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Optimal Channel Choice of Firms with New and Remanufactured Products in the Contexts of E-Commerce and Carbon Tax Policy

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Abstract: This paper is motivated by the dilemma faced by firms who sell new and remanufactured products offline that need to consider whether to enter e-commerce platforms considering that more and more consumers are shopping online on e-commerce platforms rather than shopping offline. Our paper aims to help firms with new and remanufactured products make a channel choice and determine product pricing strategies in the contexts of e-commerce and carbon tax policy. Our paper uses optimization theory, game theory, utility functions and profit-maximization models to investigate the optimal channel choice of whether a firm should enter an e-commerce platform; it also investigates the optimal prices of new and remanufactured products and referral fees in two cases—the firm does not enter the platform (N) and the firm enters the platform (Y). Some insights are presented as follows: We found that the firm should enter the platform if the annual service fee is relatively low, otherwise, the firm should not enter the platform. Interestingly, in the case of a firm with an offline store with relatively large operational costs or hassle costs, the firm is more reluctant to enter the platform. In the extension, we considered some consumers who only purchase offline products, and found that the firm considering these consumers is more likely to choose not to enter the platform. Moreover, we argue that the carbon tax policy has a positive effect on product prices but a negative effect on referral fees charged by the platform, and the choice of Y hurts the environment due to a relatively high total carbon emission.

Keywords: channel choice; pricing; carbon tax policy; e-commerce platform

1. Introduction

Recently, more and more consumers are shopping online rather than shopping offline due to the development of e-commerce [1]. Online shopping brings convenience to consumers, such as reducing the hassle and cost of visiting offline stores, glancing at more products, and returning products more easily. According to Internet Retailer's analysis, in 2018, consumers spent \$517.36 billion online in the United States, and e-commerce represented 14.3% of total retail sales [2]. Analogously, according to the National Bureau of Statistics of China, in 2018, the online sales in China totaled about \$1.33 trillion, of which 18.4% accounted for total retail sales [3]. To cope with the impact of online markets and consumers' online shopping habits, more and more firms are considering whether to open online sales channels.

With the development of e-commerce, some e-commerce giants are emerging, such as Amazon, Taobao, JD, Bestbuy, Suning, and Gome. For instance, in the United States, Amazon accounted for 33.7% of the e-commerce market in 2018 and dominated in most categories [4]. Similarly, the Alibaba

group which includes Alibaba, along with the Taobao and Tmall online marketplaces, dominated e-commerce in China, and the online market share accounted for 53.3% [3]. Given that e-commerce platforms dominate the online market, firms who want to open online sales channels need to decide whether or not to enter e-commerce platforms as third-party sellers.

In recent years, environmental pollution problems caused by carbon emissions, such as global warming, rising sea levels, plants and animals dying, etc. have become increasingly serious. To curb carbon emissions, many governments, such as Finland, the United Kingdom, Sweden, Australia, and Germany, have enacted a carbon tax policy for firms with carbon emissions [5]. In the context of the carbon tax policy, firms with durable products are increasingly producing and selling remanufactured products given that remanufacturing activities have potential economic, environmental, and social benefits. These durable products include automobiles, home appliances, furniture, tools, consumer electronics, and sports equipment. For firms who sell new and remanufactured products, if they enter e-commerce platforms as third-party sellers, they always only sell new products rather than remanufactured products in the online stores. The main reasons are that e-commerce platforms have a high quality requirement for online products and firms want to eliminate cannibalization from new and remanufactured products in the online channel. It is a normal phenomenon that firms with new and remanufactured products, such as Apple, Xiaomi, and Dell, just sell new products on their online platforms and remanufactured products in offline stores; meanwhile just new products are sold at Tmall.com. Thus, in the context of carbon tax policy and e-commerce market, firms with new and remanufactured products need to decide whether or not to enter e-commerce platforms to sell new products online.

Based on the above exposition, some questions are presented as follows: Should firms with new and remanufactured products enter e-commerce platforms? How does carbon tax policy affect the decisions of firms with new and remanufactured products, product demands, and total carbon emissions in the context of entering (or not) e-commerce platforms? How should e-commerce platforms decide referral fees for firms with new and remanufactured products? What new results will be drawn if some consumers who only shop offline are considered?

