How to promote mobile phone trade-in and the integration of green supply chain from the perspective of multi-party game theory

Abstract: In the era of economic globalization, product trading markets are strongly impacted. The comprehensive utilization of e-waste is an important way to integrate green supply chains and improve resource utilization efficiency. Based on retailers and e-commerce platforms as mobile phone recycling entities, this paper constructs a dual-channel green supply chain dynamic game model and examines the impact of the trade-in strategy on the integration of the green supply chain. The results show that offset price, recovery price, and recovery quantity are positively correlated with the income through their respective channels. The transfer payment price is positively correlated with the revenue of the two channels. Trade-in strategy will increase the offset price, recovery price, and manufacturers' profits. However, the profits of retailers and e-commerce platforms are affected by the substitutability coefficient between channels and the sensitivity of recovery price. The optimal equilibrium in the supply chain is conducive to integrate waste mobile phone green supply chain, effectively cope with the impact on the global mobile phone manufacturing supply chain, and promote the realization of the "dual carbon" goal.

Keywords: Trade-in; Dynamic game; Green supply chain; Mobile phone recycling

1. Introduction

In the context of global climate change and the importance attached to circular economy, more and more countries have taken "carbon neutrality" as a national strategy and put forward the vision of a carbon-free future. In the electronics manufacturing industry, recycling and remanufacturing of used cell phones to achieve carbon neutral programs in the supply chain and product life cycle has attracted worldwide attention. According to data from the Ministry of Industry and Information Technology of the People's Republic of China in 2020, In the 5G era, the number of mobile phone users in China has exceeded 1.59 billion. More than 718,000 5G base stations have been opened[1]. In total, China will generate about 524 million used cell phones in 2020, and the cumulative stock of used cell phones in China has exceeded 2 billion from 2014 to the present. With the rapid development of 5G, consumers' demand for cell phones is rising, a large number of used cell phones are idle. Online platform is rapidly developing, trade-in is gradually emerging. Based on this, the green supply chain is steadily advancing, and the double carbon target is gradually realized.

Due to the scarcity of resources, geopolitical issues and other factors, recycling used cell phones has a very high economic value and social benefits[2]. Developed countries

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and regions such as the United States and the United Kingdom have established more complete recycling systems. Based on the concept of circular economy, it is urgent to put forward improvement suggestions adapted to China and boost the green supply chain[3, 4, 5, 6]. Nowadays, the supply chain has completed a new change from the traditional supply chain to a new green supply chain that combines "material flow", "information chain" and "value chain". Green supply chain emphasizes environmental management and ecological protection, and green sustainability is the key factor of the whole supply chain[7, 8]. Therefore, how to integrate the green supply chain of used cell phones and effectively respond to the impact on the global cell phone manufacturing supply chain?

Trade-in is the advantage of effectively linking the market side with the recycling side. It can enable consumers to actively participate in the construction of green supply chains and promote sustainable development[9]. What's more, it is an important way to achieve carbon peaking and carbon neutrality. Then, how to determine the optimal subsidy strategy to maximize economic and social benefits?

The electronics industry today is more of a complex process of optimizing the economic and social benefits of enterprises in a coordinated manner through open and technical integration of online and offline multi-channel. In the green supply chain, the traditional recycling model of retailers and the online recycling model of e-commerce platforms are two common recycling methods, and there is horizontal price competition between the two channels, and different recycling prices will have impacts on the recycling market demand and green supply chain revenue levels[10]. The introduction of substitutable coefficients reveals the situation of competition between the two channels. Then, how to seek the optimal substitutable coefficient between the two channels?

At present, the recycling of used mobile phones faces the following challenges.

a. Promote the realization of dual-carbon goals by the green supply chain of mobile phone trade-in and remanufacturing.

b. Realize the maximization of economic and social benefits of the trade-in strategy.

c. Explore the optimal substitutability factor between the two channel platforms.

The structure of this article is as follows. In the next section, we will summary of the literature related to cell phone recycling, platform-based trade-in and green supply chain. In Section 3, set relevant assumptions and parameters. It can establish a price competition model for offline retailers and online e-commerce platforms in two channels. Comparing the two strategies, set up propositions, perform numerical analysis and test on the propositions, perform sensitivity analysis on different parameters in Section 4. Finally, conclusions and recommendations are provided in Section 5.

2. Literature review

This paper focuses on the cell phone recycling and remanufacturing process. under the introduction of online channels on traditional channels, we consider how to promote trade-in strategies and integrate green supply chains. We review related research in this section.

Recycling and remanufacturing of used cell phones is the best end-of-life option to achieve multi-win social, economic and ecological benefits. Many factors affect the recycling of used cell phones. From the survey and analysis of consumers' behavior in recycling used cell phones, consumers' strategic purchasing behavior has a significant impact on the pricing and sales of new products, and the recycling and reuse of mobile phones[6, 11, 12]. The subsidy policy can incentivize consumers' willingness to recycle used mobile phones[13]. Some scholars have explored the product collaborative pricing strategy of dual-channel supply chain under electronic coupons and government subsidies[14]. These are crucial to the research and practice of recycling used cell phones, the cell phone recycling system will be most efficient. With the development of the Internet, big data and other new generation information technology, the traditional recycling model has changed[15]. Online platform recycling is an emerging business model with two-way market characteristics, and this model will bring substantial economic benefits in the future[16, 17, 18]. With the continuous deepening of research on e-waste recycling, a paper introduces consumer online recycling preference model and analyzes the advantages and disadvantages of manufacturer recycling, retailer recycling and online recycling[19]. Based on this, a paper believes that the channel that attracts more consumer preference is definitely in the optimal league[20]. The recycling cost sharing mechanism is the uniform sharing of recycling market power and recycling costs. Application of it can promote recycling of recycling systems composed of third parties and e-retailers[21]. The new model of "Internet + recycling" is making recycling easy, it seeks a link between online and offline recycling to enable and promote online recycling methods[18]. By comparing agent and principal, this paper looks for optimization strategies for online recyclers' resale channels[22].

Trade-in of mobile phones model establishes an effective incentive mechanism, expands consumer demand. Simultaneously, it is beneficial to closing the loop on circular economy from theory to practice and back again and promotes a green recycling system[23]. Trade-in of products with innovative technologies protects manufacturers from residual value risk compared to leasing[24]. An author considers economic and social performance of trade-in, joint advertising strategies and cash-for-hire options[25]. Another author focused on comparing the three supply chain models of no trade-in and manufacturer's and retailer's trade-in[26]. These are found that the company's implementation of trade-in can bring greater profits. In addition, some studies combine other areas. From the full life cycle of the product, it considers the impact of the deposit system on the profits of manufacturers, and formulates online and offline trade-in strategy models from market segmentation, and formulates the best rebate strategy[27, 28]. Combined with the characteristics of online trade-in, another scholar constructed a closed-loop supply chain model that provides two different trade-in models of gift certificates and cash coupons[29].

With the improvement of consumers' acceptance of green products, closed-loop green supply chain began to appear, green supply chain management has become the concept of reducing environmental risks. Some scholars have explored the optimal solutions for a variety of strategies such as green-sensitive consumer demand, cost-sharing contracts, and product collaborative pricing[10, 30, 31]. From different angles, these papers analyze the maximum total profit and optimal market equilibrium of online and offline dual-channel green closed-loop supply chain system[32]. To maximize economic and social benefits requires the joint efforts of the whole society, some researchers consider the behavior of different participants in the green supply chain with or without government subsidies, corporate social responsibility, environmental regulations and carbon tax subsidies[14, 32, 33]. Green supply chain is an important starting point for promoting green transformation and improving environmental quality[34]. Furthermore, carbon tax policy has a profound impact on the development of low carbon economy and the integration of green supply chain[35, 36]. Combining with different carbon tax policies, it compares the environmental impacts of two trade-in strategies, simple and flexible[37, 38]. Based on environmental responsibility behaviors, a paper examines the environmental performance of green manufacturers under fuzzy uncertainty[35]. These articles reduce carbon emissions from the perspective of the global development of the green supply chain, and promote the achievement of carbon peak and carbon-neutral goals. The research gap between this study and other literatures is shown in Table 1.

