ISSN: 2414-1895 DOI: 10.6919/ICJE.202103_7(3).0063

Reverse Supply Chain Decision-making for Dual-channel Recycling of E-waste

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Abstract

To comply with the mainstream of sustainable development, a two-channel reverse supply chain consisting of a recyclable dealer and a recycler is constructed for E-waste recycling, and the effects of channel competition and customer recycling preference on supply chain decisions are analyzed. The pricing, recycling quantity and profit are analyzed under decentralized and centralized cases, and finally validated by numerical analysis. The results show that customer online recycling preference is beneficial to the overall profit of the supply chain. Within the range of different customer recycling preference, the channel competition has different effects on pricing and profit of the supply chain.

Keywords

Dual-recycling Reverse Supply Chain; E-waste; Recycling Preference; Channel Competition.

1. Introduction

There is a close connection between people's life and electronic products.People has generated a large number of electronic waste, and has brought incalculable lethality to the natural environment. All of E-wastes are hurting the human beings. *The Global E-waste Monitor 2020* shows that 53.6 million tons of E-waste will be generated worldwide in 2019 [1]. In order to meet the needs of modern and future generations, there is an urgent need to promote the recycling process of E-waste. In this context, residents and members of supply chain companies need to work together to achieve E-waste recycling, and reverse logistics and supply chain is a form of management organization to achieve the reuse of E-waste. Dual reverse supply chain management (DRSC) refers to a supply chain model consisting of traditional offline recycling channel and online recycling channel [2].

In order to alleviate the harm brought by E-waste, some relevant international regulations were proposed, such as the EU's *WEEE Directive*. Japan expands the various types of electronic product management catalogs, China issued *WEEE Recycling Management Regulations*, it optimized E-waste management in China. Japan's Panasonic pay attention to the dismantling and recycling of E-waste. China's Grammy deveoped a broad industrial base of E-waste disposition. *Free and useful* is an early pattern of Beijing *YunYida*, they recycle mobile phones, computers and other renewable resources. Also, *Shanghai New Jinqiao Environmental Protection Co.* develop online recycling of E-waste. The development of a dual offline and online recycling model is not only a positive response to international and domestic macro policies, but also a bellwether for new industry opportunities. For the dual-channel recycling reverse supply chain, entrepreneur need to consider whether recycling work is profitable or not. And whether there is a competition between offline and online recycling in the dual-channel recycling reverse supply chain. Moreover, the customer's recycling preference may be influence the decision-making.

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Reverse supply chain means that used products or discarded materials are returned to the reprocessing organization. Reverse supply chains will bring economic and social benefits [3]. Govindan argues that online recycling can help supply chain systems to increase profits [4]. Hosseini designed a combination of options that can increase the quantity of recycling because the thought the benefits of the reverse channel heavily depend on the quantity of recycling [5]. Customer's channnel preference is a factor often considered in dual channel supply chain research. Zhang argues that in the dual channel supply chain, when customer's online channel preference is low, manufacturer will only use traditional channel. When consumers' online channel preference is large enough, the online channel will improve the profit of the whole dual channel supply chain [6]. Due to the heterogeneity of customer preference, channel selection is also different, so channel profits will be influenced. Chen thought that channel demand selection decision depend on the operation cost of online channel and the convenience of retail channel [7]. It's a normal phenomenon that channel competition exists in dual-channel supply chain, Wang argues that a system with competition obtains greater total profits to some extent [8].

Through a review of the above literature and the current development of online recycling, it is found that few studies consider both customer's recycling preference and channel competition in the dual-channel reverse supply chain. Based on this, this paper innovates on the reverse supply chain in the following aspects: (1) taking E-waste as an example, it establishes a dual-recycling reverse supply chain model with online and offline parallel operation composed of two channel members: recycler and recyclable dealer. (2) analyzing how customer's recycling preference and channel competition affect the pricing and profit of the dual-recycling reverse supply chain.

2. Model description

2.1 Description of the problem and description of symbols

We build a reverse supply chain structure for dual-channel recycling of E-waste, consisting of a recyclable dealer, a recycler and customers. Recycling dealer opens up online and offline recycling channels.In the offline recycling channel ,customers send their E-wastes to recycling dealers on their own, and then the recyclers transport them to the recycling dealers; The online recycling is the direct way from customers to recycling dealers, and the recycling dealers cooperate with third-party logistics to provide door-to-door service by courier or the courier go to the unified E-waste collection point in customers' residential areas to pick up E-wastes directly and send to recycling dealers ,see Figure 1.