To answer these questions, we consider a firm that sells new and remanufactured products via its offline store. There is an e-commerce platform dominating the online market. The firm needs to decide whether or not to enter the platform as a third-party seller. According to whether the firm enters the platform, we consider two cases—the firm does not enter the platform (N) and the firm enters the platform (Y). We developed theoretical models to investigate optimal offline new and remanufactured product prices, online new product prices, and referral fee strategies in the cases of N and Y, respectively. Moreover, we compared the size of the firm's optimal profit to explore optimal channel choice of whether to enter the platform. In the extension, we consider some consumers who just shop offline and present some new results.

Some main insights are concluded as follows: For the optimal channel choice strategy, the firm should not enter the platform if the annual service fee is relatively large; otherwise, the firm should enter the platform. In the case of considering consumers who only purchase offline, a firm is more likely to choose not to enter the platform. For optimal decision strategies, the firm should hold its remanufactured product price no matter whether it enters the platform or not; the firm should improve its product prices while the platform should reduce the referral fee as the unit carbon tax increases; and as the acceptance of remanufactured products increases, the firm should improve remanufactured product prices and reduce online new product prices, while the platform should reduce the referral fee. For optimal demands and total carbon emissions, although the choice of entering the platform increases total new product demands, it reduces the offline new product demand and remanufactured product demand, and the total carbon emission in the case of Y is larger than the case of N.

The main methodologies of the paper are optimization theory and game theory. Concretely speaking, we use the optimization theory to build consumer preference utility functions as well as

firms' theoretical profit-maximizing models; we also use the Stackelberg game in the case of Y in which the platform is the leader and the firm is the follower.

The main objectives of our paper are to present some insights to help firms with new remanufactured products, in the contexts of e-commerce and carbon tax policy, decide the optimal channel choice and product pricing strategies. Our paper is among the first papers to explore the channel choice of whether firms with new and remanufactured products should enter e-commerce platforms in the context of the carbon tax policy; this is our main contribution to the current body of literature.

The rest of paper is arranged as follows. In Section 2, related literature is reviewed. Section 3 presents product demand functions and cost structures of the firm. Theoretical models are developed in Section 4. In Section 5, main results and insights are proposed. Section 6 considers an extension. In Section 7, main insights are concluded, and future related research is discussed.

2. Literature Review

The paper explores a firm's optimal channel choice of whether or not to enter an e-commerce platform. Thus, the related literature is mainly about research pertaining to channel choice.

Channel choice strategies are widely studied by scholars. Some scholars investigate channel choice strategies through empirical methods [6–9], and most of them explore optimal channel choices from the perspective of consumers. For instance, Polo and Sese [10] investigated how and why customers choose available channels by developing an integrated conceptual framework and empirical data in financial services; the results aid firms in managing interactions across channels more effectively. Other scholars studied channel choice strategies by developing theoretical models; for instance, Coughlan [11] investigated how to choose a vertical marketing channel in the context of competition and cooperation and found that choosing a vertical marketing channel increases price competition which leads to relatively low prices. Following Coughlan [11], some scholars further investigated whether a firm should open a direct sale channel [12,13]. Moreover, scholars have studied channel choices from various perspectives, such as collecting channel choice strategies [14,15], channel choice in the two-sided markets [16], optimal channel choice for trade-in services [17], and channel choice regarding entering e-commerce platforms [18,19].

The above-mentioned research studies channel choice strategies from the perspective of empirical research, models, reverse supply chain, two-sided markets, trade-in service, entering e-commerce platform, etc. Except for Wang et al. [18] and Shen et al. [19], none of them has investigated channel choice of whether to enter e-commerce platforms. Unlike Wang et al. [18] and Shen et al. [19], our paper investigates channel choice of whether to enter e-commerce platforms for firms who sell new and remanufactured products. Moreover, our paper studies e-commerce platform channel choice under carbon tax policy, which has not been studied before.