Table 1. Comparison of our study and relevant literature

Relevant literature	Mobile phone recycling and remanufacturing	Online platform recycling	trade-in	green supply chain
Sarath et al.[2]	√			
Yin et al.[6]	√			
Bai et al.[11]	√			
Meng et al.[14]	√			√
Gu et al.[16]		√		
Wang et al.[18]	√	√		

Feng et al.[19]	√	√		
Li and Xu [24]	√		√	
Li et al. [26]	√		√	√
Huang et al.[27]	√	√	√	
Ji et al.[28]	√	√		
Guo et al.[32]	√			√
Liu et al.[34]			√	√
Hong and Guo [35]	√			√
Our work	√	√	√	√

To sum up, there are many studies considering the implementation of the trade-in strategy. However, there are few studies on the green supply chain of mobile phone trade-in. To promote effective and green recycling and remanufacturing of used cell phones, and to achieve the dual carbon goal as soon as possible, this paper constructs recycling models for retailers and e-commerce platforms with and without trade-in scenarios, explores the impact of two scenarios on green supply chain. It provides suggestions for relevant recycling and remanufacturing enterprises to implement trade-in strategies to integrate the green supply chain effectively.

3. Material and methods

3.1. Problem description

This research constructs a closed-loop supply chain with dual recycling channels for used mobile phones consisting of a single manufacturer, a single retailer, a single consumer, and an e-commerce platform. As shown in Fig. 1, in forwarding logistics, manufacturers produce new mobile phones and wholesale them to retailers and e-commerce selling platforms at a wholesale price W. Then retailers and e-commerce sell new mobile phones to consumers at a retail price P.

Consumers can choose to sell or trade-in their used cell phones at traditional retailers or directly at e-commerce recycling platforms in reverse logistics. Under the no-trade-in mode, the first recycling method is that consumers sell their used mobile phones to retailers at a price of r_1. Manufacturers recycle their used mobile phones from retailers at the transfer recycling price t and get profits V_1 from the disposal of used mobile phones. The second is that consumers sell their used phones to an e-commerce recycling platform at a price of r_2. The e-commerce recycling platform dismantles the used phones and sells them to raw material market units for a profit of V_2. Similarly, with the trade-in model, the first recycling method is for the consumer to sell the used phone to the retailer at an offset price of r_1 and then pay part of the retail price of the new phone to achieve the trade-in. The second is that the e-commerce recycling platform recycles the used mobile phones from consumers at a recycling price r_2, and gives the consumers a coupon h for buying a new phone. And the manufacturer purchases raw materials from the raw material market at a price L for the production of new mobile phones, and L includes in the manufacturer's unit cost c for producing mobile phones.

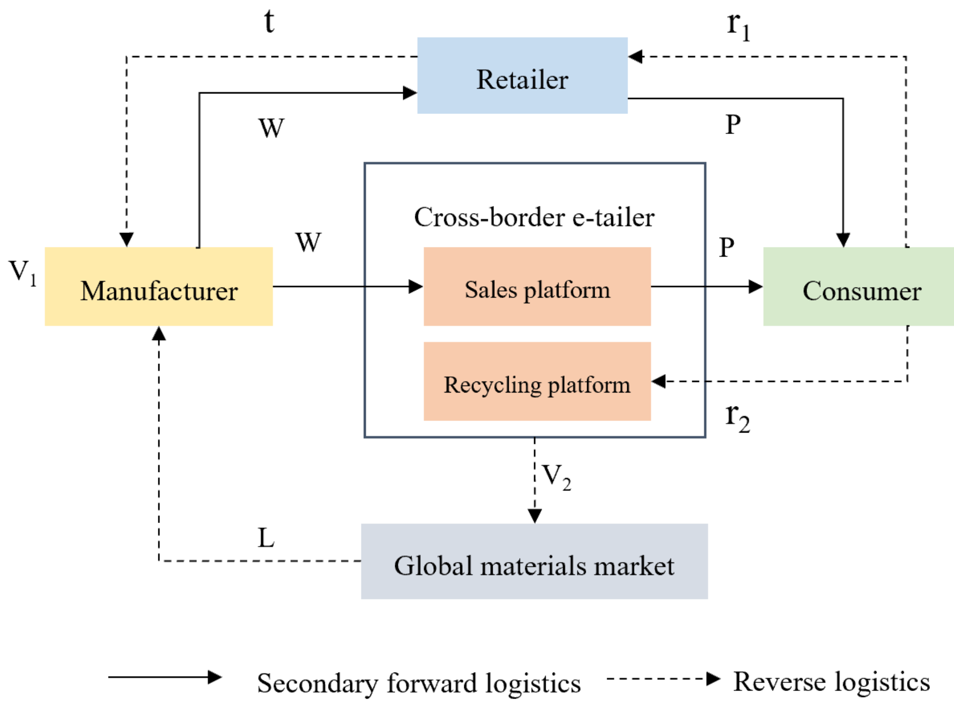


Figure 1. Schematic diagram of model structure

3.2. Related assumptions

Assumption 1: The demand function is linear in the demand variable and the manufacturing cost is linear in the quality production[39]. The raw material is homogeneous, not precisely the materials and parts extracted from used cell phones in e-commerce platforms. The raw materials extracted from used cell phones have been processed to a level that can manufacture new cell phones. This paper does not consider this process.

Assumption 2: The remanufactured product and the new product are homogeneous[40]. The manufacturer is the only one capable of producing qualified new mobile phones in the entire market. The e-commerce platform has only simple disassembly capabilities cannot realize the reorganization and reproduction of mobile phones.

Assumption 3: If the recycling amount of used mobile phones is only related to the recycling price and refer to relevant literature[41], $Q_i = g + a(r_i - br_j),\ i,j = 1,2, i \neq j$, it indicates that the amount of recycled mobile phones is an increasing function of the recycling price r_i (decreasing function of r_j), *g*, *a* >0, 0<*b*<1. And *g* represents the environmental awareness of consumers, *g* number of consumers are willing to sell their used mobile phones for free, and *a* is the sensitivity of consumers to recycling price, *b* is the substituting coefficient of the two channels. $Q_1+Q_2=Q$, *Q* is the total market demand for recycling of used mobile phones.

Assumption 4: τ represents the conversion rate of part of the recycling volume into new renewal demand when implementing the strategy of trade-in", $0 \leq \tau \leq 1$, $Q_i' = \tau[g + a(r_i - br_j)]$ will be transformed into new market demand[42].

Assumption 5: The wholesale price and retail price of mobile phone forward logistics have been determined in other ways[43, 44]. And the information of all parties is complete and perfect, and they are all risk-rational decision-makers.

Assumption 6: The recycling process does not consider issues such as inventory and transportation distance. This paper does not consider other uncertain factors[45].

The specific parameters are shown in Table 2 below.

Table 2. Related parameters and descriptions

Parameters	Meaning
W	The wholesale price of a new mobile phone
P	Retail price of the new mobile phone
c	Cost of the whole process from the raw materials to the product for the manufacturer to manufacture a new mobile phone
r_1^i	Offset price of used phones in the retailer's recycling channels, *i*=*N*, *Y*
t^i	Unit transfer recovery price paid by the manufacturer to the retailer, *i*= *N*, *Y*
r_2^i	Recycling price of used mobile phones in the recycling channels of e-commerce platforms, *i*= *N*, *Y*
V_1	Manufacturers' profits from disposing of used mobile phones
V_2	Revenue from the sale of used cell phones after simple disassembly on online platforms
h	Amount of coupons given to consumers by e-commerce recycling platforms
L	Manufacturers buy raw materials from the raw material market at the price
Q_1	Recycling of used mobile phones by retailers
Q_2	Recycling volume of used cell phones on e-commerce platform
Q_1^i	Retailer's demand for renewal of mobile phones under trade-in, *i*= *N*, *Y*
Q_2^i	E-commerce platform for renewal of mobile phones under trade-in, *i*= *N*, *Y*
π_m^i	Manufacturer's profit, *i*= *N*, *Y*
π_r^i	Retailer's profit, *i*= *N*, *Y*

π_e^i	E-commerce platform's profit, *i*= *N*, *Y*

3.3. Model construction

Based on the assumptions and related parameter descriptions, this paper considers whether the dual recycling channels composed of retailers and e-commerce platforms have different pricing strategies under the trade-in strategy. According to the relationship between the recycling price and the demand, we find the recycling function of dual recycling channels and construct a closed-loop supply chain pricing model for the retailer and online e-commerce platform. Using game theory, this paper compares the two strategies. It discusses the effects of manufacturers' disposal profit and e-commerce platform's simple dismantling and selling of used mobile phones on offset price, recycling price, transfer and recycling price and market share. It studies the influence of the degree of competition between channels on the offset price, recovery price, transfer recovery price, market share and profits.