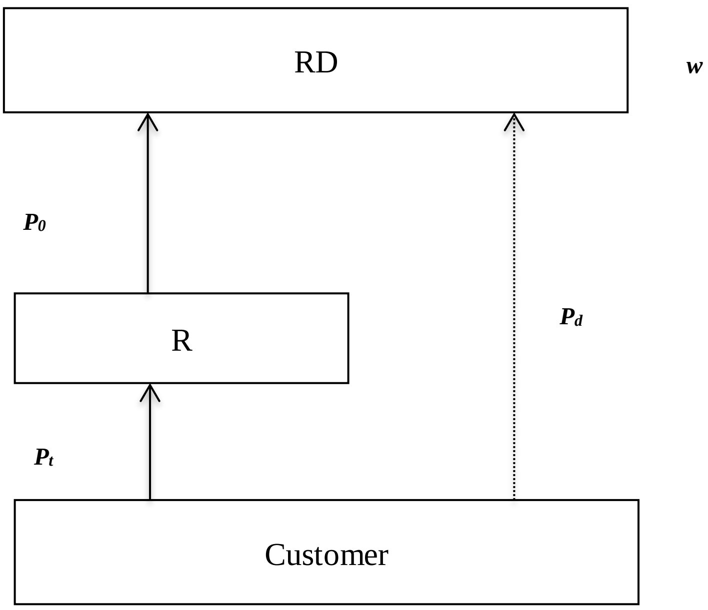

Figure 1. E-waste dual channel reverse supply chain model

ISSN: 2414-1895
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Table 1. Notations

Parameter	Definition
a	The amount of potential recycling quanties, a>0.
w	The revenue of per unit E-waste yield, $w>0$.
P_d	The unit online recycling price.
P_0	The transfer price of unit E-waste paid by recycling dealer to recycler in offline channels.
P_t	The unit offline recycling price.
Θ	Customer's online recycling preference, $\Theta \in (0,1)$.
c	The cost of recycling per unit of the offline recycling channel.
b	The elasticity factor of recycling quantity to offline recycling prices.
m	The coefficient of competition for online and offline channels, m>0.
D_d	Recycling quantity in the online recycling channel.
D_t	Recycling quantity in the the offline recycling channel.
π_R	The profit of recycler.
π_{RD}	The profit of recycling dealer.
π_T	The sum of the profit earned by the recycling dealer and the recycler.
superscript d, c, *	decentralized,centralized,the optimal solution respectively.

2.2 Model assumptions

We give the notations ,as shown in Table 1. Then we make some assumptions.

(1) Considering the diversity of recycled products, we only analyse E-waste, such as used batteries, used mobile phones and computers, etc.

(2) The work of E-waste recycling will generate revenue.

(3) Considering the complexity of the recycling procedure, we make the offline's inspection cost, collection cost, dismantling and shipping cost are expressed as c in total, and assume the cost in the online channel is zero.

(4) Without loss of realism and fairness, we assume that The revenue of per unit E-waste is higher than the unit channel price and cost, $w > P_0 > P_t > c>0$, $w > P_d > 0$.

(5) According to previous research [9], the recycling quantities in offline and online recycling channels can be expressed as

$$D_t = (1-\theta)a + bP_t - m(p_t - p_d) \quad (1)$$

$$D_d = \theta a + bP_d - m(p_d - p_t) \quad (2)$$

3. Dual channel reverse supply chain decision making

3.1 Decentralized decision-making

Each member under decentralized decision making situation seeks to maximize its own profit. As a leader in Stackelberg game, the recycler determine its own optimal recycling price according to the recycler's recycling price reaction function. Then the recycler determine its offline recycling price according to recycling dealer. The recycling dealer's and recycler's profit functions under the decentralized decision are as follows:

$$\pi_{RD} = (w - P_0 - c)D_t + (w - P_d)D_d \quad (3)$$

$$\pi_R = (P_0 - P_t - c)D_t \quad (4)$$

Proposition 1 When m<b, the profit function $\boldsymbol{\pi_{RD}}$ of the recycling dealer under decentralized decision making is a joint concave function about P_0 and P_d, and the profit function π_R of the recycler is a concave function about P_t. The optimal solutions P_0^{d*},P_d^{d*} and P_t^{d*} are exist.

Proof Substitute equation (1) into (4) and find the second-order partial derivative for P_t, $\frac{\partial^2 \pi_R}{\partial {P_t}^2} = 2m - 2b$, so when m<b , π_R is a concave function about P_t, and there exists an optimal solution P_t^{d*}.

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The optimal response function of the recycling dealer P_t is solved as follows.

$$P_t = -\frac{\theta a+cm-bc-P_0m-P_dm+P_0b-a}{2(m-b)} \tag{5}$$

Substitute equation (5) into (3) and create the Hessian matrix as follows.

$$H_1 = \begin{pmatrix} m-b & -m \\ -m & \frac{m^2-4mb+2b^2}{m-b} \end{pmatrix}$$

where the first-order principal is $|m-b|$ and the second-order principal is $\begin{vmatrix} m-b & -m \\ -m & \frac{m^2-4mb+2b^2}{m-b} \end{vmatrix}$, so when 2m<b, the first-order principal is negative, the second order principal subexpression is positive, and H_1 is a negative definite matrix, therefore π_{RD} is a joint concave function about P_0, P_d, and there are optimal solutions P_0^{d*}, P_d^{d*}.