3. Problem Description

We consider a firm who sells new and remanufactured products through its offline store. To curb carbon emission, the government implements a carbon tax policy in which the firm should pay a unit carbon tax price for its unit carbon emissions. In the online market, there is an e-commerce platform dominating this online market. Given that consumers are increasingly shopping online rather than shopping offline, the firm should consider whether or not to enter the platform to sell its new products. According to whether the firm enters the platform or not, we consider two cases—not entering the platform (N) and entering the platform (Y). Note that, we use superscripts N and Y to represent the two cases (i.e., N and Y), respectively. To clarify our problem easily, we explain some notations in Table 1 as follows.

Table 1. Notations.

Notation	Description
p_{si}	Retail price of new product ($i = n$) or remanufactured product ($i = r$) in the offline store
p_{on}	Retail price of new product in the online channel
f	Referral fee charged by the platform
ϕ	Value of the new product
α	The acceptance of the remanufactured product
θ	The acceptance of the online product
h_s	The hassle cost of visiting offline store
c	Unit production cost of new product
c_s	Unit operational cost of the offline store
β	Remanufactured product's emission intensity
t	Unit carbon tax
E	Total carbon emission
T	Annual service fee charged by the platform

Following Yenipazarli [20] and Cao et al. [21], consumers are heterogeneous with respect to new product valuation ϕ which is uniformly distributed from 0 to 1. Moreover, similar to Ferguson and Toktay [22], we assume that consumers' willingness to pay for a remanufactured product is a fraction α of their willingness to pay for a new product.

In the case of N, a consumer can obtain utility $u_{sn}^N = \phi - p_{sn} - h_s$ from purchasing a new product, and can obtain utility $u_{sr}^N = \alpha\phi - p_{sr} - h_s$ from purchasing a remanufactured product. Thus, the product demands of new and remanufactured products in the case of N can be easily presented as follows:

$$D_{sn}^N = 1 - (p_{sn} - p_{sr}) / (1 - \alpha) \quad (1)$$

$$D_{sr}^N = (p_{sn} - p_{sr}) / (1 - \alpha) - (p_{sr} + h_s) / \alpha \quad (2)$$

In the case of Y, a consumer can obtain utility $u_{sn}^Y = \phi - p_{sn} - h_s$ from purchasing a new product in the offline store, and can obtain utility $u_{on}^Y = \theta\phi - p_{on}$ from purchasing a new product in the online store, and can obtain utility $u_{sr}^Y = \alpha\phi - p_{sr} - h_s$ from purchasing a remanufactured product in the offline store. Thus, the new product demands from offline and online stores in the case of Y are given as follows:

$$D_{sn}^Y = 1 - (p_{sn} + h_s - p_{on}) / (1 - \theta) \quad (3)$$

$$D_{on}^Y = (p_{sn} + h_s - p_{on}) / (1 - \theta) - (p_{on} - p_{sr} - h_s) / (\theta - \alpha) \quad (4)$$

And the remanufactured product demand in the case of Y is proposed as follows:

$$D_{sr}^Y = (p_{on} - p_{sr} - h_s) / (\theta - \alpha) - (p_{sr} + h_s) / \alpha \quad (5)$$

The unit new product production cost is denoted by parameter c and the unit remanufactured product production cost is c_r . To simplify our model, we assume that $c_r = 0$ [23]. Moreover, given the firm's need to undertake operational costs from the offline store, we assume that the unit operational cost of the offline store is c_s [17]. Moreover, the government taxes the firm per unit carbon emission with carbon tax price t [24,25]. The unit carbon emission of the new product is e_n [26], and the unit carbon emission of the remanufactured product is assumed by βe_n , where β is the remanufactured product's emission intensity [24]. To simplify our model, similar to Yenipazarli [20], we assume that the unit carbon emission of the new product is equal to 1 (i.e., $e_n = 1$).

4. Theoretical Models

In this section, we develop theoretical models to investigate optimal decisions of the firm and the platform in the cases of N and Y, respectively.

