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Manufacturer's Decision as Consumers' Low-Carbon Preference Grows

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Abstract: This paper investigates five channel structures for manufacturers including three single channels and two dual channels. Consumers' low-carbon preference is considered to explore how market demands and channel selections will change as it remains stable and grows. To compare performances of the five channel structures, we further get the critical points consisting of construction cost of a platform, revenue proportion through a third-party platform, and offline proportion of total demands. The findings show that, when the construction cost is low, a self-owned platform performs better than a retail channel and a third-party platform. If the offline proportion is high, manufacturers would adopt or add a retail channel. When the manufacturers' revenue proportion is high, a third-party platform is more profitable. If the consumers' low-carbon preference grows, dual channels can be chosen to satisfy the increasing online and offline demands. The critical revenue proportion and offline proportion become smaller while the construction cost becomes larger. In addition, numerical analysis is provided to show profit changes and robustness of channel structure. Our findings can provide useful insights for decision-makers to implement low-carbon sustainability.

Keywords: channel selection; low-carbon preference; enhancement; sustainability; sustainability management practices

1. Introduction

In a globalized world, the environment has suffered serious damage. As an important part of environmental issues, global warming which is mainly caused by carbon emissions from human activities is further intensifying [1]. In terms of government cooperation, the 22nd United Nations Climate Change Conference was held in Morocco on 8 November 2016, and 160 countries submitted documents named "Nationally Determined Emission Reduction Contribution", which meant that the developed and developing countries have taken initiatives towards low-carbon economies. Governments have launched many policies which targeted corporate carbon emissions to achieve sustainable development. There are two major policies to control carbon emission: one is the carbon emission trading scheme (Chan et al. [2]; Demailly and Quirion [3]), and the other is the carbon tax (Al-Amin et al. [4]; Hartikainen et al. [5]) [6].

Apart from introducing relevant policies, governments also adopted the "Carbon Label" to guide consumers to low-carbon consumption. Carbon label is a practice of public environmental measures, by making the greenhouse gas (GHG) emissions label associated with a product or service [7]. The carbon label presents the awareness of consumers' environmental protection, which promotes low-carbon products to be manufactured and consumed. With the concept of low carbon

and environmental protection widely being accepted by the public, consumers are shown to have an appetite for low-carbon products, and the preference is constantly increasing [8]. Low-carbon preferences can affect demands so it is of wide application value and practical significance to consider the enhancement of consumers' low-carbon preference. Chitra [9] proposed that the higher the consumers' environmental preference is, the more the consumers are willing to pay higher prices for low-carbon products. The higher price attracts more manufacturers to use environmental-friendly technologies for production, which enhances the competitiveness of their products [10]. However, in the period of the Internet, the transparency and the rapid diffusion of information make consumers' low-carbon preference more easily disrupted.

At the same time, the development of the Internet has provided an attractive alternative for many manufacturers to sell low-carbon products through the online channel [11], which forms a co-existence of dual channels. The co-existence of both direct and retail channels undoubtedly places pressure on previous cooperation between the manufacturers and the retailers. This rapid development of e-commerce has prompted many retailers to make strategic decisions on whether to be a pure online retailer, a pure offline retailer, or a dual-channel retailer [12].

Based on the above background, it is significant to take both low-carbon preference and channel selection into consideration. In the former studies, Ji et al. [8] found that when the degree of consumers' low-carbon sensitivity satisfies certain conditions, introduction of the online channel is profitable for manufacturers. Wang et al. [1] put forward that improving consumers' low-carbon preference is more acceptable to the supply chain members. It is always beneficial for both manufacturers and retailers. However, there is still a shortage of comparisons between different channels' profits while considering the impact of consumers' low-carbon preference. With the increasing demands of low-carbon products and multi-channel sales, manufacturers face the problem on how to choose models and make decisions as consumers' low-carbon preference grows.

From what we have discussed above, we try to answer the following research questions: (1) What impacts do low-carbon preference and its enhancement have on manufacturers' pricing as well as profits? (2) How do those critical points (construction cost of a platform, revenue proportion through a third-party platform, and offline proportion of total demands) change as the preference remains stable and grows? (3) How can a manufacturer make channel selections while considering low-carbon preference and its enhancement?

To address these questions, this paper establishes five channel structures: a manufacturer has a self-owned platform and a retail channel (Scenario PR), a manufacturer has a third-party platform and a retail channel (Scenario TPR), a manufacturer only has a self-owned platform (Scenario P), a manufacturer simply has a third-party platform (Scenario TP), and a manufacturer only has a retail channel (Scenario R). This paper makes at least four main contributions: First, it considers the consumers' low-carbon preference and its enhancement to establish the five channel structures. Second, it compares the profits among the five structures and finds out critical points when the two profits are equal, to provide managers with channel selections (single or dual channels, self-owned or third-party platform). Third, it discusses the necessity of a retail or an online channel while there is already one channel operating. We find that as the preference grows, the critical offline proportion and the revenue proportion become smaller while the construction cost becomes larger. Fourth, it uses numerical analysis to show profit changes and structure robustness. It is found that channel structures with a retail channel fluctuate sharply while those with an online channel perform steadily.

2. Literature Review

This study is closely related to the literature on consumers' low-carbon preference and channel selection and disruption management in the supply chain. We present a concise review below.

2.1. Consumers' Low-Carbon Preference

As the consumers' environmental consciousness improves, low-carbon consumption is becoming more and more popular in the whole society [13]. The preference for low-carbon products means that this kind of product could result in extra utilities for consumers [14]. Kotchen et al. [15] found that consumers are shown to have a preference for low-carbon products and are concerned about products' effects on environment. Vanclay et al. [16] studied consumers' low-carbon behaviors through low-carbon labeling experiments and found that they have a distinct preference for low-carbon consumption. Consumers tend to choose low-carbon products when products are in the same price. Chitra [9] and Du et al. [17] put forward that consumers' low-carbon preference can provide low-carbon products with added value. It could also be said that the preference actually gives an added market for low-carbon products [10].

