - 6A + 6c_r - 9s}{16(\alpha-1)} = \frac{A}{8} + \frac{6c_r - 9s}{16(\alpha-1)} > 0$

② $\frac{\partial CS_1}{\partial A} = \frac{2\alpha + 2A - 2c_r + 3s}{8\alpha} > 0$

It can be seen from ① that the consumer surplus of old users in the second stage increases with the increase of government subsidies. In the second stage, old users face two options: "trade-in" and "trade-in". Compared with "trade-in", "trade-in" can obtain government subsidies, that

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is, old users can complete the replacement at a lower price, so it is manifested that the consumer surplus of "trade-in" by old users in the second stage increases with the increase of government subsidies. At the same time, the consumer surplus of "trade-in" decreases with the increase of government subsidies, but because the impact of government subsidies directly acts on "trade-in" and has a greater impact, the consumer surplus of old users in the second stage is incrementally affected by government subsidies. Similarly, the consumer surplus of old users in the second stage also increases with the increase of the replacement price A.

It can be seen from ② that the consumer surplus of the old users in the second stage increases with the increase of the replacement price A. For the old users who choose to trade-in, the larger the remanufacturing value discount coefficient, the smaller the consumer surplus of these consumers.

When the recycled product cannot be fully remanufactured, the consumer surplus for new users in the second stage can be expressed as:

$$CS_2 = \int_{\theta_4}^{\theta_3} U_{2fr}\, d\theta + \int_{\theta_3}^{1} U_{2fn}\, d\theta$$

$$CS_2 = \frac{(4-8A)\alpha^2 + (4A^2 - 4 + (4s + 8c_r + 8)A)\alpha - 4(A + \frac{3}{2}s + c_r)^2}{32\alpha(\alpha-1)}$$

① $\frac{\partial CS_1}{\partial s} = \frac{2A(\alpha-1)-2c_r-s}{16\alpha(\alpha-1)} > 0$

② $\frac{\partial CS_1}{\partial A} = \frac{2A+2c_r+s-2\alpha}{8\alpha} > 0$

For ease of analysis, the consumer surplus of new users in the second stage of "direct purchase of new products" and "direct purchase of remanufactured products" is also expressed as follows: ([CS] 21 means the consumer surplus of "direct purchase of new products", [CS 22 means the consumer surplus of "direct purchase of remanufactured products")

$$CS_{21} = \int_{\theta_4}^{\theta_3} U_{2fr}\, d\theta$$

$$= \frac{(2\alpha - 2 + 2c_r + s)^2}{32(1-\alpha)} - \frac{(2\alpha - 2 + 2c_r + s)^2}{32(1-\alpha)^2} + \frac{1}{4(\alpha-1)} - \frac{A(\frac{2c_r + s}{4(\alpha-1)^2})}{2}$$

③ $\frac{\partial CS_{21}}{\partial s} = \frac{2A(\alpha-1)-2c_r-s}{16\alpha(\alpha-1)^2} < 0$

④ $\frac{\partial CS_{21}}{\partial A} = \frac{2c_r+s-2\alpha}{8\alpha-8} < 0$

$$CS_{21} = \int_{\theta_3}^{1} U_{2fn}\, d\theta$$

⑤ $\frac{\partial CS_{22}}{\partial s} = \frac{2c_r+s+2A-2A\alpha}{16\alpha(\alpha-1)^2} > 0$

⑥ $\frac{\partial CS_{22}}{\partial A} = \frac{2A(\alpha-1)-2c_r-s}{8\alpha(\alpha-1)} > 0$

It can be seen from the above formula that the consumer surplus of new users in the second stage is not directly affected by the government subsidy s and the replacement price A, but because the new users face the same price as the old users, but there is no recycling subsidy s for the old users. And replacement subsidy A, so the consumer surplus of new users in the second stage will be affected by the government subsidy s and replacement price A. The specific performance is that the consumer surplus of new users directly purchasing new products in the second stage decreases with the increase of the government subsidy s, the consumer surplus of direct purchase reproducts increases with the increase of the subsidy s, and the government subsidy s has a greater impact on the direct purchase of reproducts. The consumer surplus of

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reproducts has a greater impact, so in the second stage, the consumer surplus of new users will increase with the increase of the government subsidy s. Similarly, the consumer surplus of new users in the second stage increases with the increase of the replacement price A.