4.1. Model N

In the case of N, the firm chooses not to enter the platform. The decision variables of the firm are retail prices of new and remanufactured products (i.e., p_{sn} and p_{sr}). The problem of the firm is described as follows:

$$\max_{(p_{sn}, p_{sr})} \prod_F^N = D_{sn}^N(p_{sn} - c - c_s - t) + D_{sr}^N(p_{sr} - c_s - \beta t) \quad (6)$$

By optimizing the model N, we can easily present the optimal retail prices of the two products which are shown in Table 2 and Appendix A.1.

Table 2. The optimal decisions.

Model	The Optimal Decisions
N	$p_{sn}^{N*} = (1 + c + c_s + t - h_s)/2$; $p_{sr}^{N*} = (\alpha + c_s + \beta t - h_s)/2$
Y	$p_{sn}^{Y*} = (1 + c + c_s + t - h_s)/2$; $p_{sr}^{Y*} = (\alpha + c_s + \beta t - h_s)/2$; $p_{on}^{Y*} = [t + t\beta + c + c_s + h_s + (2 + c + t - \beta t)\theta - 2(c + c_s + t + \theta + h_s)\alpha]/[4(1 - \alpha)]$; $f^{Y*} = [(c_s + h_s)(1 - \alpha) - c + \theta c - (1 - \theta)(1 - \beta)t]/[2(1 - \alpha)]$

4.2. Model Y

In the case of Y, the firm chooses to enter the platform. There is a Stackelberg game in which the platform is the leader and the firm is the follower. The decision variables of the firm is the offline retail prices of the two products (i.e., p_{sn} and p_{sr}) and the online retail price of the new product p_{on} , and the decision variable of the platform is the referral fee f . The problem of the firm under model Y is given as follows:

$$\max_{(p_{sn}, p_{sr}, p_{on})} \prod_F^Y = D_{sn}^Y(p_{sn} - c - c_s - t) + D_{sr}^Y(p_{sr} - c_s - \beta t) + D_{on}^Y(p_{on} - c - t - f) \quad (7)$$

And the problem of the platform can be described as follows:

$$\max_{(f)} \prod_P^Y = D_{on}^Y f \quad (8)$$

According to backward induction, we can easily solve the model Y, and the optimal decisions are shown in Table 2 and Appendix A.2.

5. Analysis

In this section, the main results are presented, and corresponding insights are obtained.

Theorem 1. The optimal channel choice of whether to enter the platform are given as follows:

- if $T < \hat{T}$, we have $\prod_F^{N*} < \prod_F^{Y*}$;
- and if $T \geq \hat{T}$, we have $\prod_F^{N*} \geq \prod_F^{Y*}$, where $\hat{T} = (c + t - c_s - h_s - \theta c + \alpha c_s + \alpha h_s - \theta t - \beta t + \theta \beta t)^2 / [16(\theta - \alpha)(1 - \theta)(1 - \alpha)]$.

Theorem 1(a) shows that if the annual service fee is less than a threshold value, the firm's profit in the case of Y is larger than that in the case of N. Although the product competition in the case of Y is relatively more intense, the firm in the case of Y can relatively entice more consumers to buy new products. If the platform charges the firm a small annual service fee, the firm will choose to enter the platform due to considerable online profit.

Theorem 1(b) indicates that if the annual service fee is larger than the threshold, the firm in the case of N can obtain more of a profit than in the case of Y. In the context of relatively large annual

service fees, and given channel conflict and negative or tiny online profit, the firm will choose not to enter the platform.

Theorem 1 implies that the firm should adopt N (Y) if the annual service fee is relatively large (small).

Based on the threshold value $\hat{T}$, we can easily find that $\hat{T}$ decreases with c_s and h_s , which means that the firm is more likely to choose N rather than Y if c_s or h_s is relatively large. These results are counterintuitive. In the context of a relatively large c_s or h_s , the firm is more reluctant to enter the platform. We explain these results as follows. As the operational cost of the offline store or the hassle cost increases, the online sales channel benefits the firm, but the demand of remanufactured products in the case of Y decreases which hurts the firm. The decrement of profit from remanufactured product sales is larger than the increment of profit from online sales, thus the firm is more likely to choose N rather than Y.