As low-carbon consumption grows, enterprises must take full account of this new factor in their decision-making. Research shows that consumers' preference can affect supply chain performance [18]. Therefore, it is of practical significance to consider consumers' low-carbon preference in the supply chain. Liu et al. [19] gave the first step to study the impact of consumers' environmental awareness and competition intensity levels on the profitability of manufacturers and retailers from a supply chain network perspective. Du et al. [13] showed that the channel profit will increase while considering consumers' low-carbon preference in the emission-concerned supply chain. Kumar et al. [20] hold that GSCM (environmental dimensions in supply chain management) implementation has mainly resulted from top management's insight that tapping potential opportunities leads to reducing emissions. They found that if the firms can meet consumers' preference, they will stand out amongst competition.

Although the consumers' preference to low carbon is increasingly popular, there are still few studies researching consumers' low-carbon preference and analyzing the optimal decision-making in supply chain. By studying the influences of consumers' low-carbon preference and its enhancement, this paper explores the profits and the critical conditions under five different models to provide manufacturers with reasonable operating modes.

2.2. Channel Selection

Nowadays, the online and the offline channels are widely researched by scholars. Online channels allow manufacturers to directly confront larger consumer markets, which can overcome the geographic distances and compete with traditional offline retail channels. With the extensive development of multi-channel models, it becomes easier for consumers to transfer between online and offline, which has become an important topic for many scholars to study.

Regarding channel selection, Xu et al. [21] found that the use of new channels is likely to have lower product price. Khouja et al. [22,23] analyzed the pricing problems of single offline channels, single online channels and dual channels, the results showed that the dual-channel model has a higher profitability than the single channel model. Chiang et al. [24] found that it is beneficial for a supplier to set up a direct channel to compete with its retailer in a model. Yang et al. [25] considered two competitive supply chains, each of which consists of one manufacturer and one retailer, and compared the equilibrium solutions of different channel structures. Cattani et al. [26] developed a model in which a manufacturer with an independent retail channel opens a direct Internet channel. Fruchter et al. [27] considered a manufacturer who sells a product through retail stores and an online virtual store. Tsay et al. [28] took both retail and direct channels into consideration. If a manufacturer uses both channels, the demand in each channel is a proportion of the total demands. McGuire [29] provided an explanation of why a supplier would want to use an intermediary retailer in the context of two supply chains with one supplier in each chain.

At the same time, the problem of channel conflicts arises from adding online channels to traditional channels, which has caused extensive research in the academic field. Abdelsalam et al. [30] considered that an additional channel may partly cannibalize the sales of existing channels, rather than increasing the total sales. Bucklin et al. [31] suggested that some channel conflicts motivate channel members

to be creative to seize new opportunities and improve channel performance, but Geyskens et al. [32] revealed that channel conflicts could cause negative effects on channel operations.

However, the above literature focuses on just one or two models and channel conflicts, researchers have not explicitly studied the profit functions of different supply chain structures, especially a dual-channel with a retail channel and either a self-owned or a third-party platform. Meanwhile, the studies on comparisons between both online and offline channels are still insufficient and far from abundant. The innovation of this paper is to solve the critical conditions and compare the five different channels' profits, which can help managers to make optimal channel selections.

2.3. Disruption Management

With the rapid development of the economy, external changes in supply chain management are gradually increasing. The impact of external changes on operation and efficiency of enterprises is vital for scholars to research. Therefore, the problem of disruptions in supply chain has become a hot issue. Huang and Yang [33] used the asymmetric cost disruption information as a factor to consider the design of supply chain contract. Xiao and Qin [34] studied the coordination of a supply chain with one manufacturer and two competing retailers after the disruption of manufacturer's production cost. Cao et al. [35] developed a coordination mechanism for a supply chain consisting of one manufacturer and multiple competing retailers when the production cost and demands are simultaneously disrupted. Chen et al. [36] considered that under the linear quantity discount schedule, the manufacturer only need to adjust the maximum variable wholesale price with the enhancement of demand. They also found that the disrupted amount of demand largely affects the allocation of a supply chain's profit. Chen et al. [37] investigated pricing decisions and information value in two competing supply chains, they found that a retailer is reluctant to share his private information on disrupted demand with his partners. Meanwhile, the performance of the whole chain may become worse if the information of disrupted demand is shared in this chain. Zhao et al. [38] studied the online disturbance in the fresh supply chain of agricultural products. Among the foreign scholars, Qi et al. [39] studied the problems of supply chain coordination when the original production plan must be suspended under the condition of large disruptions in sudden situations.

Scholars have done in-depth studies on demand and cost disruptions in the supply chain, but these disruptions are general. They have not studied how specific factors affect demands and considered the disruption of consumers' low-carbon preference. In real life, the gradual increase in consumers' low-carbon preference has practical significance. For example, if a carbon policy certifies a green product, this will in turn enhance consumers' demand. With the aim to discuss the issues of decision-making in different channels, we describe the functional relationship between preference and demand. Therefore, this paper fills the gap of the disruption of consumers' low-carbon preference in the supply chain.

3. The Models

3.1. Notations

To be specific, we summarize the model notations in Table 1.