3.3.1. No trade-in model

Not considered the renewal demand of secondary forwarding logistics, forward logistics and reverse logistics are separated. In reverse logistics with dual recycling channels, horizontal competition between the two channels and the steep competition between retailer channels exist simultaneously. The former constitutes a Bertrand game, while the latter includes the manufacturer-led Stackelberg two-stage master-slave game. The specific process of this dynamic game is as follows. In the first stage of the Stackelberg game, the manufacturer determines the transfer and recovery price *t*. In the second stage of the Stackelberg game, the optimal recovery price is set according to the manufacturer's decision and the information of each party. The retailer and e-commerce platform play Bertrand's game on the recycling price. This paper solves by reverse induction.

Calculate the corresponding profit function of manufacturers, retailers, and e-commerce platforms under no trade-in.

The profits of manufacturers, retailers and e-commerce platforms are respectively:

$$\pi_m^N = [g + a(r_1 - br_2)](V_1 - t) \tag{3.1}$$

$$\pi_r^N = [g + a(r_1 - br_2)](t - r_1) \tag{3.2}$$

$$\pi_e^N = [g + a(r_2 - br_1)](V_2 - r_2) \tag{3.3}$$

In the second stage of the Stackelberg game, the retailer and the e-commerce platform compete in Bertrand recycling price and determine the optimal recycling price of used mobile phones. Take the second derivative of the two profit functions (3.2) (3.3) concerning recovery price r_1, r_2, $\frac{d^2\pi_r^N}{dr_1^2} < 0$、$\frac{d^2\pi_e^N}{dr_2^2} < 0$. This paper finds that the profit functions of both the retailer and the e-commerce platform are strictly concave for the recycling price, so there is the only optimal recovery price that maximizes their respective profits. The first-order conditions of the (3.2) (3.3) two profit functions are:

$$\frac{d\pi_r^N}{dr_1} = a(t - r_1) - a(r_1 - br_2) - g = 0 \tag{3.4}$$

$$\frac{d\pi_e^N}{dr_2} = a(V_2 - r_2) - a(r_2 - br_1) - g = 0 \tag{3.5}$$

The first-order condition of the above two profit functions is Bertrand's reaction function, and the intersection point of them is the equilibrium point of the game. According to (3.4) (3.5), the recycling prices of retailers and e-commerce platforms are as follows:

$$r_1^{N*} = \frac{-a(bV_2+2t)+g(b+2)}{a(b^2-4)} \tag{3.6}$$

$$r_2^{N*} = \frac{-a(bt+2V_2)+g(b+2)}{a(b^2-4)} \tag{3.7}$$

In the first stage of the Stackelberg game, the dominant manufacturer in the reverse supply chain determines the optimal transfer price of used products. Take the expressions (3.6) (3.7) into (3.1), and calculate the second derivative of the transfer recovery price *t* for π_m^N, $\frac{d^2\pi_m^N}{dt^2} < 0$, Then there is the only optimal transfer recovery price t^{N*} . That maximizes the manufacturer's profit. Let $\frac{d\pi_m^N}{dt} = 0$, find the transfer recycling price from the manufacturer to the retailer under the no trade-in model:

$$t^{N*} = \frac{g(b+2)+a\left(b^2V_1-bV_2-2V_1\right)}{2a(b^2-2)} \tag{3.8}$$

Taking equation (3.8) back into the expressions of (3.6) (3.7), the optimal recovery price for retailers and e-commerce platforms under no trade-in:

$$r_1^{N*} = \frac{(-aV_2+g)b^3+(-aV_1+2g)b^2-3(-aV_2+g)b+2aV_1-6g}{a(b^4-6b^2+8)} \tag{3.9}$$

$$r_2^{N*} = \frac{(-aV_1+2g)b^3+(-3aV_2+3g)b^2+2(aV_1-3g)b+8aV_2-8g}{2a(b^4-6b^2+8)} \tag{3.10}$$

Bringing equation (3.9) (3.10) into $Q_i = g + a\left(r_i - br_j\right),\ i,j = 1,2, i \neq j$.

$$Q_1^{N*} = g + a(r_1 - br_2) = \frac{aV_1b^2+(aV_2-g)b-2aV_1-2g}{2(b^2-4)} \tag{3.11}$$

$$Q_2^{N*} = g + a(r_2 - br_1) = \frac{2aV_2b^4+(aV_1-2g)b^3-(9aV_2+3g)b^2-2(aV_1-3g)b+8aV_2+8g}{2(b^4-6b^2+8)} \tag{3.12}$$

Bring equations (3.8) (3.9) (3.10) back to (3.1) (3.2) (3.3) to get the optimal profit of manufacturer, retailer, and e-commerce platform under the no-trade-in model:

$$\pi_m^{N*} = \frac{\left[aV_1b^2+(aV_2-g)b-2aV_1-2g\right]^2}{4a(b^4-6b^2+8)} \tag{3.13}$$

$$\pi_r^{N*} = \frac{\left[a\left(V_1b^2+bV_2-2V_1\right)-g(b+2)\right]^2}{4a(b^2-4)^2} \tag{3.14}$$

$$\pi_e^{N*} = \frac{[2aV_2b^4+(aV_1-2g)b^3-(9aV_2+3g)b^2+(6g-2aV_1)b+8aV_2+8g]^2}{4a(b^4-6b^2+8)^2} \tag{3.15}$$

3.3.2. Trade-in model

Under the trade-in mode, there is a second forward logistics; there is a demand for renewal. However, the dynamic game process is roughly similarly as the no trade-in model. The difference is that in the second stage of the Stackelberg game, the e-commerce platform has to give back coupons in the trade-in amount. This paper solves by reverse induction.

Calculate the profit function of manufacturers, retailers, and e-commerce platforms under the trade-in model.

The profits of manufacturers, retailers and e-commerce platforms are respectively

$$\pi_m^Y = \tau[2g + a(r_1 - br_2) + a(r_2 - br_1)](W - c) + [g + a(r_1 - br_2)](V_1 - t) \quad (3.16)$$

$$\pi_r^Y = \tau[g + a(r_1 - br_2)](P - W) + [g + a(r_1 - br_2)](t - r_1) \quad (3.17)$$

$$\pi_e^Y = \tau[g + a(r_2 - br_1)](P - W - h) + [g + a(r_2 - br_1)](V_2 - r_2) \quad (3.18)$$

Similarly, taking the second derivative of the two profit functions (3.17) (3.18) concerning recovery price, $\frac{d^2\pi_r^Y}{dr_1^2} < 0, \frac{d^2\pi_e^Y}{dr_2^2} < 0$, the profit functions of both the retailer and the e-commerce platform are strictly concave for the recycling price. The first-order conditions of the above two profit functions are as follows:

$$\frac{d\pi_r^Y}{dr_1} = \tau a(P - W) + a(t - r_1) - a(r_1 - br_2) - g = 0 \quad (3.19)$$

$$\frac{d\pi_e^Y}{dr_2} = \tau a(P - W - h) + a(V_2 - r_2) - a(r_2 - br_1) - g = 0 \quad (3.20)$$

The intersection of the above two functions is the Bertrand equilibrium point. Combining (3.19) (3.20) and solving, the equilibrium recovery price is:

$$r_1^{Y*} = \frac{[((W-P+h)\tau - V_2)b + 2\tau(W-P) - 2t]a + g(b+2)}{a(b^2-4)} \quad (3.21)$$

$$r_2^{Y*} = \frac{[((W-P)\tau - t)b + 2((W-P+h)\tau - V_2)]a + g(b+2)}{a(b^2-4)} \quad (3.22)$$