Proposition 1. *The size relationships between optimal decisions in the cases of N and Y are shown as follows:*

- (a) $p_{sn}^{N^*} = p_{sn}^{Y^*}$
- (b) $p_{rn}^{N^*} = p_{rn}^{Y^*}$

Proposition 1(a) shows that the offline retail price of a new product in the case of N is equal to that in the case of Y. Although there is a competition between online and offline new product sales, the firm still holds its offline retail price considering the competition is just internal competition.

Proposition 1(b) shows that the retail price of remanufactured products in the case of N is equal to that in the case of Y. Given the firm only sells remanufactured products via its offline store, if the firm chooses to enter the platform, the competition between offline new products and remanufactured products will turn into a competition between online new products and remanufactured products. Moreover, the above-mentioned competition is internal competition, thus the firm in the case of Y compared with that in the case of N will hold its remanufactured product's retail price to pursue maximal profit.

Proposition 1 implies that channel choices of whether to enter the platform do not affect the retail price of offline new products and remanufactured products.

Proposition 2. *The size relationships between new and remanufactured products in the cases of N and Y are proposed as follows:*

- (a) $D_{sn}^{N^*} > D_{sn}^{Y^*}$
- (b) $D_{sr}^{N^*} > D_{sr}^{Y^*}$
- (c) $D_{sn}^{N^*} < D_{sn}^{Y^*} + D_{on}^{Y^*}$

Proposition 2(a) shows that the offline new product demand in the case of N is larger than that in the case of Y. It is intuitive that there is competition between offline new products and online new products. The firm chooses to enter the platform, which brings competition to its offline new product sales. That is why the offline new product demand in the case of Y is relatively low.

Proposition 2(b) shows that the remanufactured product demand in the case of N is larger than that in the case of Y. If the firm enters the platform as a third-party seller, there is competition between online new products and remanufactured products, which reduces the remanufactured product demand.

Proposition 2(c) shows that the total new product demand in the case of N is less than that in the case of Y. Although a new sales channel brings and enhances product competition, it benefits for total new product sales.

Proposition 2 implies that the choice of entering the platform reduces the offline new product demand and remanufactured product demand but improves the total new product demand.

Proposition 3. *The size relationship between total carbon emissions in the cases of N and Y is given as follows: $E^{N^*} < E^{Y^*}$.*

Proposition 3 shows that the total carbon emission in the case of Y is larger than that in the case of N. From Proposition 2, we know that the remanufactured product demand in the case of Y is less than that in the case of N while the total new product demand in the case of Y is larger than that in the case of N. As we all know, remanufactured products compared with new products emit lower carbon. Thus, the total carbon emission in the case of Y is larger.

Proposition 3 implies that the choice of entering the platform hurts the environment.

Proposition 4. *The monotonicities of optimal decisions are given as follows:*

- (a) p_{sn}^* and p_{sr}^* increase with c_s and t but decrease with h_s ;
- (b) p_{sr}^* increases with α and β ;
- (c) p_{on}^* increases with t , β and θ but decreases with α ;
- (d) f^* increases with c_s , h_s , θ , β but decreases with t and α .

Proposition 4(a) shows that the optimal offline new product price and remanufactured product price increase with unit operational cost of the offline store and unit carbon tax but decrease with the hassle cost. As c_s or t increases, the firm needs to undertake more costs, which forces the firm to raise prices for its new and remanufactured products. However, as the hassle cost increases, consumers are less willing to buy new and remanufactured products, thus the firm should reduce new and remanufactured products prices to attract consumers.

Proposition 4(b) shows that the remanufactured product price increases with the acceptance of a remanufactured product and the remanufactured product's emission intensity. As α increases, consumers' valuation for remanufactured products increases, thus the firm could improve its remanufactured product price to earn more profit. As β increases, the firm needs to bear more costs from carbon tax, thus the firm should improve the remanufactured product price to defend against the raised costs.

Proposition 4(c) indicates that the online new product price increases with the unit carbon tax, the remanufactured product's emission intensity and the acceptance of the online product but decreases with the acceptance of the remanufactured product. As unit carbon tax increases, the firm will improve its online new product price to cope with the increased cost from carbon tax. As β increases, the firm will improve its remanufactured product price, which forces the firm to improve the online new product price considering there is competition between the remanufactured product and the online new product. As θ increases, the firm will improve online new product prices given that consumers' increased willingness to pay for the online product. As α increases, the competitiveness of the remanufactured product increases, thus the firm should reduce online new product price to improve the competitiveness of the online new product.