3.2. Model Formulation and Analysis

We study and compare five different models as illustrated in Figure 1; the dotted and the solid lines represent the self-owned and the third-party platforms respectively when the online platforms exist. We use PR to represent the Scenario that a manufacturer who has a self-owned platform (P) and a retail channel (R). Similarly, in Scenario TPR, a manufacturer has a third-party platform (TP) and a retail channel (R). In Scenario P, a manufacturer only has a self-owned platform (P). In Scenario TP, a manufacturer only has a third-party platform (TP). Scenario R represents a traditional channel structure in which a manufacturer sells products through a retailer (R) [40–46].

Table 1. Notations for parameters and variables.

Model Parameters	
e_r	Low-carbon environmental coefficient in retail channel
e_e	Low-carbon environmental coefficient in direct channel
m	Coefficient of consumers' low-carbon preference
Δm	Enhancement of consumers' low-carbon preference
θ	Proportion of manufacturer's revenue through an online platform, $\theta \in [0, 1]$
μ	The offline proportion of total demand, $\mu \in [0, 1]$
C_p	Construction cost of a platform
k	The unit procurement cost
D_r	The demand in retail channel
D_e	The demand in direct channel
Decision Variables	
p_r	The retail channel price
p_e	The direct channel price
w	Wholesale price for retailer

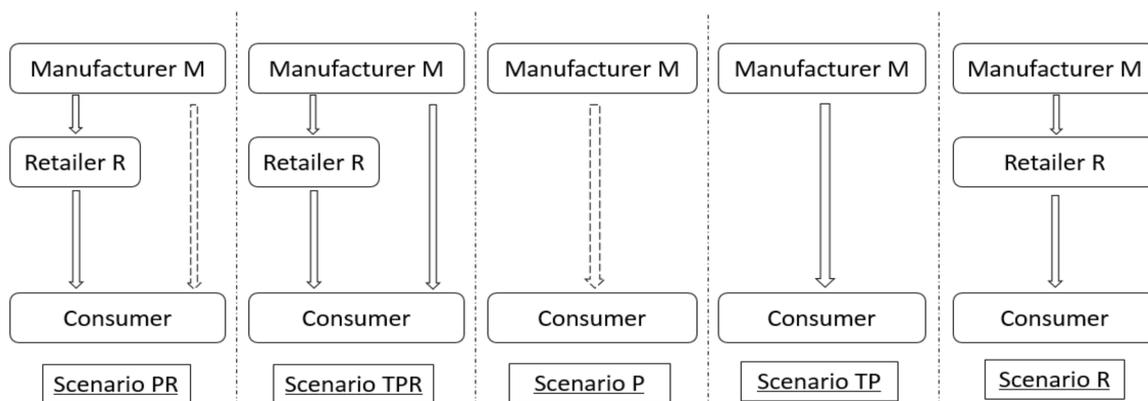


Figure 1. The models of Scenario PR, TPR, P, TP, and R. The dotted and the solid lines represent the self-owned and the third-party platform respectively.

The relationship between a manufacturer and a retailer is modelled as a Stackelberg game as Chen [47] did, where the manufacturer is the leader and the retailer is the follower [48–53]. We assume that the market size is 1 (Ferguson et al. [54]; Yi et al. [55]; Zhang et al. [12]), and only the enhancement of consumers' low-carbon preference ($\Delta m > 0$) is considered in this paper. The offline channel means that consumers directly go to retail stores to purchase, which eliminates the need for intermediate transportation compared to online shopping, being more low-carbon and environmentally-friendly. Therefore, we assume that the low-carbon environmental coefficient in the retail channel is larger than that in the direct channel ($e_r > e_e$). We use D_e to represent demand in the direct channel and D_r in the retail channel ($D_e, D_r > 0$). The direct channel price is denoted by p_e , and the retail (channel) price p_r . To obtain the demand functions in different channel structures, demands for each channel without enhancement are expressed as follows:

$$D_e = (1 - \mu) - p_e + me_e, \tag{1}$$

$$D_r = \mu - p_r + me_r. \tag{2}$$

With enhancement, we use \tilde{D}_e to represent enhanced demand in the direct channel and \tilde{D}_r in the retail channel ($\tilde{D}_e, \tilde{D}_r > 0$). The enhanced direct channel price is denoted by \tilde{p}_e , and the retail (channel) price \tilde{p}_r . Therefore, the demands for each channel with enhancement are expressed as follows:

$$\tilde{D}_e = (1 - \mu) - \tilde{p}_e + (m + \Delta m)e_e, \tag{3}$$

$$\tilde{D}_r = \mu - \tilde{p}_r + (m + \Delta m)e_r. \tag{4}$$

Additionally, π_m^i, π_r^i denote the manufacturer's and retailer's profits without enhancement, $\tilde{\pi}_m^i, \tilde{\pi}_r^i$ are the manufacturer's and retailer's profits with enhancement, and $i = PR, TPR, P, TP, R$ denotes five models.

3.2.1. Without Enhancement

When without enhancement, in five models, the retailer's and the manufacturer's profit functions can be written as Table 2, Table 3 explains the decision variables, and Table 4 solves the manufacturer's optimal profits.

Table 2. Profit functions without enhancement.

Scenario i	π_r^i	π_m^i
PR	$(p_r - w)D_r$	$wD_r + p_eD_e - c_p$
TPR	$(p_r - w)D_r$	$wD_r + \theta p_eD_e$
P	—	$p_eD_e - c_p$
TP	—	θp_eD_e
R	$(p_r - w)D_r$	wD_r

Table 3. Decisions without enhancement.

Scenario	p_r	p_e	w
PR	$\frac{3(me_r + \mu)}{4}$	$\frac{me_e - \mu + 1}{2}$	$\frac{\mu + me_r}{2}$
TPR	$\frac{3(me_r + \mu)}{4}$	$\frac{me_e - \mu + 1}{2}$	$\frac{\mu + me_r}{2}$
P	—	$\frac{me_e + 1}{2}$	—
TP	—	$\frac{me_e + 1}{2}$	—
R	$\frac{3(me_r + 1)}{4}$	—	$\frac{1 + me_r}{2}$

Table 4. The manufacturer's profit without enhancement.