Similarly, Taking the expressions (3.21) (3.22) into (3.16), for the second derivative of the transfer recovery price *t* for π_m^Y, $\frac{d^2\pi_m^N}{dt^2} < 0$. Calculate the only optimal transfer recovery price to maximize the manufacturer's profit. Let $\frac{d\pi_m^Y}{dt} = 0$, find the transfer and recycling price from the manufacturer to the retailer under the trade-in model as:

$$t^{Y*} = \frac{[((-P+2W-c)\tau + V_1)b^2 + ((-P+2W+h-c)\tau - V_2)b + (2P-4W+2c)\tau - 2V_1]a + g(b+2)}{2a(b^2-2)} \quad (3.23)$$

Bringing equation (3.23) back to (3.21) (3.22), it can obtain the optimal offset price for the retailer and the optimal recycling price for the e-commerce platform, respectively.

$$r_1^{Y*} = \frac{\left(((W-P+h)\tau - V_2)a + g\right)b^3 + \left(((c-P)\tau - V_1)a + 2g\right)b^2 + \left(((3P-4W+c-3h)\tau + 3V_2)a - 3g\right)b + 2((P-c)\tau + V_1)a - 6g}{a(b^4-6b^2+8)}$$

(3.24)

$$r_2^{Y*} = \frac{[((-P+c)\tau-V_1)b^3-((3P-2W-c-3h)\tau+3V_2)b^2+((2P-2c)\tau+2V_1)b+((8P-8W-8h)\tau+8V_2)]a+(2b^2-b-4)(2+b)g}{a(b^4-6b^2+8)}$$

(3.25)

Bringing equation (3.24) (3.25) into $Q_i = g + a(r_i - br_j),\ i,j = 1,2, i \neq j$.

$$Q_1^{Y*} = \frac{a((P-c)\tau+V_1)b^2+a((P-c-h)\tau+V_2)b+2a((c-P)\tau-V_1)-g(b+2)}{2(b^2-4)} \quad (3.26)$$

$$Q_2^{N*} = \frac{2a((W-P-h)\tau+V_2)b^4+(((P-c)\tau+V_1)a-2g)b^3-((\tau(2P-2c)+2V_1)a-6g)b}{2(b^4-6b^2+8)} + \frac{(((-9P+10W-c+9h)\tau-9V_2)a-3g)b^2-8a((P-W-h)\tau+V_2)-8g}{2(b^4-6b^2+8)} \quad (3.27)$$

Bring equations (3.23) (3.24) (3.25) back to (3.16) (3.17) (3.18) to get the optimal profit of manufacturer, retailer, and e-commerce platform under the no-trade-in model:

$$\pi_m^{Y*} = \frac{(c^2+(-6P+4W+4h)c+P^2+4WP-4W(W+h))\tau^2ab^4+2\tau^2ab^3-4\tau^2ab[(P-c)(P-c-h)]+a(b^2V_1+bV_2-2V_1)^2}{4a(b^4-6b^2+8)} + \frac{\tau^2ab^2(-3c^2+c(26P-20W-18h)-3P^2+P(-20W-2h)+20W^2+20Wh+h^2)+4\tau^2a(P^2+4WP-4W(W+h))}{4a(b^4-6b^2+8)} + \frac{2\tau^2a(c^2+(-6P+4W+4h)c)+(c(-2V_2-V_1)+PV_1+2WV_2)\tau ab^4+(c(-V_1-V_2)+(V_1+V_2)P-hV_1)\tau ab^3}{2a(b^4-6b^2+8)} + \frac{((9V_2+4V_1)c+P(V_2-4V_1)-10WV_2-V_2h)\tau ab^2+(c(V_1+V_2)-(V_1+V_2)P+hV_1)2\tau ab+(c(-V_1-2V_2)+PV_1+2WV_2)4\tau a}{2a(b^4-6b^2+8)} - \frac{2g(b+2)\left(((P+2W-3c)b^2+(P-2W+c-h)b-2P-4W+6c)\tau+b^2V_1+bV_2-2V_1\right)a-g^2(b+2)^2}{4a(b^4-6b^2+8)} \quad (3.28)$$

$$\pi_r^{Y*} = \frac{a\left(\tau((-P+2W-c)b^2+(P-c-h)b+2(3P-4W+c))+b^2V_1+bV_2-2V_1\right)-g(b+2)}{2(b^2-4)} \cdot \frac{[((\tau(P-c)+V_1)b^2+((P-c-h)\tau+V_2)b+(2c-2P)\tau-2V_1)a-g(2b^2+b-6)]}{2a(b^2-4)} - \frac{\left(((P-2W+c)b^2+(-W+c+h)b-2(2P-3W+c))\tau-b^2V_1-bV_2+2V_1\right)ag+g^2(b+2)}{2a(b^2-4)} + \frac{\tau(P-W)a^2\left(\tau((P-c)b^2+(P-c-h)b-2P+2c)+b^2V_1+bV_2-2V_1\right)}{2a(b^2-4)} \quad (3.29)$$

$$\pi_e^{Y*} = \frac{1}{4a}\left[\frac{(2(P-W-h)\tau+2V_2)ab^4+((P-c)\tau+V_1)ab^3+((-9P+10W-c+9h)\tau-9V_2)ab^2}{(b^2-2)(b^2-4)} + \frac{((c-P)\tau-V_1)2ab+8a((P-W-h)\tau+V_2)-g(b+2)(2b^2-b-4)}{(b^2-2)(b^2-4)}\right]^2 \quad (3.30)$$

4. Discussion and results

Table 3 shows the equilibrium results of the game between manufacturers, retailers, and e-commerce platforms with or without a trade-in. This article compares the impact of implementing the trade-in strategy on all parties and analyzes the effects of the trade-in strategy on the pricing strategy.

Table 3. Balanced results of the implementation of no trade-in strategy

	No trade-in model
r_1	$\frac{(-aV_2+g)b^3+(-aV_1+2g)b^2-3(-aV_2+g)b+2aV_1-6g}{a(b^4-6b^2+8)}$
r_2	$\frac{(-aV_1+2g)b^3+(-3aV_2+3g)b^2+2(aV_1-3g)b+8aV_2-8g}{2a(b^4-6b^2+8)}$
Q_1	$\frac{aV_1b^2+(aV_2-g)b-2aV_1-2g}{2(b^2-4)}$
Q_2	$\frac{2aV_2b^4+(aV_1-2g)b^3-(9aV_2+3g)b^2-2(aV_1-3g)b+8aV_2+8g}{2(b^4-6b^2+8)}$
t	$\frac{g(b+2)+a(b^2V_1-bV_2-2V_1)}{2a(b^2-2)}$
	Trade-in model
r_1	$\frac{(((W-P+h)\tau-V_2)a+g)b^3+(((c-P)\tau-V_1)a+2g)b^2+(((3P-4W+c-3h)\tau+3V_2)a-3g)b+2((P-c)\tau+V_1)a-6g}{a(b^4-6b^2+8)}$
r_2	$\frac{[((-P+c)\tau-V_1)b^3-((3P-2W-c-3h)\tau+3V_2)b^2+((2P-2c)\tau+2V_1)b+((8P-8W-8h)\tau+8V_2)]a+(2b^2-b-4)(2+b)g}{a(b^4-6b^2+8)}$
Q_1	$\frac{a((P-c)\tau+V_1)b^2+a((P-c-h)\tau+V_2)b+2a((c-P)\tau-V_1)-g(b+2)}{2(b^2-4)}$
Q_2	$\frac{2a((W-P-h)\tau+V_2)b^4+(((P-c)\tau+V_1)a-2g)b^3-((\tau(2P-2c)+2V_1)a-6g)b}{2(b^4-6b^2+8)}+\frac{(((-9P+10W-c+9h)\tau-9V_2)a-3g)b^2-8a((P-W-h)\tau+V_2)-8g}{2(b^4-6b^2+8)}$
t	$\frac{[((-P+2W-c)\tau+V_1)b^2+((-P+2W+h-c)\tau-V_2)b+(2P-4W+2c)\tau-2V_1]a+g(b+2)}{2a(b^2-2)}$