Proposition 4(d) shows that the referral fee increases with the operational cost of the offline store, the hassle cost, the acceptance of the online product and remanufactured product's emission intensity but decreases with unit carbon tax and acceptance of the remanufactured product. As c_s or β increases, the firm needs to undertake more offline costs, which means that the firm is more likely to sell products via an online channel. In this context, the platform will improve its referral fee to earn more profit. As h_s or θ increases, consumers are more likely to buy online products, thus the platform can improve its referral fee to earn more profit. As t increases, the firm needs to undertake more costs, thus the platform will reduce its referral fee considering that the firm's profit decreases. As α increases, the competitiveness of the remanufactured product increases, the platform should reduce its referral fee to help the firm improve the competitiveness of the online new product.

Proposition 4 implies that carbon tax policy has a positive effect on new and remanufactured products prices but has a negative effect on referral fee, and the acceptance of remanufactured products

has a positive effect on remanufactured product price but has a negative effect on online new product price and referral fee.

6. Extension

In this extension, we consider some consumers who only purchase products in the offline store, and we call these consumers, special consumers, and call other consumers, normal consumers. It is reasonable that some consumers only purchase products offline due to lack of Internet tools and capabilities or distrust of online products. Moreover, we assume that the percent of offline consumers is ρ . Note that, we use superscript E to represent this extension.

Given that special consumers do not affect the decisions of the firm in the case of N, we in the extension use E to represent the case of Y of the basic model.

In the case of E, a special consumer can obtain utility $u_{ssn}^E = \phi - p_{sn} - h_s$ from purchasing a new product in the offline store, and can obtain utility $u_{ssr}^E = \alpha\phi - p_{sr} - h_s$ from purchasing a remanufactured product in the offline store. Thus, the new and remanufactured product demands from special consumers are given as follows:

$$D_{ssn}^E = \rho[1 - (p_{sn} - p_{sr}) / (1 - \alpha)] \quad (9)$$

$$D_{ssr}^E = \rho[(p_{sn} - p_{sr}) / (1 - \alpha) - (p_{sr} + h_s) / \alpha] \quad (10)$$

In the case of E, a normal consumer can obtain utility $u_{nsn}^E = \phi - p_{sn} - h_s$ from purchasing a new product in the offline store, and can obtain utility $u_{non}^E = \theta\phi - p_{on}$ from purchasing a new product in the offline store, and can obtain utility $u_{nsr}^E = \alpha\phi - p_{sr} - h_s$ from purchasing a remanufactured product in the offline store. Thus, the new product demands from the offline and online store in the case of E are given as follows:

$$D_{nsn}^E = (1 - \rho)[1 - (p_{sn} + h_s - p_{on}) / (1 - \theta)] \quad (11)$$

$$D_{non}^E = (1 - \rho)[(p_{sn} + h_s - p_{on}) / (1 - \theta) - (p_{on} - p_{sr} - h_s) / (\theta - \alpha)] \quad (12)$$

The remanufactured product demand in the case of Y is proposed as follows:

$$D_{nsr}^E = (1 - \rho)[(p_{on} - p_{sr} - h_s) / (\theta - \alpha) - (p_{sr} + h_s) / \alpha] \quad (13)$$

The problem of the firm under model Y is given as follows:

$$\max_{(p_{sn}, p_{sr}, p_{on})} \prod_F^E = (D_{nsn}^E + D_{ssn}^E)(p_{sn} - c - c_s - t) + (D_{nsr}^E + D_{ssr}^E)(p_{sr} - c_s - \beta t) + D_{non}^E(p_{on} - c - t - f) \quad (14)$$