Scenario	Profit
PR	$\frac{(2e_e^2 + e_r^2)m^2 + 2((e_r - 2e_e)\mu + 2e_e)m + 3\mu^2 - 4\mu + 2}{8} - c_p$
TPR	$\frac{(me_r + \mu)^2 + 2\theta(me_e - \mu + 1)^2}{8}$
P	$\frac{(me_e + 1)^2}{4} - c_p$
TP	$\frac{\theta(me_e + 1)^2}{4}$
R	$\frac{(me_r + 1)^2}{8}$

3.2.2. With Enhancement

When with enhancement, in five models, the retailer's and the manufacturer's profit functions can be written as Table 5, Table 6 explains the decision variables, Table 7 solves the manufacturer's optimal profits.

Table 5. Profit functions with enhancement.

Scenario <i>i</i>	$\tilde{\pi}_r^i$	$\tilde{\pi}_m^i$
PR	$(\tilde{p}_r - \tilde{w})\tilde{D}_r - k(\tilde{D}_r - D_r^*)$	$\tilde{w}\tilde{D}_r + \tilde{p}_e\tilde{D}_e - c_p - k(\tilde{D} - D^*)$
TPR	$(\tilde{p}_r - \tilde{w})\tilde{D}_r - k(\tilde{D}_r - D_r^*)$	$\tilde{w}\tilde{D}_r + \theta\tilde{p}_e\tilde{D}_e - k(\tilde{D} - D^*)$
P	—	$\tilde{p}_e\tilde{D}_e - c_p - k(\tilde{D} - D^*)$
TP	—	$\theta\tilde{p}_e\tilde{D}_e - k(\tilde{D} - D^*)$
R	$(\tilde{p}_r - \tilde{w})\tilde{D}_r - k(\tilde{D}_r - D_r^*)$	$\tilde{w}\tilde{D}_r - k(\tilde{D} - D^*)$

Table 6. Decisions with enhancement.

Scenario	\tilde{p}_r	\tilde{p}_e	\tilde{w}
PR	$\frac{3(m+\Delta m)e_r+3\mu+2k}{4}$	$\frac{1+(m+\Delta m)e_e-\mu+k}{2}$	$\frac{(m+\Delta m)e_r+\mu}{2}$
TPR	$\frac{3(m+\Delta m)e_r+3\mu+2k}{4}$	$\frac{(m+\Delta m)\theta e_e+(1-\mu)\theta+k}{2}$	$\frac{(m+\Delta m)e_r+\mu}{2}$
P	—	$\frac{1+(m+\Delta m)e_e+k}{2}$	—
TP	—	$\frac{(m+\Delta m)\theta e_e+\theta+k}{2}$	—
R	$\frac{3(m+\Delta m)e_r+3+2k}{4}$	—	$\frac{(m+\Delta m)e_r+1}{2}$

Table 7. The manufacturer’s profit with enhancement.

Scenario	Profit
PR	$\frac{(2e_e^2+e_r^2)\Delta m^2+(4(me_e-k-\mu+1)e_e+2e_r(me_r-2k+\mu))\Delta m+2m^2e_e^2-4m(\mu-1)e_e+m^2e_r^2+2e_r(\mu-k)m+3\mu^2-(2k+4)\mu+6k^2+2}{8} - c_p$
TPR	$\frac{2(me_e+\Delta me_e-\mu+1)^2\theta^2+(\Delta m^2e_r^2-(4ke_e-2e_r(me_r-2k+\mu))\Delta m+\mu^2+(2me_r-2k)\mu+m^2e_r^2-2me_rk+4k^2)\theta+2k^2}{8\theta}$
P	$\frac{(m+\Delta m)^2e_e^2+2((-k+1)\Delta m+m)e_e+k^2+1}{4} - c_p$
TP	$\frac{(1+(m+\Delta m)e_e)^2\theta^2-2\theta\Delta me_ek+k^2}{4\theta}$
R	$\frac{(m+\Delta m)^2e_r^2+2((1-2k)\Delta m-m(k-1))e_r+4k^2-2k+1}{8}$

4. Comparative Analysis

This section focuses on channel selection of a specific channel structure under certain circumstances. Since manufacturers behave differently in different channel structures, we would like to figure out and compare the critical points with and without enhancement theoretically or numerically. Firstly, those with the same channel structures are analyzed. When there is only one single channel, we compare these three structures (TP, P, R) to find which one performs better. When dual channels are adopted, we make a comparison between a third-party platform and a self-owned platform (TPR, PR). Secondly, we put emphasis on the necessity of a retail channel (R) when an online channel has been used. Lastly, when there is a retail channel, we analyze the differences of two types of online channels (TP, P). The detailed methods of comparisons are shown as Figure 2.

4.1. Comparisons of the Same Channel Structure

We analyze the three scenarios which have the same channel structure, including single channels (TP and P, P and R, TP and R) and dual channels (PR and TPR). We further get and compare the critical conditions with or without enhancement, such as self-owned cost of a platform and revenue proportion through a third-party platform.