5. Example Analysis

This section will verify the correctness and reliability of the above conclusions by assigning the relevant parameters of each participant in the above model and conducting simulation experiments on the above research results. When all the products recycled by the manufacturer cannot be used for remanufacturing, that is, when

① $\alpha > \frac{1}{3}$ and $s > s'$ and $A > A'$ ② $\alpha > \frac{1}{3}, s < s'$ and $c_r > c_r'$ *and* $A > A'$ ③ $\alpha < \frac{1}{3}, c_r > c_r'$ *and* $A > A'$ $s' = \frac{2\alpha(\alpha-1)}{1-3\alpha}, A' = \frac{2\alpha^2+2\alpha c_r+3\alpha s-2\alpha+2c_r-s}{2(1-\alpha)}, c_r' = \frac{2\alpha+s-2\alpha^2-3\alpha s}{2\alpha+2}$.

(1) Verify the conclusion of the influence mechanism of the government's "old-for-re" subsidy in the second stage. Let cr = 0.170, 0, α = 0.400, A = 0.300 After assigning values to the above parameters, at this time [cr] = 0.160, s '= 0.240, A ' = 0.013, meet the conditions ② α > 1/3, s < s 'and cr > cr ' and A > A ', the following results are obtained:

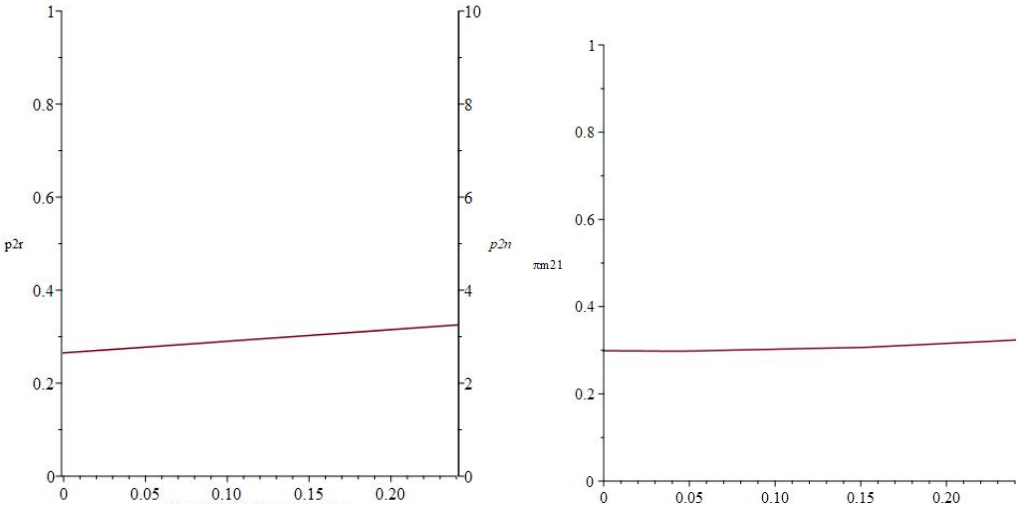

Figure 1. The second stage of government subsidies **Figure 2.** government subsidies

As shown in Figure 1 and Figure 2, the simulation results are consistent with the calculated analysis results: the price of "trade-in" in the second stage p2r increases with the increase of subsidy s, and the price of "trade-in" p2n independent of subsidy s; the total profit of the manufacturer in the second stage, π m21, increases with the increase of subsidy s.

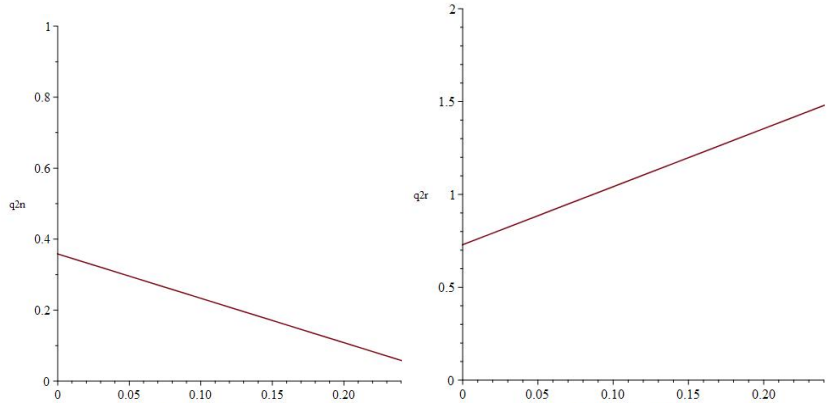

Figure 3. government subsidies 1 **Figure 4.** government subsidies 2

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As shown in Figure 3 and Figure 4, the simulation results are consistent with the calculated analysis results: the number of "trade-in" in the second stage q2n decrease with the increase of subsidy s, and the number of "trade-in" q2r increase with the increase of subsidy s.