4.1. Proposition

Proposition 1

With or without trade-in model, the recycling price of the retailer, the e-commerce platform, and the transfer recycling price paid by the manufacturer to the retailer are positively correlated with the manufacturer's revenue from disposing of the used phone and the e-commerce platform's revenue from disposing of the used phone, and the income has an impact on the price at which retailers recycle used phones, the recycling price on e-commerce platforms and the transfer recycling price offered to retailers by manufacturers, and the impact of the revenue of the former on the retailer's cost of recycling old mobile phones is $\frac{2-b^2}{b(3-b^2)}$ of the revenue of the latter. Specifically, when $0 < b < \frac{\sqrt{5}-1}{2}$, the profit of the former has a greater impact on the price of the retailer's recycled old mobile phone than the profit of the latter; When $b=\frac{\sqrt{5}-1}{2}$, both have an equal impact; When $\frac{\sqrt{5}-1}{2}< b<1$, the profit of the former has less impact on the retailer's price of recycling used mobile phones than the profit of the latter; Moreover, the effect of the former on the cost of recycled old mobile phones on the e-commerce platform is $\frac{(2-b^2)b}{(8-3b^2)}$ of the latter. The degree of impact of the former on the transfer recovery price provided by the manufacturer to the retailer is $\frac{2-b^2}{b}$ of the latter.

Proof:

Calculate the partial derivatives of r_1^{N*} in equation (3.9) concerning the returns V_1 and V_2 respectively: $\frac{\partial r_1^{N*}}{\partial V_1}=\frac{-ab^2+2a}{a(b^4-6b^2+8)}=\frac{2-b^2}{b^4-6b^2+8}>0$, $\frac{\partial r_1^{N*}}{\partial V_2}=\frac{-ab^3+3ab}{a(b^4-6b^2+8)}=\frac{b(3-b^2)}{b^4-6b^2+8}>0$, and due to $a>0, 0<b<1$, therefore, $\frac{\partial r_1^{N*}}{\partial V_1}>0$ $\frac{\partial r_1^{N*}}{\partial V_2}>0$ and

$\frac{\partial r_1^{N*}}{\partial V_1}\Big/\frac{\partial r_1^{N*}}{\partial V_2}=\frac{2-b^2}{b(3-b^2)}$. When $0<b<\frac{\sqrt{5}-1}{2}$, $\frac{\partial r_1^{N*}}{\partial V_1}\Big/\frac{\partial r_1^{N*}}{\partial V_2}>1$; When $b=\frac{\sqrt{5}-1}{2}$, $\frac{\partial r_1^{N*}}{\partial V_1}\Big/\frac{\partial r_1^{N*}}{\partial V_2}=1$; When $\frac{\sqrt{5}-1}{2}< b<1$, $\frac{\partial r_1^{N*}}{\partial V_1}\Big/\frac{\partial r_1^{N*}}{\partial V_2}<1$.

Similarly.

Calculate the partial derivatives of r_2^{N*} in equation (3.10) concerning the returns V_1 and V_2, respectively: $\frac{\partial r_2^{N*}}{\partial V_1}=\frac{-ab^3+2ab}{2a(b^4-6b^2+8)}=\frac{(2-b^2)b}{2(b^4-6b^2+8)}>0$, $\frac{\partial r_2^{N*}}{\partial V_2}=\frac{-3ab^2+8a}{2a(b^4-6b^2+8)}=\frac{8-3b^2}{2(b^4-6b^2+8)}>0$, so $\frac{\partial r_2^{N*}}{\partial V_1}>0$, $\frac{\partial r_2^{N*}}{\partial V_2}>0$, and $\frac{\partial r_2^{N*}}{\partial V_1}\Big/\frac{\partial r_2^{N*}}{\partial V_2}=\frac{(2-b^2)b}{(8-3b^2)}$.

Calculate the partial derivatives of t^{N*} in equation (3.8) concerning the returns V_1 and V_2 : $\frac{\partial t^{N*}}{\partial V_1}=\frac{a(b^2-2)}{2a(b^2-2)}=\frac{1}{2}>0$, $\frac{\partial t^{N*}}{\partial V_2}=\frac{-b}{2(b^2-2)}>0$, and $\frac{\partial t^{N*}}{\partial V_1}>\frac{\partial t^{N*}}{\partial V_2}>0$, $\frac{\partial t^{N*}}{\partial V_1}\Big/\frac{\partial t^{N*}}{\partial V_2}=\frac{2-b^2}{b}$.

Completed.

Proposition 2

With or without trade-in model, the market share of the retailer channel is positively correlated with the manufacturer's revenue of disposing of used cell phones and negatively correlated with the revenue of the e-commerce platform of disposing of used cell phones. The effect of the former on the market share of the retailer channel is greater than the latter.

The market share of the e-commerce platform channel is negatively correlated with the manufacturer's revenue from the disposal of used mobile phones. However, it is positively correlated with the e-commerce platform's revenue from processing used mobile phones. The former's revenue has less impact on the retailer's market share than the latter.

Proof:

Calculate the partial derivatives of Q_1^{N*} in equation (3.11) concerning the returns V_1 and V_2, respectively: $\frac{\partial Q_1^{N*}}{\partial V_1} = \frac{a(b^2-2)}{2(b^2-4)} > 0$, $\frac{\partial Q_1^{N*}}{\partial V_2} = \frac{ab}{2(b^2-4)} < 0$, and $\left| \frac{\partial Q_1^{N*}}{\partial V_1} \Big/ \frac{\partial Q_1^{N*}}{\partial V_2} \right| = \left| \frac{b^2-2}{b} \right| > 1$.

Calculate the partial derivatives of Q_2^{N*} in equation (3.12) concerning the returns V_1 and V_2, Then, $\frac{\partial Q_2^{N*}}{\partial V_1} = \frac{ab(b^2-2)}{2(b^4-6b^2+8)} < 0$, $\frac{\partial Q_2^{N*}}{\partial V_2} = \frac{a(2b^4-9b^2+8)}{2(b^4-6b^2+8)} > 0$, and $\left| \frac{\partial Q_2^{N*}}{\partial V_1} \Big/ \frac{\partial Q_2^{N*}}{\partial V_2} \right| = \left| \frac{b(b^2-2)}{2b^4-9b^2+8} \right| < 1$.

Completed.

Proposition 3

Implementing the trade-in strategy will increase the retailer's offset price and the recycling price of the e-commerce platform and expand the recycling quantity of the retail channel. Meanwhile, the recycling quantity of the e-commerce platform channel is affected by the trade-in strategy. It depends on the profit relationship between the e-commerce platform and the manufacturer. When the ratio of manufacturer's profit to e-commerce platform's profit is less than $\frac{b^3+b^2-2b}{9b^2-2b^4-8}$, the number of used cell phones traded in by e-commerce platform is less than the number recycled no trade-in, and vice versa is greater than.

Proof:

Subtracting equation (3.22) from equation (3.9):

$r_1^{Y*} - r_1^{N*} = \frac{(W-P+h)\tau b(b^2-3)+(c-P)\tau(b^2-2)+(c-W)\tau b}{b^4-6b^2+8}$, because of $0 > c-W > c-P$, $W-P+h < 0$ and $a, g > 0$, $0 < b < 1$, we get $(c-P)\tau(b^2-2)+(c-W)\tau b > (c-P)\tau(b^2-2)+(c-P)\tau b$. However, $(c-P)\tau(b^2-2)+(c-P)\tau b = (c-P)\tau(b^2+b-2) > 0$, then $(c-P)\tau(b^2-2)+(c-W)\tau b > 0$, therefore, $(W-P+h)\tau b(b^2-3)+(c-P)\tau(b^2-2)+(c-W)\tau b > 0$, easy to get $r_1^{Y*} - r_1^{N*} > 0$.

Similarly.