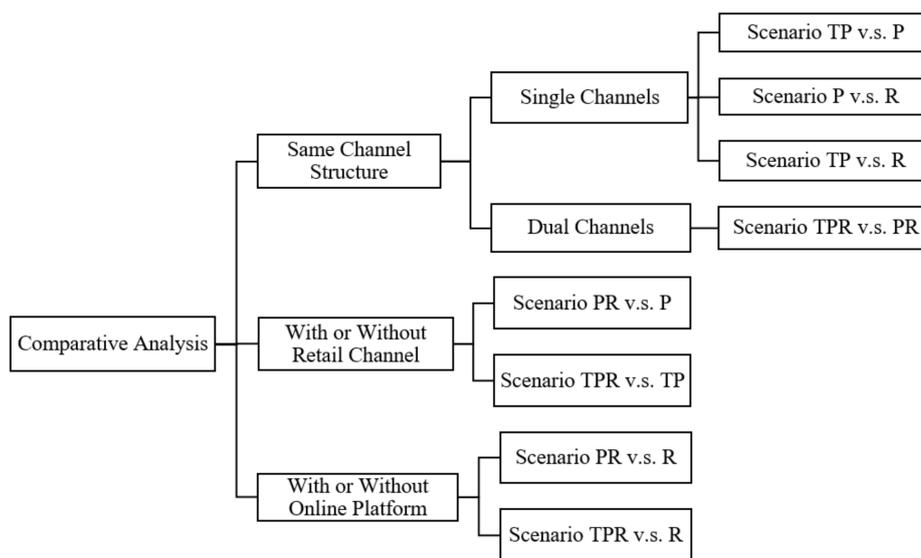


Figure 2. Methods of comparing different channels.

4.1.1. Comparisons of Single Channels

We first compare the profits of TP and P. In Scenario TP, the manufacturer pays a certain proportion of revenue to a third-party platform, while the manufacturer invests in building up and owning a platform in Scenario P. A concern over which will be more profitable arises. Comparing the two online channels, we obtain the critical construction cost of a self-owned platform.

Theorem 1. Scenario TP outperforms Scenario P with respect to profit if:

(1) Without enhancement

$$c_p > c_p^{O1} = \frac{(me_e + 1)^2(1 - \theta)}{4}$$

(2) With enhancement

$$\tilde{c}_p > c_p^{W1} = \frac{((1 + (m + \Delta m)e_e)^2\theta - k^2)(1 - \theta)}{4\theta}$$

(3) If $\Delta m > \frac{\sqrt{\theta(\theta(me_e+1)^2+k^2)}-\theta}{\theta e_e} - m$, $c_p^{W1} > c_p^{O1}$; Otherwise, $c_p^{W1} \leq c_p^{O1}$.

The first and second items of Theorem 1 provide two critical points between the profit changes of TP and P for a manufacturer. The third item shows the relationship between two critical construction costs without and with enhancement. A manufacturer benefits from having a third-party platform when c_p is large. On the one hand, when there is no enhancement, using a third-party platform will be more profitable if the construction cost is higher than $\frac{(me_e+1)^2(1-\theta)}{4}$. On the other hand, when the enhancement occurs, total market demand will be higher, it is more necessary to build up a platform. A third-party platform should be chosen if the construction cost is more than $\frac{((1+(m+\Delta m)e_e)^2\theta-k^2)(1-\theta)}{4\theta}$. Additionally, when $\Delta m > \frac{\sqrt{\theta(\theta(me_e+1)^2+k^2)}-\theta}{\theta e_e} - m$, which means that if the low-carbon preference is over a certain level, the critical self-owned cost with enhancement will be larger than that without enhancement.

It is reasonable that a manufacturer needs plenty of investment to build up a platform, while it just pays a fixed revenue proportion to a third-party platform. So, it depends on the construction cost. As the construction cost continues to rise, a third-party platform will be more beneficial for a manufacturer. With the enhancement of the low-carbon preference, the total demand and profit

also rise. A manufacturer is encouraged to build up a platform without paying the third-party fee. Therefore, only when the construction cost becomes extremely high, TP performs better than P, so we get $c_p^{W1} > c_p^{O1}$. When the enhancement is high, Scenario P performs better than TP.

Then we compare the profits of P and R. The manufacturer has no online platform but a retail channel in Scenario R. When there is only one single channel, we should consider whether an online or an offline channel would be better. Comparing a retail channel with a self-owned online channel, we calculate the critical cost of a self-owned platform.

Theorem 2. Scenario P outperforms Scenario R with respect to profit if:

(1) Without enhancement

$$c_p < c_p^{O2} = \frac{2(me_e + 1)^2 - (me_r + 1)^2}{8}$$

(2) With enhancement

$$\tilde{c}_p < c_p^{W2} = \frac{2(m+\Delta m)^2 e_e^2 - (m+\Delta m)^2 e_r^2 + 2e_r((m+2\Delta m)k - (m+\Delta m)) + 4e_e(m - \Delta m(k-1)) - 2k^2 + 2k + 1}{8}$$

Theorem 2 suggests two critical construction costs of Scenarios P and R. In addition, it proves that a manufacturer benefits from having a self-owned platform when c_p is small. For one thing, if there is no enhancement, owning a platform will be more beneficial than a retail channel if the construction cost is lower than $\frac{2(me_e+1)^2 - (me_r+1)^2}{8}$. For another, if the enhancement occurs, a self-owned platform should be used if the construction cost is less than $\frac{2(m+\Delta m)^2 e_e^2 - (m+\Delta m)^2 e_r^2 + 2e_r((m+2\Delta m)k - (m+\Delta m)) + 4e_e(m - \Delta m(k-1)) - 2k^2 + 2k + 1}{8}$.

It is intuitive that if the construction cost is low, a self-owned platform earns more profits than a retail channel, which depends on the construction cost. As the construction cost continues to rise, a retail channel will be more profitable even if the manufacturer offers a wholesale price. Furthermore, since the environmental coefficient in a retail channel is higher than that of a direct channel, offline demand increases more than online with enhancement. Therefore, a retail channel would become more profitable if the enhancement is large.