Solve the optimal solution for price, recycling quantities and profit are as follows.

$$P_0^{d*} = -\frac{\theta ab-2mwb+wb^2+am-ab}{2b(2m-b)} \tag{6}$$

$$P_d^{d*} = \frac{\theta ab+2mwb-wb^2-am}{2b(2m-b)} \tag{7}$$

$$P_t^{d*} = -\frac{\theta ab(4m-3b)+b^3(2c-w)+4mwb(b-m)+2cmb(2m-3b)+2am(m-3b)+3ab^2}{4b(2m-b)(m-b)} \tag{8}$$

$$D_d^{d*} = \theta a - bP_d^{d*} - m(P_d^{d*} - P_t^{d*}) \tag{9}$$

$$D_t^{d*} = (1-\theta)a + bP_t^{d*} - m(P_t^{d*} - P_d^{d*}) \tag{10}$$

$$\pi_R^{d*} = (P_0^{d*} - P_t^{d*} - c)D_t^{d*} \tag{11}$$

$$\pi_{RD}^{d*} = \left(w - P_0^{d*} - c\right)D_t^{d*} + \left(w - P_d^{d*}\right)D_t^{d*} \tag{12}$$

$$\pi_T^{d*} = \pi_{RD}^{d*} + \pi_R^{d*} \tag{13}$$

Proposition 2 When 2m<b, the online recycling price P_d^{d*} is negatively correlated with θ, the offline recycling price P_t^{d*} is positively correlated with θ.

Proof Taking the first-order partial derivative of Eq. (8) for θ, $\frac{\partial P_d^{d*}}{\partial \theta} = \frac{a}{2(2m-b)}$, since a>0 and 2m<b, therefore $\frac{\partial P_d^{d*}}{\partial \theta}$ <0. Taking the first-order partial derivative of Eq. (9) for θ, $\frac{\partial P_t^{d*}}{\partial \theta} = -\frac{4amb-3ab^2}{4b(2m-b)(m-b)}$, since a>0 and 2m<b, therefore $\frac{\partial P_t^{d*}}{\partial \theta}$>0.

Proposition 1 shows that when the customer preference for the online recycling channel increases, the online recycling quantity increases. In order to increase the revenue of the online recycling channel, the online recycling price should be decreased. When customer preference for the online recycling channel increases, the optimal offline recycling price increases, that's because the offline recycling quantities decrease when θ increases. In order to retain or attract customers, the offline channel need to increase its' price.

Proposition 3 When θ>0.5, the online recycling channel optimal price P_d^{d*} is negatively related to the channel competition coefficient m. When θ<0.5, the online recycling channel optimal price P_d^{d*} is positively related to the channel competition coefficient m.

Proof Solve the first-order partial derivative of P_d^{d*} with respect to m according to Eq. (8) yields $\frac{\partial P_d^{d*}}{\partial m} = -\frac{a(2\theta-1)}{2(2m-b)^2}$, which is negatively correlated when θ>0.5 and positively correlated when θ<0.5. Solve the first-order partial derivative of P_t^{d*} with respect to m according to Eq. (9). Due to the complexity of the equation , the relation will be analyzed in detail in the numerical analysis section.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202103_7(3).0063

Proposition 3 shows that when θ>0.5, customers prefer online recycling channel over offline channel, under this premise, the intensity of competition between channels increases, in order to mitigate the adverse effects of channel competition on their own channel profits, online channel reduce recycling price to maintain and improve their own channel profits. When the intensity of channel competition decreases, in order to improve the profit of online channel, it need to increase the recycling price. When θ<0.5, customers prefer offline channel over online recycling channel, under this premise, the intenser between online and offline channels competition, the online channel has to increase the online recycling price in order to increase the quantity of recycling. When the competition between channels decreases, the online channel lowers the price in order to obtain higher profits.

3.2 Centralized decision-making

The centralized decision is to unify the recyclable dealer and recycler into a single entity with the decision goal of maximizing overall profit. Recycling dealers work with recyclers to set the online recycling price and the offline recycling price, so the total profit function under centralized decision making is as follows.

$$\pi_T^c = (w - P_t - c)D_t + (w - P_d)D_d \tag{14}$$

Proposition 4 The total profit function π_T^c under centralized decision making is a joint concave function about P_t, P_d. The optimal solution P_t^{c*}, P_d^{c*} are exist.