Subtracting equation (3.23) (3.24) (3.25) from equation (3.10) (3.11) (3.12):

$r_2^{Y*} - r_2^{N*} = \frac{(c-P)\tau b^3-(3P-2W-c-3h)\tau b^2+(2P-2c)\tau b+(8P-8W-8h)\tau}{2(b^4-6b^2+8)} > 0$

$$Q_1^{Y*} - Q_1^{N*} = \frac{a\tau[(P-c)b^2+(P-c-h)b-2P+2c]}{2(b^2-4)} > 0$$

$$Q_2^{Y*} - Q_2^{N*} = \frac{a\tau[2(P-W-h)b^4+(P-c)b^3+(-9P+10W-c+9h)b^2+2(c-P)b+8P-8W-8h]}{2(b^4-6b^2+8)}$$

Let the above equation be less than zero and simplify the solution. When $\frac{P-W-h}{W-c} < -\frac{b^3+b^2-2b}{2b^4-9b^2+8} < 1$, $P - W - h < \frac{b^3+b^2-2b}{-2b^4+9b^2-8}(W-c)$, at this time, $Q_2^{Y*} - Q_2^{N*} < 0$, it is not difficult to find that the implementation of the trade-in strategy will reduce the number of used cell phones recycled by the e-commerce platform when the manufacturer's profit is greater than the profit of the e-commerce platform. On the contrary, When $\frac{P-W-h}{W-c} > \frac{b^3+b^2-2b}{-2b^4+9b^2-8}$, $Q_2^{Y*} - Q_2^{N*} > 0$, then when the manufacturer's profit is less than the profit of the e-commerce platform, the implementation of the old-for-new strategy will increase the number of used mobile phones to be recycled on the e-commerce platform.

Completed.

Proposition 4

The implementation of the trade-in strategy affects the transfer recovery price paid by the manufacturer to the retailer. It depends on the relationship between the number of coupons on e-commerce platforms and the profit margins of manufacturers and retailers. manufacturer and the retailer to the coupon amount are less than $\frac{b}{2-b^2-b}$, the implementation of the trade-in strategy will increase the transfer recycling price paid by manufacturers to retailers and vice versa.

Proof:

Subtracting equation (3.21) from equation (3.8):

$$t^{Y*} - t^{N*} = \frac{\tau[(-P+2W-c)b^2+(-P+2W-c+h)b+(2P+2c-4W)]}{2(b^2-2)}$$

Let the above equation be less than zero and simplify it to get: when $\frac{-P+2W-c}{h} < \frac{b}{2-b-b^2} < 1$, $(W-c)-(P-W) < \frac{bh}{2-b-b^2}$, then $t^{Y*} - t^{N*} > 0$; when $\frac{-P+2W-c}{h} > \frac{b}{2-b-b^2}$, $(W-c)-(P-W) > \frac{bh}{2-b-b^2}$, then $t^{Y*} - t^{N*} < 0$.

From the above proof process, when $(W-c)-(P-W) < h$, when the profit margin between the manufacturer and the retailer is less than the number of coupons on the e-commerce platform, the implementation of the old trade-in strategy will also increase the transfer and recovery price paid by the manufacturer to the retailer.

Completed.

4.2. Numerical analysis

According to the problem description and related papers, the initial case parameters are assumed in Table 4. Next, the proposition will provide then numerical simulation analysis to verify the conclusion.

Table 4. Basic parameter assumptions

V_1	V_2	τ	a	b	g	W	P	c	h
800	300	0.3	0.2	0.4	40	2500	3000	1600	200

The wholesale, cost and revenue of mobile phones are the results of field research and fitting based on Samsung. Set the parameters as follows: $W = 2500, P = 3000, c = 1600, V_1 = 800, V_2 = 300$.

The recycling data is based on the actual research as well as simulation of used cell phones of Samsung on the Internet recycling platform. With the severe environmental impact and the increasing environmental awareness of consumers, the sensitivity of consumers to the recycling price decreases. The corresponding parameters are set as follows: $a = 0.2, b = 0.4, g = 40$.

Since there is no national subsidy standard related to online recycling of used cell phones, we refer to the Regulations on the Management of Recycling of Used Electrical and Electronic Products[46]. When the e-commerce subsidy enters the recycling system, the magnitude of the influence of this factor on the recycling volume is a large variation to a steady state. The relevant parameters are set as follows: $h = 200$.

Next, the proposition will provide then numerical simulation analysis to verify the conclusion.

According to the above parameter assumptions, $P - W - h < W - c$,$(W - c) - (P - W) < h$, substituting the above parameters into the equilibrium results of the model:

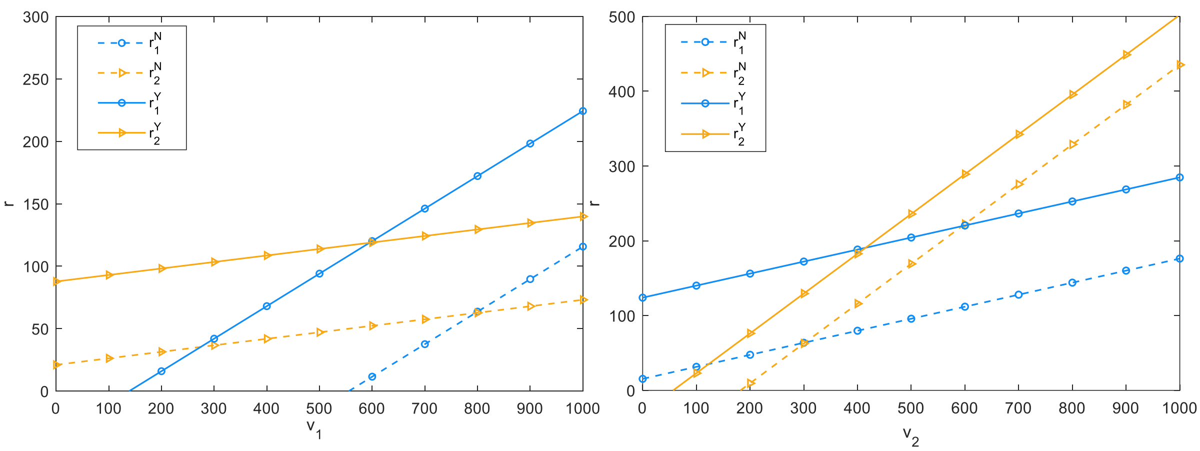
$r_1^{Y*} - r_1^{N*} = 108.5598$, $r_2^{Y*} - r_2^{N*} = 66.7120$, $Q^{Y*}_1 - Q^{N*}_1 = 16.3750$, $Q_2^{Y*} - Q_2^{N*} = 4.6576$, $t^{Y*} - t^{N*} = 40.4348$.

Implementing the trade-in strategy will increase the retailer's offset price and the recycling price of the e-commerce platform. It expands the number of recycling of the retailer's channel. When the manufacturer's profit is less than the e-commerce platform, it can boost the recycling of e-commerce platform channels. When the profit margin between the manufacturer and the retailer is less than the amount of the e-commerce platform coupons, the transfer recovery price will increase.

Verify the model's accuracy and proposition, this article deals with the following scenarios to simulate and analyze. When b=0.4 to explore the impact of V_1 or V_2 on r_1, r_2, Q_1, Q_2, t in the two modes respectively; When b=0.4 , b=0.618 , b=0.8 , to examine the impact of V_1 or V_2 on r_1, r_2 in the two modes; When the initial conditions remain unchanged, $a = b = [0,1]$, to explore the impact of a, b on r_1 , r_2 in the two modes respectively.