We make a comparison of the critical construction costs c_p between the conditions without and with enhancement. Since it is difficult to compare them by theoretical analysis, we provide numerical analysis to show their differences. We get the related parameters and specify that $e_r = 0.8, e_e = 0.6, m = 0.6, \theta = 0.9, \mu = 0.4, c_p = 0.1, k = 0.2$, which are all used from Figure 3 to Figure 8. The superscript of O and W mean without and with respectively, which is also applicable from Figure 3 to Figure 8.

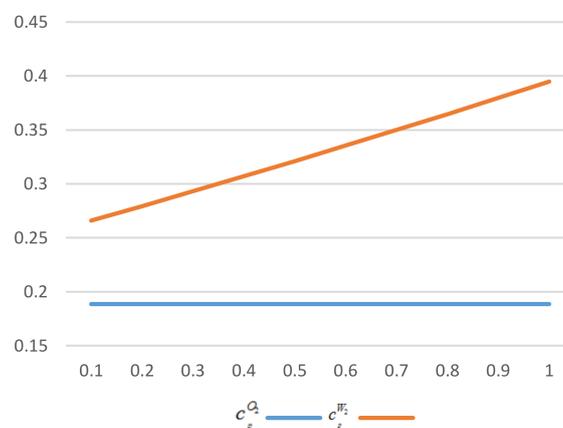


Figure 3. Comparison with critical points $\Delta m \in [0, 1]$

As we can see in Figure 3, the critical construction cost with enhancement is always higher than that without enhancement. The intersection does not appear as enhancement becomes larger. It is reasonable that the enhancement increases both total demand and profit. A manufacturer would rather build up a self-owned platform than offer a wholesale price to a retailer. Therefore, Scenario P performs better than R, we get $c_p^{W2} > c_p^{O2}$.

Next, we compare the profits of TP and R. The platform is owned by a third party in Scenario TP, while the manufacturer has no platform but a retail channel in Scenario R. One concern is that Scenario TP or R performs better. By comparing a third-party platform with a retail channel, we get the critical proportion of manufacturer's revenue through an online platform.

Theorem 3. Scenario TP outperforms Scenario R with respect to profit if:

(1) Without enhancement

$$\theta > \theta^{O1} = \frac{(me_r + 1)^2}{2(me_e + 1)^2}$$

(2) With enhancement

$$\tilde{\theta} > \theta^{W1} = \frac{\sqrt{(A + 4kme_e + 8k\Delta me_e + 2k)(A - 4kme_e - 6k)} + A + 4\Delta mke_e - 2k}{4(me_e + \Delta me_e + 1)^2},$$

$$\text{where } A = (m + \Delta m)^2 e_r^2 - 2((m + 2\Delta m)k - m - \Delta m)e_r + 1 + 4k^2.$$

Theorem 3 provides two critical revenue proportions of TP and R. Additionally, it demonstrates that if there is just a single channel, using a third-party platform will be more profitable than a retail channel when the revenue proportion is high. Without enhancement, when the proportion is larger than $\frac{(me_r + 1)^2}{2(me_e + 1)^2}$, a third-party platform will be more beneficial. With enhancement, a retail channel earns more if the proportion is smaller than $\frac{\sqrt{(A + 4kme_e + 8k\Delta me_e + 2k)(A - 4kme_e - 6k)} + A + 4\Delta mke_e - 2k}{4(me_e + \Delta me_e + 1)^2}$.

When the proportion θ is high, it is so reasonable that owning a third-party platform can earn more without offering a wholesale price to a retailer. Therefore, if a manufacturer just considers a single channel and the proportion is small, choosing a retail channel will be more beneficial since high proportion of revenue is deprived by a third-party platform. When there is an enhancement of low-carbon preference, a retail channel gains higher demand and profit.

We make a comparison of the two critical revenue proportions θ between the conditions without and with enhancement below:

In Figure 4, it is obvious that the critical proportion with enhancement of low-carbon preference is always higher than that without enhancement. There is no intersection between two critical points. The total demand goes up along with enhancement, but the offline demand increases more due to higher offline environmental coefficient. Thus, when there is an enhancement, a manufacturer would like to adopt a retailer channel unless it serves higher revenue proportion through a third-party platform.

4.1.2. Comparisons of Dual Channels

Compare the profits of PR and TPR. The manufacturer owns a platform and a retail channel in Scenario PR, while a third-party platform and a retail channel are possessed in Scenario TPR. Comparing these two dual channels, we get the critical construction cost.

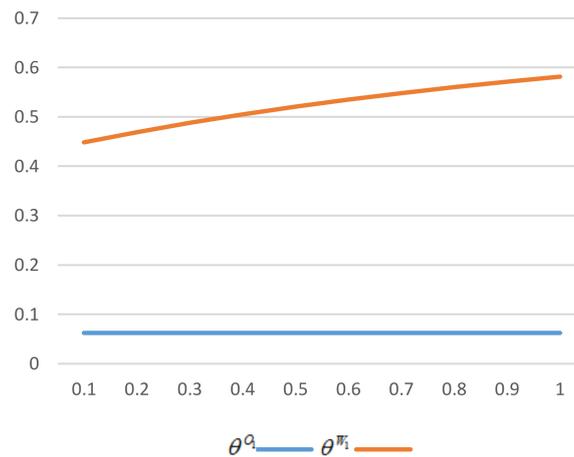


Figure 4. Comparison with critical points $\Delta m \in [0, 1]$

Theorem 4. Scenario TPR outperforms Scenario PR with respect to profit if

(1) Without enhancement

$$c_p > c_p^{O_3} = \frac{(me_e - \mu)(me_e - \mu + 2)(1 - \theta)}{4}$$

(2) With enhancement

$$\tilde{c}_p > c_p^{W_3} = \frac{(((m + \Delta m)e_e - \mu + 1)^2 \theta - k^2)(1 - \theta)}{4\theta}$$

(3) If $\Delta m > \frac{\sqrt{\theta(m e_e - \mu)(m e_e - \mu + 2) + k^2} - (m e_e - \mu + 1)\theta}{\theta e_e}$, $c_p^{W_3} > c_p^{O_3}$; Otherwise, $c_p^{W_3} \leq c_p^{O_3}$.