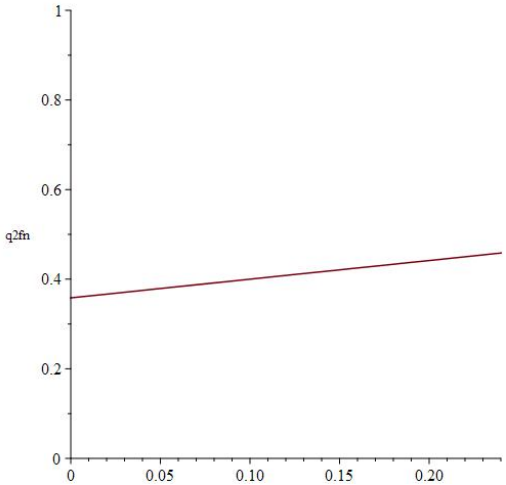

Figure 5. government subsidies

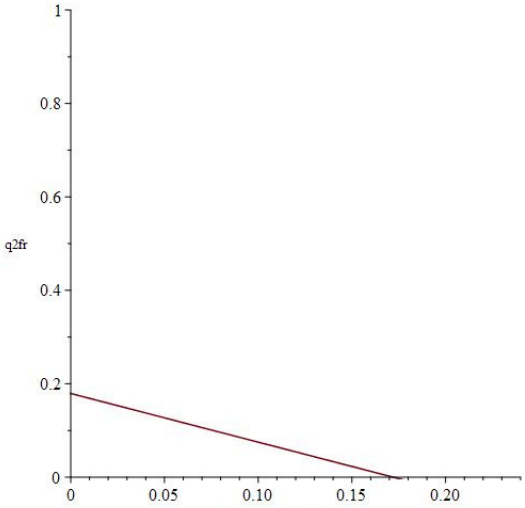

Figure 6. government subsidies

As shown in Figure 5 and Figure 6, the simulation results are consistent with the calculation and analysis results: the number of "direct purchase new products" in the second stage q2fn increase with the increase of subsidy s, and the number of "direct purchase reproducts" q2fr decrease with the increase of subsidy s.

Verify the influence mechanism of the consumer surplus in the second stage, so that cr = 0.170, s = 0.100, α=0.400, A=0.300 After assigning the above parameters, at this time [cr] '=0.160, s'=0.240, A'=0.013, meets the conditions ②α> 1/3, s < s 'and cr > cr 'and A > A ', the following results are obtained:

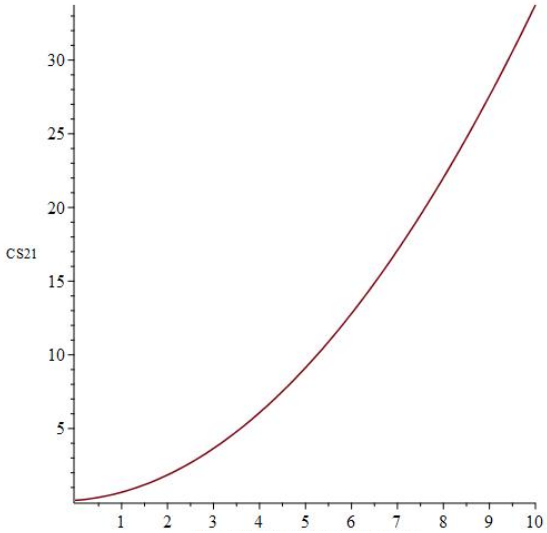

Figure 7. The second stage of waste products replacement rebate

As shown in Figure 7 and Figure 8, the simulation results are consistent with the calculation and analysis results: the consumer surplus of the old user in the second stage [CS] 21 and the consumer surplus of the new user in the second stage [CS] 22 with the replacement of waste products Recycling discount A increases.