The problem of the platform can be described as follows:

$$\max_{(f)} \prod_P^E = D_{on}^E f \quad (15)$$

There is a Stackelberg game. According to backward induction, we can easily solve the model E and present the optimal decisions as follows:

$$\begin{aligned} p_{sn}^{E*} &= (1 + c + c_s + t - h_s) / 2; \quad p_{sr}^{E*} = (\alpha + c_s + \beta t - h_s) / 2; \\ p_{on}^{E*} &= [t + t\beta + c + c_s + h_s + (2 + c + t - \beta t)\theta - 2(c + c_s + t + \theta + h_s)\alpha] / [4(1 - \alpha)]; \\ f^{E*} &= [(c_s + h_s)(1 - \alpha) - c + \theta c - (1 - \theta)(1 - \beta)t] / [2(1 - \alpha)]. \end{aligned}$$

Theorem 2. The optimal channel choice in this extension is given as follows:

- if $T < \hat{T}^E$, we have $\prod_F^{N*} < \prod_F^{E*}$;
- and if $T \geq \hat{T}^E$, we have $\prod_F^{N*} \geq \prod_F^{E*}$, where $\hat{T}^E = (1 - \rho)\hat{T}$.

Theorem 2 shows that the firm should choose (not) to enter the platform if the annual service fee is less (larger) than a threshold value, which is similar to the results of Theorem 1. Theorem 2 implies the optimal channel choice strategy still holds if special consumers who only purchase offline are considered.

Moreover, by comparing the size of $\hat{T}$ and $\hat{T}^E$, we know that $\hat{T}^E < \hat{T}$, which implies that the firm in the case of considering offline consumers is more likely to choose not to enter the platform. We also find that $\hat{T}^E$ decreases with ρ , which implies that, as the percent of offline consumers increases, the firm is more likely to choose not to enter the platform.

Remark 1. *The size relationships between optimal decisions in the case of N and E are shown as follows: $p_{sn}^{N^*} = p_{sn}^{E^*}$; $p_{rn}^{N^*} = p_{rn}^{E^*}$.*

The results of Remark 1 are the same as those of Proposition 1, which means that the results of size relationships between optimal decisions in the case of considering offline consumers still holds.

7. Conclusions

With the development of e-commerce, consumers' shopping habits are shifting from offline shopping to online shopping. To cope with consumers online shopping habits, firms are increasingly developing online sales channels. Considering online market in practice is dominated by some e-commerce giants such as Amazon, Ebay, Taobao, Tmall and JD. That is to say, most offline firms need to decide whether or not to enter an e-commerce platform. Moreover, many governments have enacted a carbon tax policy to curb carbon emissions, which is driving more and more firms with durable products to engage in remanufacturing activities (i.e., they produce and sell remanufactured products as well as new products). According to whether a firm with new and remanufactured products enters an e-commerce platform or not, we consider two cases—not entering the platform (N) and entering the platform (Y). Under the carbon tax policy, we build theoretical models to investigate the optimal decisions of the firm and the platforms in the cases of N and Y, respectively, and explore the optimal channel choice of the firm. In the extension, we also consider some consumers who only purchase products in the offline store. Some insights are concluded as follows:

Optimal channel choice: If the annual service fee is less than a threshold value, the firm should enter the platform, otherwise, the firm should not enter the platform. If the offline operational cost or hassle cost is relatively large, the firm is more likely to choose to not enter the platform. The optimal channel choice strategies still hold if special consumers who only purchase in the offline store are considered. Moreover, the firm in the case of considering special consumers is more likely to choose not to enter the platform.

Optimal decisions: No matter whether the firm enters the platform, the firm will hold its new and remanufactured products prices. If the government improves the unit carbon tax, the firm should improve its new and remanufactured products prices while the platform should reduce its referral fee. As consumers' acceptance of remanufactured products increases, the firm should improve its remanufactured product price and reduce its online new product price while the platform should reduce its referral fee. As the remanufactured products' emission intensity increases, the firm should improve its remanufactured product price and online new product price and the platform should improve its referral fee.

Optimal demands: The choice of entering the platform has a positive effect on the total new product demand but has a negative effect on the offline new product demand and remanufactured product demand. Moreover, we found that the choice of entering the platform hurts the environment due to relatively high carbon emissions.