Theorem 4 comes up with two critical construction costs for profit changes between PR and TPR. On the one hand, when there is no enhancement, having a self-owned platform will be more beneficial than a third-party platform if the construction cost is lower than $\frac{(me_e - \mu)(me_e - \mu + 2)(1 - \theta)}{4}$. On the other hand, when there is an enhancement of low-carbon preference, a self-owned platform should be used if the self-owned cost is less than $\frac{(((m + \Delta m)e_e - \mu + 1)^2 \theta - k^2)(1 - \theta)}{4\theta}$. As the enhancement is larger than $\frac{\sqrt{\theta(m e_e - \mu)(m e_e - \mu + 2) + k^2} - (m e_e - \mu + 1)\theta}{\theta e_e}$, the critical construction cost with enhancement is higher than that without enhancement.

As the construction cost continues to rise either without or with enhancement, a third-party platform will be more profitable for a manufacturer. Furthermore, when the enhancement becomes large, total demand goes up. Owning a platform is more worthwhile instead of paying the third-party platform fee, so PR performs better than TPR, which means that a manufacturer is likely to select a self-owned platform rather than a third-party platform. When construction cost is very high, a third-party platform would be more profitable, so we get $c_p^{W_3} > c_p^{O_3}$.

4.2. With or without Retail Channel

Comparing those channel structures which manufacturers already have online platforms (PR and P, TPR and TP), we would like to find whether it is necessary to set up a retail channel. We obtain and compare the critical conditions of the offline proportion with or without enhancement, which helps manufacturers to make profitable decisions.

4.2.1. Comparison: PR versus P

Comparing with Scenario P, there is an extra retail channel in Scenario PR. It is reasonable that adding a retail channel decreases the online demand. Therefore, whether to set up an offline channel depends on offline revenue. Comparing the corresponding profits in Scenarios PR and P, we obtain the critical offline proportion.

Theorem 5. Scenario PR outperforms Scenario P with respect to profit if:

(1) Without enhancement

$$\mu > \mu^{O_1} = \frac{2me_e - me_r + 2 + 2\sqrt{m^2e_e^2 - m^2e_e e_r - \frac{1}{2}m^2e_r^2 + 2me_e - me_r + 1}}{3}$$

(2) With enhancement

$$\tilde{\mu} > \mu^{W_1} = \frac{(2e_e - e_r)\Delta m + 2me_e - me_r + k + 2 + B}{3},$$

where

$$B = \sqrt{4(m + \Delta m)^2 e_e^2 - 4(m + \Delta m)(me_r + \Delta me_r - k - 2)e_e - 2\Delta m^2 e_r^2 - (4me_r^2 - 10e_r k + 4e_r)\Delta m - 11k^2 + 4(me_r + 1)k - 2(me_r + 1)^2 + 2}.$$

Theorem 5 provides two critical offline proportions of PR and P. Additionally, it indicates that a manufacturer benefits from having a retail channel when the proportion is large. On one hand, when there is no enhancement, applying a retail channel will be more profitable if the proportion is higher than $\frac{2me_e - me_r + 2 + 2\sqrt{m^2e_e^2 - m^2e_e e_r - \frac{1}{2}m^2e_r^2 + 2me_e - me_r + 1}}{3}$. On the other hand, when there is an enhancement and the proportion is smaller than $\frac{(2e_e - e_r)\Delta m + 2me_e - me_r + k + 2 + B}{3}$, a retail channel will be unnecessary.

Since the environmental coefficient in a retail channel is higher than that of a direct channel, enhancement promotes more offline demand. Therefore, adding a retail channel for manufacturers will be more beneficial. However, if the proportion is rather low, a direct channel is able to satisfy most of the demands. It simply depends on the offline proportion. With enhancement, offline demand increases more than online demand, a manufacturer is motivated to build up a retail channel even though the offline proportion is not high compared to that without enhancement, so we draw $\mu^{W_1} < \mu^{O_1}$.

We make a comparison of the critical points μ between the conditions without and with enhancement below:

As we can see in Figure 5, the critical offline proportion of total demand without enhancement is always higher than that with enhancement. However, if the enhancement becomes larger, the gap between two critical points firstly becomes wider then smaller. An enhancement would increase the market demand, especially the offline demand. A manufacturer prefers to build up a retail channel even though the offline proportion is not so high, so PR performs better than P. We draw $\mu^{O_1} > \mu^{W_1}$. When the enhancement is small, the offline income cannot offset the gap between whole price and direct price, so the critical offline proportion becomes higher. However, when the enhancement is large, the critical proportion becomes smaller as offline demand is high enough.

4.2.2. Comparison: TPR versus TP

Comparing with Scenario TP, there is an extra retail channel in TPR. We compare the corresponding profits in Scenarios TPR and TP to consider whether to set up a retail channel, then we obtain the critical offline proportion of total demand.