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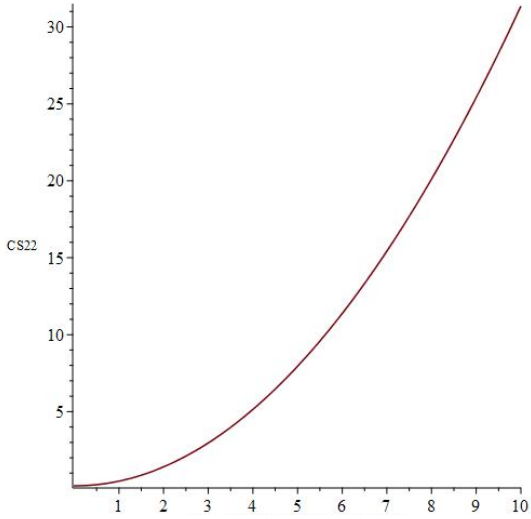

Figure 8. The second stage of waste products replacement rebate

Let cr = 0.170,0, α = 0.400, A = 0.300 After assigning the above parameters, at this time [cr] '= 0.160, s ' = 0.240, A '= 0.013, meet the conditions ② α > 1/3, s < s ' and cr > cr 'and A > A ' conditions, the following results are obtained:

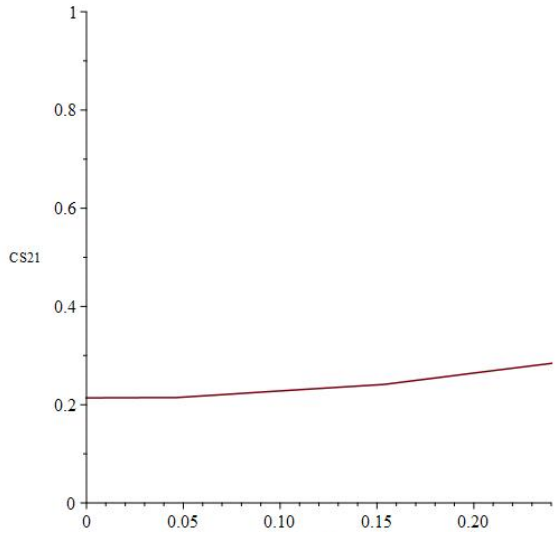

Figure 9. Government subsidy

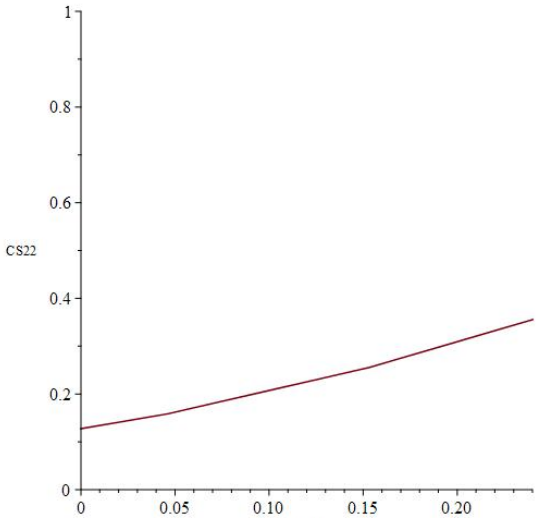

Figure 10. Government subsidy

As shown in Figure 9 and Figure 10, the simulation results are consistent with the calculation and analysis results: the consumer surplus of the old users in the second stage [CS] 21 and the consumer surplus of the new users in the second stage [CS] 22 with the waste The government subsidy of the product is increasing.

The verification process for all recycled products for remanufacturing is similar to the above, and the simulation results are also consistent with the previous conclusions. Considering the length, I will not repeat them here.

6. Conclusion

The government's subsidy to consumers "trade-in" will benefit manufacturers to a certain extent. The government subsidy seems to supply consumers, but in fact it is supplemented to manufacturers and sellers. Because the subsidy is only for "trade-in", the higher the subsidy,

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the higher the price of "trade-in" p2r, so it will only affect the price of "trade-in" q2r: as the subsidy increases, the price of "trade-in" will also increase.

In the second stage, the consumer surplus of old users [CS] 21 and the consumer surplus of new users [CS] 22 increases with the increase of government subsidies. The consumer surplus of old users in the second stage [CS] 21 and the second stage the consumer surplus of new users [CS] 22 increases with the replacement and recycling discount A of waste products. This means that consumers are more willing to pay a higher price for the product. For enterprises, enterprises should understand the demand elasticity of consumers for the commodity through market surveys and analysis in order to determine the optimal price. At the same time, enterprises should formulate flexible price strategies to adapt to changes in market demand.

When considering the "old-for-X" recycling form, this paper does not consider a direct contrast with the recycling forms such as entrusting retailers to recycle and outsourcing third-party recycling. After comparison in the future, it can give more distinct differences, and then make more reasonable recommendations to the government and enterprises.

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