Proof Substituting equations (1) and (2) into equation (14) yields equation (15) and creates the Hessian matrix as follows.

$$\pi_T^c = (w - P_t - c)((1-\theta)a + bP_t - m(p_t - p_d) + (w - P_d)(\theta a + bP_d - m(p_d - p_t) \tag{15}$$

$$H_2 = \begin{pmatrix} 2m-2b & -2m \\ -2m & 2m-2b \end{pmatrix}$$

where the first-order principal is |2m-2b| and the second-order principal is $\begin{vmatrix} \mathbf{2m-2b} & \mathbf{2m} \\ \mathbf{2m} & \mathbf{2m-2b} \end{vmatrix}$, so when b>2m, the first-order principal is negative, the second-order principal is positive, and H_2 is a negative definite matrix, yielding that π_T^c is a joint concave function about P_t, P_d, and there are optimal solutions P_t^{c*} and P_d^{c*}.

In order to solve the optimal solution for each decision variable, it is necessary to solve the first-order partial derivative of π_T^c with respect to P_t and P_d. Then solve the optimal solution for price and recycling quantity by simultaneous equations as follows.

$$P_d^{c*} = \frac{\theta ab + 2mwb - wb^2 - am}{2b(2m-b)} \tag{16}$$

$$P_t^{c*} = -\frac{\theta ab + 2cmb - cb^2 - 2mwb + wb^2 + am - ab}{2b(2m-b)} \tag{17}$$

$$D_d^{c*} = \theta a + bP_d^{c*} - m(P_d^{c*} - P_t^{c*}) \tag{18}$$

$$D_t^{c*} = (1-\theta)a + bP_t^{c*} - m(P_t^{c*} - P_d^{c*}) \tag{19}$$

$$\pi_T^c = (w - P_t^{c*} - c)D_t^{c*} + (w - P_d^{c*})D_d^{c*} \tag{20}$$

Proposition 5 Under centralized decision making, when θ>0.5, online recycling optimal price P_d^{c*} is negatively related to channel competition coefficient m and offline recycling optimal price P_t^{c*} is positively correlated to m. When θ<0.5, online recycling optimal price P_d^{c*} is positively correlated to channel competition coefficient m and offline recycling optimal price P_t^{c*} is negatively correlated to m.

Proof The procedure as same as Proposition 2.

Proposition 6 $\boldsymbol{P_d^{c*} = P_d^{d*}}$ **and** $\boldsymbol{D_d^{c*} = D_d^{d*}}$**.**

Proof It is intuitively found that $\boldsymbol{P_d^{c*} = P_d^{d*}}$ through equations (7) and (16), and $\boldsymbol{D_d^{c*} = D_d^{d*}}$ through (10) and (18). Due to the complexity of the metric, the magnitude relationships between P_t^{d*} and P_t^{c*}, D_t^{d*} and D_t^{c*} will be analysed in the numerical analysis section.

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4. Numerical analysis

The above derivation by formula alone cannot fully guarantee its correctness and scientific validity, and the conclusions need to be verified and analyzed by numerical examples. In order to clearly shows the influence of customer recycling preference and channel competition on the pricing, recycling quantity and profit of the dual-channel reverse supply chain, numerical examples are conducted to validate and compare the above conclusions, as well as to provide suggestions for better decision making by channel members. Assume w=50, c=2, a=20, b=5. Combining the previous assumptions, we know that 0<θ<1 and 2m<b. *Table 2.* shows the effect of θ on each decision variable and *Table 3.* shows the effect of m on each decision variable.

Table 2. The effect of θ on each decision variable (*m*=0.1)

θ	Centralized					Decentralized						
	P_t^{c*}	P_d^{c*}	D_t^{c*}	D_d^{c*}	π_T^{c*}	P_t^{d*}	P_d^{d*}	D_t^{d*}	D_d^{d*}	π_{RD}^{d*}	π_R^{d*}	π_T^{d*}
0.1	21.6	24.8	129.1	125.9	6503.6	8.5	24.8	62.1	124.5	4676.2	787.0	5463.2
0.2	21.9	24.6	128.1	126.9	6502.7	8.8	24.6	61.6	125.5	4702.5	774.4	5476.9
0.3	22.1	24.4	127.1	127.9	6502.6	9.1	24.4	61.1	126.6	4729.5	761.9	5491.4
0.4	22.3	24.2	126.1	128.9	6503.3	9.4	24.2	60.6	127.6	4757.1	749.5	5506.6
0.5	22.5	24.0	125.1	129.9	6504.9	9.7	24.0	60.1	128.6	4785.3	737.1	5522.4
0.6	22.7	23.8	124.1	130.9	6507.3	10.0	23.8	59.6	129.6	4814.2	724.9	5539.1
0.7	22.9	23.6	123.1	131.9	6510.6	10.4	23.6	59.1	130.6	4843.6	712.8	5556.4
0.8	23.1	23.4	122.1	132.9	6514.7	10.7	23.4	58.6	131.6	4873.7	700.8	5574.5
0.9	23.3	23.2	121.1	133.9	6519.6	11.0	23.2	58.1	132.6	4904.5	688.9	5593.4