4.2.1. The impact of V_1, V_2 on r_1, r_2, Q_1, Q_2, t

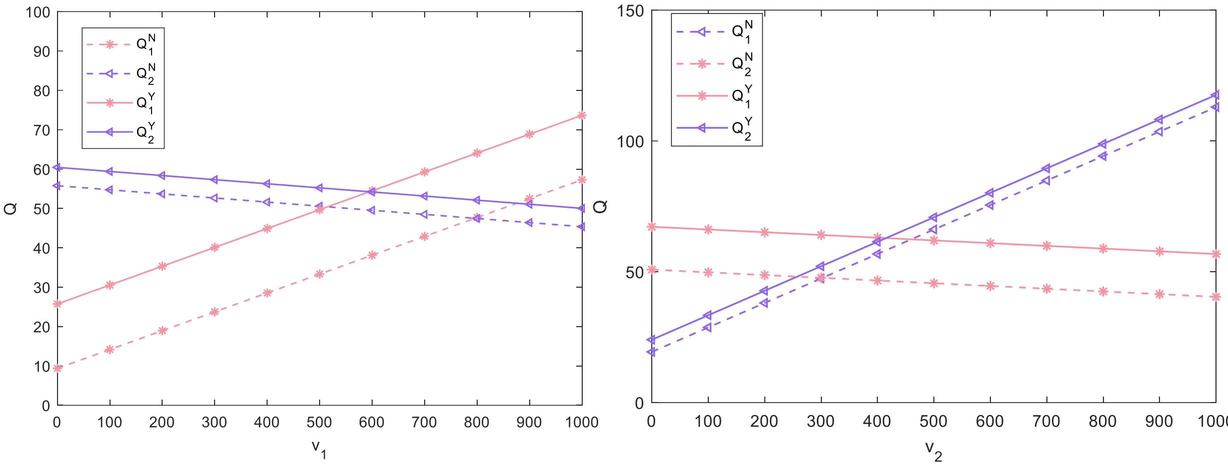
When other factors remain unchanged, take $V_1 = [0,1000]$, $V_2 = [0,1000]$ to discuss the respective influence in the two modes. The slope of each line is greater than zero, and the lines are parallel to each other, which shows that r_1, r_2 are positively correlated with V_1, V_2. In Fig.2 (a), the degree of impact V_1 on r_1 is greater than r_2. In Fig.2(b), the degree of impact V_2 on r_1 is less than r_2. Comparing Fig. 2(a) and 2(b), the degree of impact of V_1 on r_1 is greater than the degree of effect of V_2 on r_1. And the degree of impact of V_2 on r_2 is greater than that of V_1 on r_2. This figure shows that the revenue from the manufacturers has always had a greater positive effect on the offset price of the retailer's channels. The income from dismantling and selling used mobile phones on e-commerce platforms has had a greater positive impact on the recycling price of e-commerce recycling channels.



(a)The impact of V_1 on r_1, r_2 (b) The impact of V_2 on r_1, r_2

Figure 2. Impact of V_1, V_2 on r_1, r_2

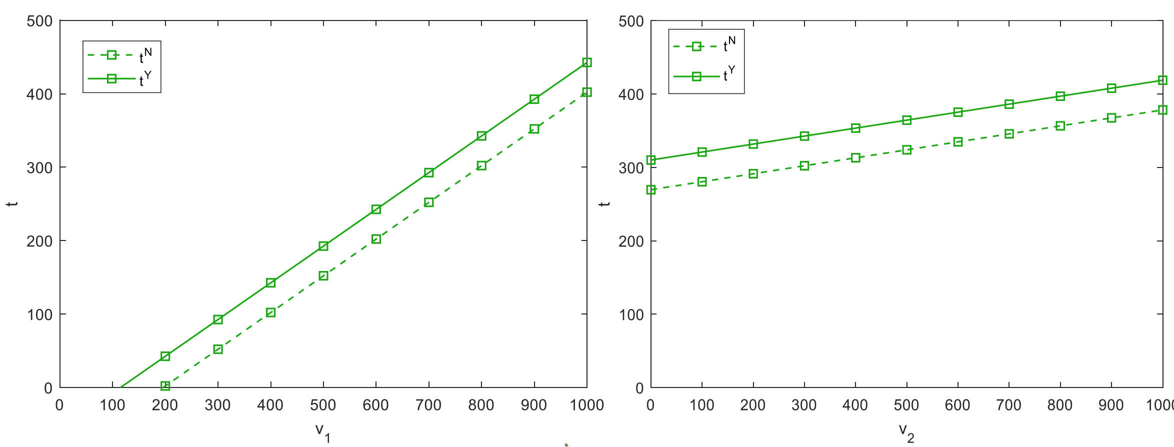
In Fig. 3 (a), in the two modes, Q_1 is positively correlated with the change of V_1. And Q_2 is negatively correlated with the shift in V_1. The degree of impact of V_1 on Q_1 is greater than Q_2. In Figure 3 (b), Q_1 is negatively correlated with the change of V_2, and Q_2 is positively correlated with the shift in V_2. The degree of impact of V_2 on Q_2 is greater than Q_1. Comparing Fig. 3 (a) and Figure 3 (b), the effect of V_1 on Q_1 is greater than the degree of impact of V_2 on Q_1. And the degree of effect of V_2 on Q_2 is greater than the degree of impact of V_1 on Q_2. This figure shows that the revenue from the manufacturer's disposal of used mobile phones and the income from the dismantling and sale of used mobile phones on the e-commerce platform positively impact the recycling of their channels.



(a) The impact of V_1 on Q_1, Q_2 (b) The impact of V_2 on Q_1, Q_2

Figure 3. Impact of V_1, V_2 on Q_1, Q_2

In Fig. 4, This paper finds that both t and V_1, V_2 are positively correlated. The degree of impact of V_1 on t is greater than the degree of influence of V_2 on t. This figure indicates that the manufacturer's transfer and recycling price to the retailer is affected by the manufacturer's income from disposing of used mobile phones and the profit of e-commerce platforms from dismantling and selling used mobile phones, and their impact is positive.

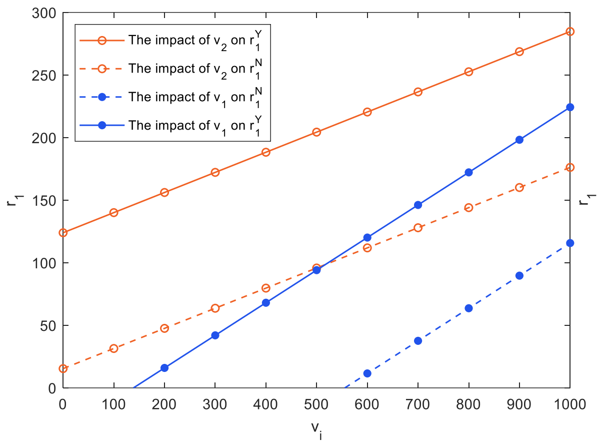


(a) The impact of V_1 on t (b) The impact of V_2 on t

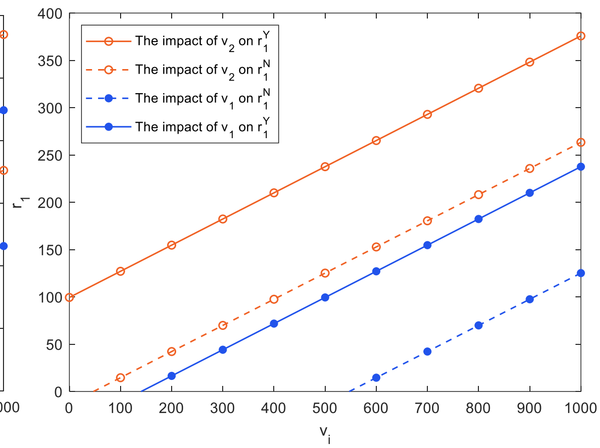
Figure 4. Impact of V_1, V_2 on t

4.2.2. The impact of V_1, V_2 on r_1

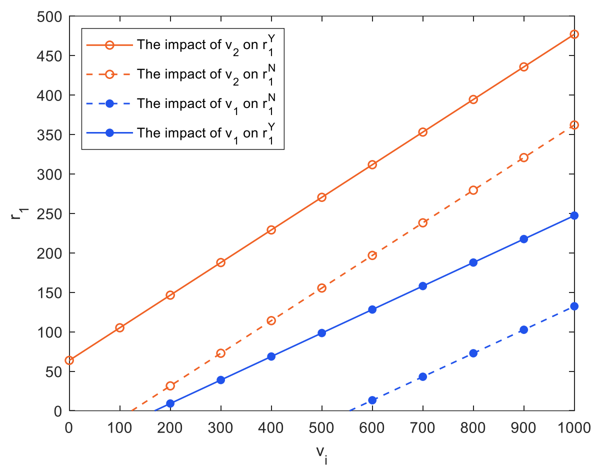
When $b = 0.4, b = 0.618, b = 0.8$, use to compare with Fig. 5 (a)(b), and (c), it can get the impact of V_1, V_2 on r_1 is positive, as the value b increases, the effect of V_1 on r_1 is gradually reduced, while the effect of V_2 on r_1 is gradually increased. And when $b < 0.618$, the former impact is greater than the latter influence. When $b = 0.618$, the former effect is equal to the later impact; When $b > 0.618$, the former result is less than the latter influence.