Some limitations exist for our paper, as well as opportunities for future study. Our paper only considers one firm which sells new and remanufactured products; thus, it would be interesting to study optimal channel choice in the context of two or more competing firms. In addition to product

price, product service is also considered by consumers. It is another perspective for future study if produce service is considered. At last, information symmetric between the firm and the platform is assumed in our paper, and some new results will be found if information asymmetric between the firm and the platform is used.

Author Contributions: J.C. analyzed the problems of determining optimal channel choice strategies for firms with new and remanufactured products by developing theoretical models, and she also wrote the draft of this paper. B.X. helps solve the optimal decisions and make some analysis for the main results. J.W. revised the written draft and provided theoretical and technical guidance for this paper.

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Appendix A

Appendix A.1. The Proof of Optimal Decisions in the Case of N

The profit of firm in the case of N is $\max_{(p_{sn}, p_{sr})} \Pi_F^N = D_{sn}^N(p_{sn} - c - c_s - t) + D_{sr}^N(p_{sr} - c_s - \beta t)$.

To solve the second-order conditions of the firm's profit function, we can present the Hessian matrix $H(\Pi_F^N(p_{sn}, p_{sr}))$ as follows:

$$\begin{bmatrix} \partial^2 \Pi_F^N / \partial p_{sn}^2 & \partial^2 \Pi_F^N / \partial p_{sn} \partial p_{sr} \\ \partial^2 \Pi_F^N / \partial p_{sr} \partial p_{sn} & \partial^2 \Pi_F^N / \partial p_{sr}^2 \end{bmatrix} = \begin{bmatrix} -2/(1-\alpha) & 2/(1-\alpha) \\ 2/(1-\alpha) & -2/(1-\alpha) - 2/\alpha \end{bmatrix}$$

It is easy to find that the Hessian matrix is negative-definite. Thus, the optimal decisions can be obtained from first-order conditions, i.e., $\partial \Pi_F^N / \partial p_{sn} = 0$ and $\partial \Pi_F^N / \partial p_{sr} = 0$.

The optimal decisions in the case of N is presented in Table 2.

Appendix A.2. The Proof of Optimal Decisions in the Case of Y

There is a Stackelberg game in which the platform is the leader and the firm is the follower. Firstly, we solve the response functions of the firm.

The profit function of the firm in the case of Y is

$$\max_{(p_{sn}, p_{sr}, p_{on})} \Pi_F^Y = D_{sn}^Y(p_{sn} - c - c_s - t) + D_{sr}^Y(p_{sr} - c_s - \beta t) + D_{on}^Y(p_{on} - c - t - f).$$

According to the second-order conditions, we present the Hessian matrix $H(\Pi_F^Y(p_{sn}, p_{sr}, p_{on}))$ as follows:

$$\begin{bmatrix} \partial^2 \Pi_F^Y / \partial p_{sn}^2 & \partial^2 \Pi_F^Y / \partial p_{sn} \partial p_{on} & \partial^2 \Pi_F^Y / \partial p_{sn} \partial p_{sr} \\ \partial^2 \Pi_F^Y / \partial p_{on} \partial p_{sn} & \partial^2 \Pi_F^Y / \partial p_{on}^2 & \partial^2 \Pi_F^Y / \partial p_{on} \partial p_{sr} \\ \partial^2 \Pi_F^Y / \partial p_{sr} \partial p_{sn} & \partial^2 \Pi_F^Y / \partial p_{sr} \partial p_{on} & \partial^2 \Pi_F^Y / \partial p_{sr}^2 \end{bmatrix} = \begin{bmatrix} -2/(1-\alpha) & 2/(1-\alpha) & 0 \\ 2/(1-\alpha) & -2/(1-\alpha) - 2/(\theta-\alpha) & 2/(\theta-\alpha) \\ 0 & 2/(\theta-\alpha) & -2/\alpha - 2/(\theta-\alpha) \end{bmatrix}$$

It is easy to find that the Hessian matrix is negative-definite. Thus, the response function can be derived from the first-order conditions, i.e., $\partial \Pi_F^Y / \partial p_{sn} = 0$, $\partial \Pi_F^Y / \partial p_{on} = 0$ and $\partial \Pi_F^Y / \partial p_{sr} = 0$. The optimal decisions in the case of Y are shown in Table 2.

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