To make the effect of customer online recycling preference on each decision variable more clearly visible, make *m*= 0.1 and the results are shown in Table 2. Under the decentralized decision, the online recycling price decreases as customers' online recycling preference increases, while the offline recycling price increases. The online recycling quantity increases as customers' online recycling preference increases, while the offline recycling quantity decreases. The profit of recyclable dealers increases as customers' online recycling preference increases, while the profit of recyclers decreases, and the total profit of the supply chain increases under the decentralized decision. Under centralized decision making, online recycling price decreases as customers' online recycling preference increase, while offline recycling price increase. Online recycling quantity increases as customers' online recycling preference increase, while the offline recycling quantity is opposite. The total profit under centralized decision making increases as customers' online recycling preference increase. In summary, an increase in customers' online recycling preference is beneficial to the overall profit of the supply chain. In addition, a comparison of the profit of decentralized and centralized decisions shows that the total profit under centralized decision is higher than the total profit under decentralized decision.

Figure 2 clearly shows that the online recycling price for the decentralized decision is the same as the online recycling price under centralized decision and both of them decrease when θ increases. The offline recycling price under decentralized decision is lower than the offline recycling price under centralized decision and both of them increase when θ increases. The gap between the online recycling price and the offline recycling price under decentralized decision situation is large, but it gets smaller when θ close to 1. The difference between online and offline recycling price is small under centralized decision. The online recycling price is higher than offline recycling price when θ is less than 0.72. The online recycling price equals offline recycling price when θ is 0.72, and lower than offline recycling price when θ is higher than 0.72. Figure 3 shows that online recycling quantity under centralized decisions is slightly higher than online recycling quantity under decentralized decisions. The offline recycling quantity under centralized decision is much higher than it in the decentralized situation. The online recycling quantity is much higher than offline recycling quantity

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under decentralized decision. The difference between online recycling quantity and offline recycling quantity under centralized decision is small, and the recycling quantity in offline is higher than the online when θ less than 0.3 and lower than the online when θ exceeds 0.3. Both of them are equal when θ is 0.3.

Table 3. Effect of m on each decision variable (θ=0.5)

m	Centralized					Decentralized						
	P_t^{c*}	P_d^{c*}	D_t^{c*}	D_d^{c*}	π_T^{c*}	P_t^{d*}	P_d^{d*}	D_t^{d*}	D_d^{d*}	π_{RD}^{d*}	π_R^{d*}	π_T^{d*}
0.2	22.5	24	125.2	129.8	6504.8	9.5	24	60.2	127.1	4749.2	755.0	5504.2
0.4	22.5	24	125.4	129.6	6504.6	8.9	24	60.4	123.9	4672.2	793.1	5465.3
0.6	22.5	24	125.6	129.4	6504.4	8.2	24	60.6	120.5	4588.3	834.6	5422.9
0.8	22.5	24	125.8	129.2	6504.2	7.5	24	60.8	116.8	4496.5	880.2	5376.7
1.0	22.5	24	126.0	129.0	6504.0	6.8	24	61.0	112.8	4395.5	930.3	5325.8
1.2	22.5	24	126.2	128.8	6503.8	5.9	24	61.2	108.3	4283.9	985.6	5269.5
1.4	22.5	24	126.4	128.6	6503.6	4.9	24	61.4	103.3	4160.0	1047.2	5207.2
1.6	22.5	24	126.6	128.4	6503.4	3.9	24	61.6	97.8	4021.5	1116.0	5137.5
1.8	22.5	24	126.8	128.2	6503.2	2.7	24	61.8	91.6	3865.8	1193.5	5059.3
2.0	22.5	24	127.0	128.0	6503.0	1.3	24	62.0	84.7	3689.3	1281.3	4970.6

Table 4. Effect of m on each decision variable (θ=0.2 and θ=0.8)

m	Θ=0.2				Θ=0.8			
	Centralized		Decentralized		Centralized		Decentralized	
	P_t^{c*}	P_d^{c*}	P_t^{d*}	P_d^{d*}	P_t^{c*}	P_d^{c*}	P_t^{d*}	P_d^{d*}
0.2	22.34	24.65	8.49	24.65	23.65	23.34	10.42	23.34
0.4	22.28	24.71	7.83	24.71	23.71	23.28	9.91	23.28
0.6	22.21	24.78	7.09	24.78	23.78	23.21	9.35	23.21
0.8	22.11	24.88	6.28	24.88	23.88	23.11	8.76	23.11
1.0	22.00	25.00	5.37	25.00	24.00	23.00	8.12	23.00
1.2	21.84	25.15	4.34	25.15	24.15	22.84	7.44	22.84
1.4	21.63	25.36	3.16	25.36	24.36	22.63	6.72	22.63
1.6	21.33	25.66	1.77	25.66	24.66	22.33	5.99	22.33
1.8	20.85	26.14	0.07	26.14	25.14	21.85	5.29	21.85
2.0	20.00	27.00	0.00	27.00	26.00	21.00	4.83	21.00