(a) $b = 0.4$



(b) $b = 0.618$

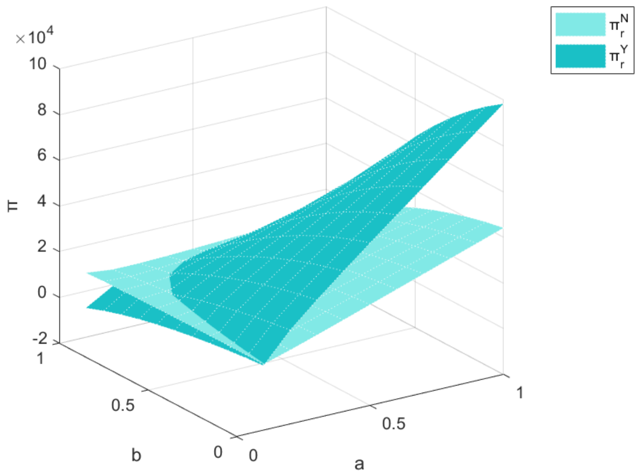


(c) $b = 0.8$

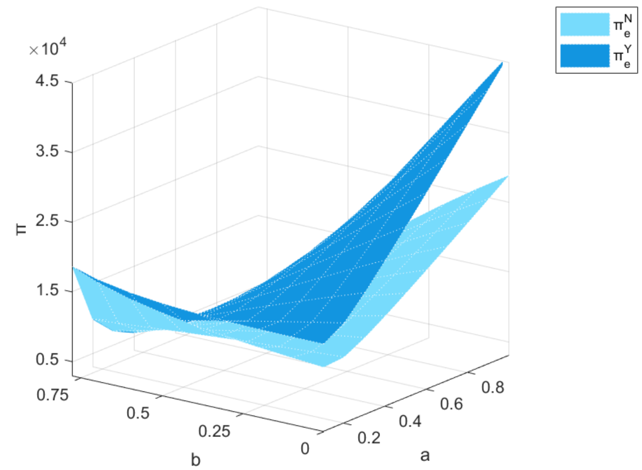
Figure 5. Impact of V_1, V_2 on r_1

4.2.3. The impact of *a*, *b* on π

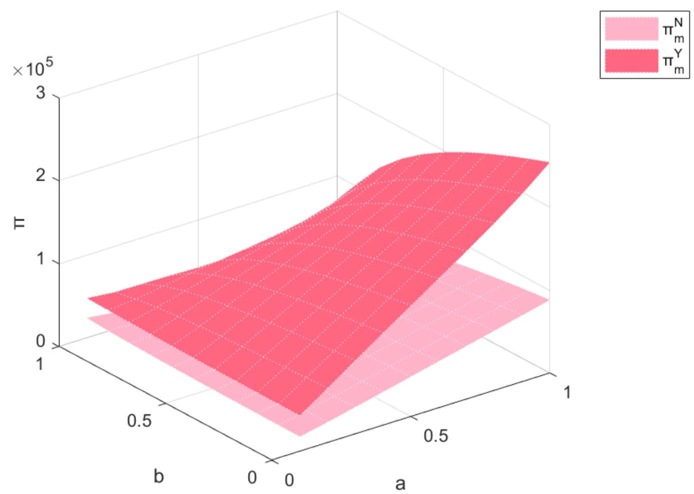
When $a = b = [0,1]$, Figure 6 (a) and (b) show the decrease of the substitutability coefficient b between channels and the increase of consumers' sensitivity to the recycling price. The profit of retailers π_r with trade-in and the profit of e-commerce platforms π_e have gradually expanded compared with no trade-in. In Fig. 6 (c), the manufacturer's profit π_m under the trade-in, the model is always greater than without the trade-in model.



(a) π_r



(b) π_e



(c) π_m

Figure 6. Impact of a, b on π

5. Conclusions

The result of propositions shows:

With or without the trade-in model, the greater the revenue from the disposal of used cell phones by manufacturers and e-commerce platforms, the greater the offset price or recycling price of old cell phones in the retailer channel or e-commerce platform channel and the greater the transfer recovery price provided by the manufacturer to the retailer. Specifically, both the manufacturer's and e-commerce platform's revenue from the disposal of used cell phones impacts the offset price of the retailer channel. It depends on the relevant substitution coefficient between the two channels. The manufacturer's profit and the manufacturer's revenue have less impact on the recycling price of the e-commerce platform channel than the e-commerce platform's revenue. However, the manufacturer's profit from disposing of used mobile phones has a greater impact on the price of transfer and recycling provided by the manufacturer to retailer than the revenue of the e-commerce platform. The recycling price is mainly affected by the income of the e-commerce platform from processing old mobile phones. And the price of recycling and recycling provided by the manufacturer to retailers is primarily influenced by the manufacturer's income from disposing of used mobile phones.

With or without the trade-in model, the greater the manufacturer's income from disposing of old mobile phones and the retailer channel's market share, the smaller the market share of e-commerce platform channels. The e-commerce platform processing old mobile phones, the greater revenue of the retailer, the smaller retail channel market share, and the greater the market share of the e-commerce platform channel. And The impact of manufacturers' income from disposal of used mobile phones on the market share of the retailer channel is greater than that of the e-commerce platform, and the impact on the market share of the e-commerce platform channel is smaller than that of the e-commerce platform.

Trade-in strategy will increase the retailer's offset price and expand the number of retail channels to be recycled and increase the recycling price of the e-commerce platform. But the amount of recycling of e-commerce platform channels depends on the profit relationship between the e-commerce platform and the manufacturer.

Trade-in strategy will affect the transfer recovery price provided by the manufacturer to the retailer. Still, the transfer recovery price depends on the relationship between the amount of the e-commerce platform coupons and the profit margin of the manufacturer and the retailer.

Trade-in strategy enhances manufacturers' profits. In contrast, retailers and e-commerce platforms' profits increase with decreased substitutability coefficient between channels and increased consumers' sensitivity to recycling prices. Its advantage gradually expands compared to the no trade-in.

According to the above research findings, the main factors affecting the choice of trade-in strategy are offset price, recycling price, transfer recycling price, recycling quantity and revenue of recycling and disposal. The implementation of trade-in strategy can effectively expand consumer demand, develop circular economy and improve the green supply chain management system of cell phones. This paper argues that to promote the implementation of the trade-in strategy, we should start from the equilibrium results of the main body at each stage from trade-in to remanufacturing of used cell phones, and choose a suitable recycling strategy to make the profits of all participants in the dual-channel supply chain reach a better equilibrium. It ensures the healthy and sustainable development of the used cell phone recycling market under trade-in, and integrate the green supply chain, reduces carbon emissions, and help achieve the dual carbon goals.

Future outlook

Under the condition of information asymmetry, it can consider a new pricing strategy based on government participation and multi-vendor competition in the future.

Table for contribution by the authors

All authors have made substantial contributions to all the following: the conception and design of the study, or analysis and interpretation of data; drafting the article or revising it critically for intellectual content; final approval of the version to be submitted. The specific contributions are as follows in table 5:

Table 5. Contribution by the authors

Name	Contribution
Xinyi Hu	Methodology, software, formal analysis, and writing-original draft preparation.
Xin Li	Supervision, conceptualization, and visualization.
Fanjie Luo	Software, formal analysis, and validation.
Minxi Wang	Supervision, writing-reviewing, and editing.
Litao Liu	Writing-reviewing and editing.

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