In order to clearly show the effect of channel competition coefficient on each decision variable, let θ=0.5, and the results are shown in Table 3. With θ=0.5, online recycling price under decentralized decision is not affected by the channel competition coefficient, the offline recycling price gradually decreases as the channel competition coefficient increases, the online recycling quantity decreases as the channel competition coefficient increases, the offline recycling quantity slightly increases as the channel competition coefficient increases, the profit of recycling dealer decreases as θ increases, the profit of recycler increases as θ increases, but total supply chain profit decreases as θ increases. Both online and offline recycling prices under centralized decision are not affected by *m*. However, the online recycling quantity decreases and offline recycling quantity increases slightly, and total supply chain profits decrease as θ increases. Furthermore, it reveals that the total profit under centralized decision is higher than it under decentralized decision. To compensate for the limitations of Table 3, we briefly analyze pricing and profit when θ<0.5 and θ>0.5, as shown in Table 4, when θ=0.2, the offline recycling price decreases and the online recycling price increases as *m* increases under decentralized decision. The offline recycling price decreases and the online recycling price increases as *m* increases under centralized decision. When θ=0.8, the offline recycling price decreases and the online recycling price decreases with an increase as *m* increase under decentralized decision making.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202103_7(3).0063

The online recycling price decreases and the offline recycling price increases as *m* increase under centralized decision making.

Figure 4 shows that when θ is 0.5, the online recycling prices under centralized and decentralized decisions are the same and not affected by *m*. The gap of the offline recycling prices between decentralized and centralized decision is large. The offline recycling price decreases as *m* increases under decentralized decisions, while it is not affected by *m* under centralized decision. The offline recycling price under centralized decision is higher than it under decentralized decision. Figure 5 clearly shows the effect of *m* on the quantity of recycling, and the gap of online recycling quantity between decentralized and centralized decision is increasing when *m* increases. The offline recycling quantity under centralized decision is much higher than it under decentralized decision. Under centralized decision making, the gap between online and offline recycling quantity is smaller and smaller as *m* increases. Under decentralized decision making, the gap between online and offline recycling quantity will be smaller as *m* increases. Figure 6 shows the variation of total profit as *m* changes when θ=0.2,θ=0.5 and θ=0.8 under centralized decision making, and it can be seen the total profit is higher than others in the figure when θ is 0.8, and total profit is increasing with *m* when θ=0.8 and 0.2, and decreasing with *m* when θ= 0.5.

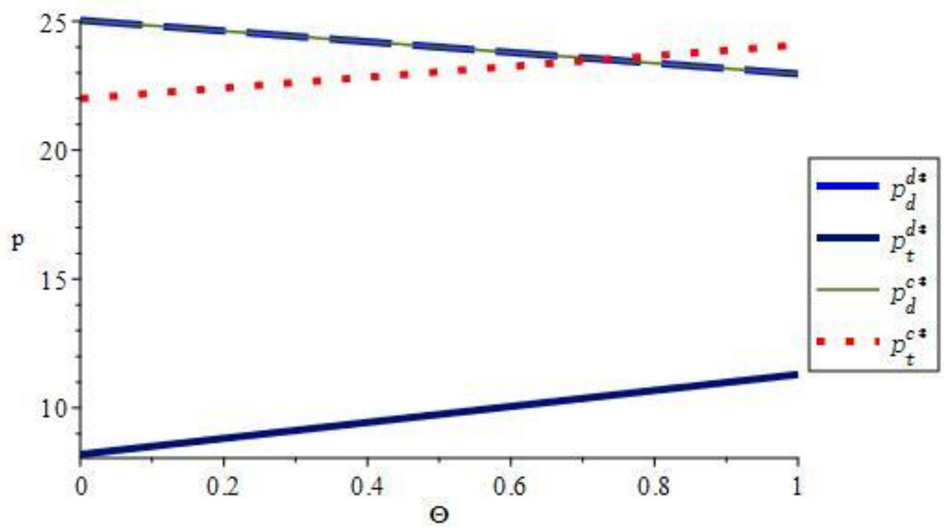

Figure 2. The effect of θ on p

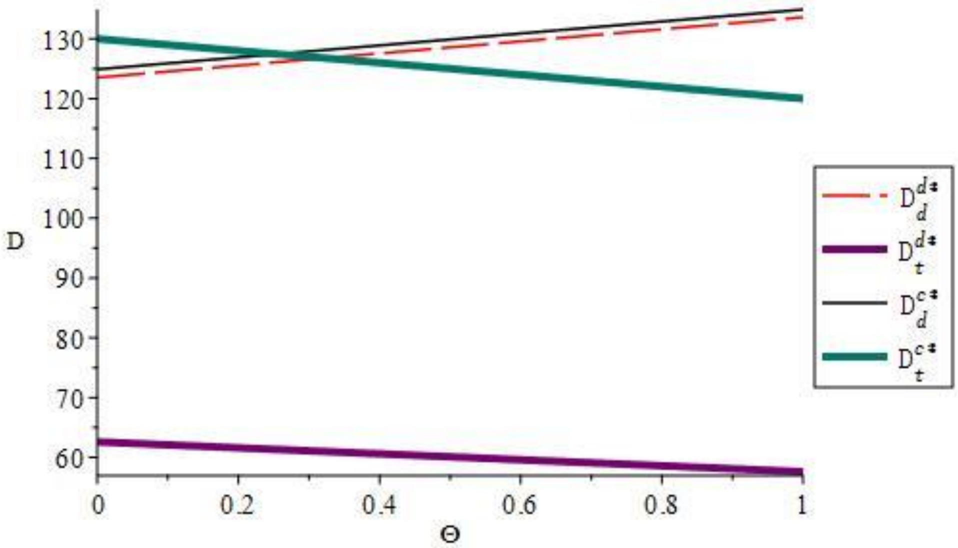

Figure 3. The effect of θ on D

ISSN: 2414-1895
DOI: 10.6919/ICJE.202103_7(3).0063

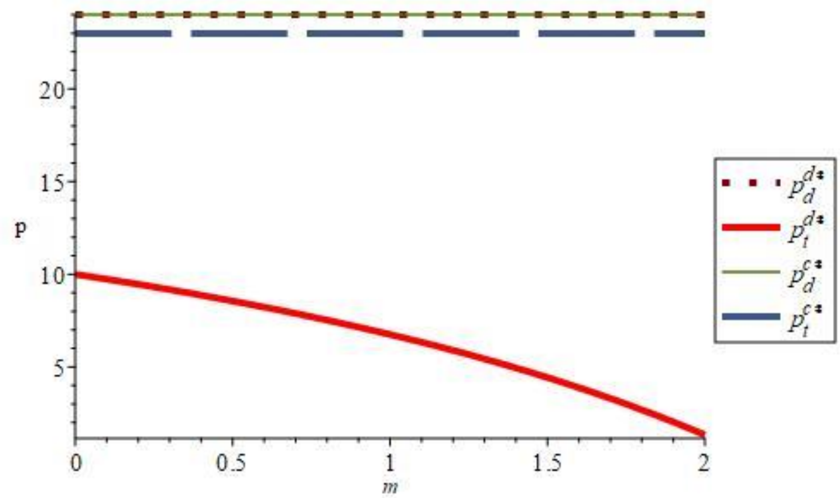

Figure 4. The effect of *m* on *p*

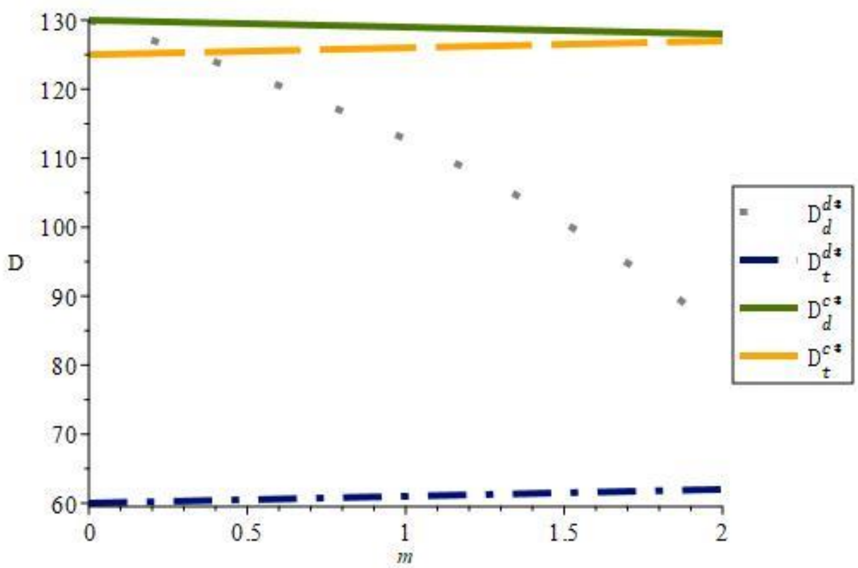

Figure 5. The effect of *m* on *D*

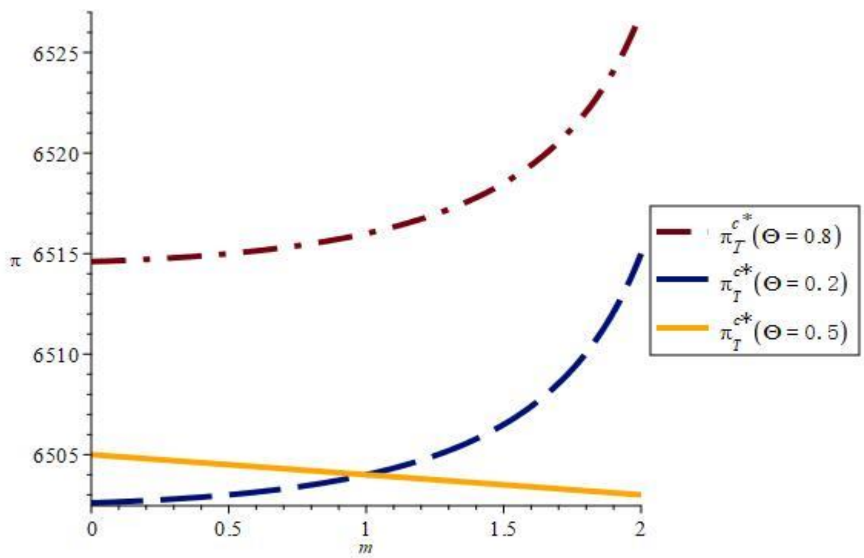

Figure 6. The effect of *m* on *π*

ISSN: 2414-1895 DOI: 10.6919/ICJE.202103_7(3).0063

5. Conclusion

A reverse supply chain consisting of a recyclable dealer and a recycler with dual-channel recycling of E-waste is used to analyze the effects of customer online recycling preference and channel competition on supply chain pricing, recycling quantity, and profit. Under the premise of θ less than 0.5, the online recycling price increases and offline recycling price decreases when channel competition increases. Under the premise of θ higher than 0.5, online recycling price and offline recycling price decrease when channel competition increases under decentralized decision making. The online price decreases, and offline price increases when channel competition increases under centralized decision making. Under the premise of θ equals 0.5, the online and offline recycling prices are not affected by channel competition under centralized decision making, but the offline recycling price under decentralized decision making decreases, while the online recycling price is not be affected. The greater the online recycling preference of customers, the greater the total supply chain profit. The effect of channel competition on the profit of the supply chain depends on θ. The total profit of the supply chain varies with channel competition in different ranges.

Based on these previous findings, it is clear that in a dual-recycling reverse supply chain,recyclable dealers should increase their online channel recycling efforts in order to achieve higher profits for the supply chain as a whole. Moreover, channel competition is not absolutely detrimental to the interests of the supply chain, and managers should take advantage of differences in customer recycling preference to introduce channel competition into a situation that benefits the supply chain.

References

[1] GARRIDO-HIDALGO C, OLIVARES T, RAMIREZ F J, et al. An end-to-end Internet of Things solution for Reverse Supply Chain Management in Industry 4.0 [J]. Computers in Industry, 2019, 112(103127.

[2] WU D, CHEN J H, LI P, et al. Contract coordination of dual channel reverse supply chain considering service level [J]. Journal of Cleaner Production, 2020, 260(

[3] RAHMANI S, HAERI A, HOSSEINI-MOTLAGH S M. Proposing channel coordination and horizontal cooperation in two competitive three-echelon reverse supply chains [J]. International Transactions in Operational Research, 2020, 27(3): 1447-77.

[4] FENG L, GOVINDAN K, LI C. Strategic planning: Design and coordination for dual-recycling channel reverse supply chain considering consumer behavior [J]. European Journal of Operational Research, 2017, 260(2): 601-12.

[5] HOSSEINI-MOTLAGH S M, NOURI-HARZVILI M, CHOI T M, et al. Reverse supply chain systems optimization with dual channel and demand disruptions: Sustainability, CSR investment and pricing coordination [J]. Information Sciences, 2019, 503(1): 606-34.

[6] ZHANG G, DAI G, SUN H, et al. Equilibrium in supply chain network with competition and service level between channels considering consumers' channel preferences [J]. Journal of Retailing and Consumer Services, 2020, 57(102199-214.

[7] CHEN K-Y, KAYA M, ÖZER Ö. Dual Sales Channel Management with Service Competition [J]. 2008, 10(4): 654-75.

[8] WANG Z Z, WANG M Z, LIU W W. To introduce competition or not to introduce competition: An analysis of corporate social responsibility investment collaboration in a two-echelon supply chain [J]. Transportation Research Part E-Logistics and Transportation Review, 2020, 133(

[9] ZHU X D, WANG J, TANG J. Recycling Pricing and Coordination of WEEE Dual-Channel Closed-Loop Supply Chain Considering Consumers' Bargaining [J]. International Journal of Environmental Research and Public Health, 2017, 14(12):