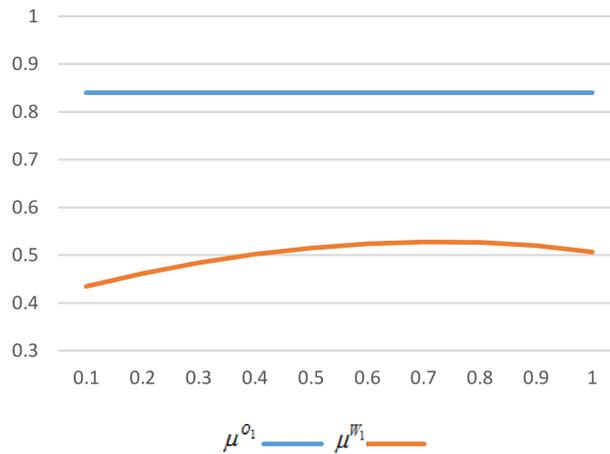


Figure 5. Comparison with critical points $\Delta m \in [0, 1]$.

Theorem 6. Scenario TPR outperforms Scenario TP with respect to profit if:

(1) Without enhancement

$$\mu > \mu^{O_2} = \frac{2m\theta e_e - me_r + 2\theta + 2X}{2\theta + 1},$$

where $X = \sqrt{\theta^2 m^2 e_e^2 - \theta m^2 e_e e_r - \frac{1}{2} \theta m^2 e_r^2 + 2\theta^2 m e_e - \theta m e_r + \theta^2}$.

(2) With enhancement

$$\tilde{\mu} > \mu^{W_2} = \frac{2m\theta e_e + 2\Delta m\theta e_e - me_r - \Delta m e_r + 2\theta + k + Y}{2\theta + 1},$$

where

$$Y = \sqrt{4\theta^2(m + \Delta m)^2 e_e^2 - 4\theta((m + \Delta m)e_r - 2\theta - k)(m + \Delta m)e_e - 2\theta(m + \Delta m)^2 e_r^2 + ((4m\theta + (8\theta + 2)\Delta m)k - 4\theta(m + \Delta m))e_r - (8\theta + 3)k^2 + 4\theta k + 4\theta^2}.$$

Theorem 6 illustrates two critical offline proportions of TPR and TP for a manufacturer. Similar to Theorem 5, it indicates that a manufacturer benefits from having a retail channel when the offline proportion is large. Without enhancement, a retail channel will be more profitable if the proportion is higher than $\frac{2m\theta e_e - me_r + 2\theta + 2X}{2\theta + 1}$. With enhancement, when the proportion is smaller than $\frac{2m\theta e_e + 2\Delta m\theta e_e - me_r - \Delta m e_r + 2\theta + k + Y}{2\theta + 1}$, there is no need for a retail channel. It simply depends on the offline proportion of demand. As the offline proportion continues to rise, it is necessary for a manufacturer to own a retail channel. However, if the proportion is rather low, a retail channel grabs online demand rather than bring more profit.

We make a comparison of the critical points μ between the conditions without and with enhancement below:

As we can see in Figure 6, the critical offline demand without enhancement is always higher than that with enhancement. However, as the enhancement becomes larger, the gap between two critical points becomes smaller then wider. Reasons are similar to that in Figure 5, it is reasonable that when there is a large enhancement, market demand increases sharply, especially the offline demand. A manufacturer is encouraged to set up a retail channel, TPR performs better than TP, so we draw $\mu^{O_2} > \mu^{W_2}$.

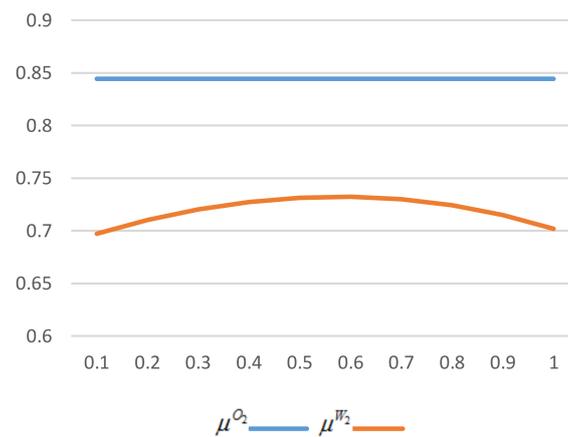


Figure 6. Comparison with critical points $\Delta m \in [0, 1]$.

4.3. With or without Online Platform

By comparing the channels PR and R, TPR and R, we calculate the critical conditions with or without enhancement to decide whether manufacturers should own online platforms. The application of online platform mainly depends on the construction cost of a self-owned platform and the proportion of platform's revenue.

4.3.1. Comparison: PR Versus R

The manufacturer has a self-owned platform and a retail channel in Scenario PR, but only has a retail channel in Scenario R. Whether a manufacturer needs a self-owned platform or not is of great importance to consider. By comparing the corresponding profits in Scenarios PR and R, we obtain the critical construction cost.

Theorem 7. Scenario PR outperforms Scenario R with respect to profit if:

(1) Without enhancement

$$c_p < c_p^{O4} = \frac{2(me_e + 1)^2 + 2m\mu e_r - 4m\mu e_e + 3\mu^2 - 4\mu - 2me_r - 1}{8}$$

(2) With enhancement

$$\tilde{c}_p < c_p^{W4} = \frac{2(m+\Delta m)^2 e_e^2 - 4((k+\mu-1)\Delta m + m(\mu-1))e_e + 2\Delta m(\mu-1)e_r + 2(me_r - k - 2)\mu - 2me_r + 3\mu^2 + 2k^2 + 2k + 1}{8}$$

Theorem 7 indicates two critical points between the profit changes of PR and R for a manufacturer. A manufacturer earns more from having a self-owned platform when c_p is small. If there is no enhancement, having a self-owned platform will be more beneficial than a retail channel if the construction cost is lower than $\frac{2(me_e + 1)^2 + 2m\mu e_r - 4m\mu e_e + 3\mu^2 - 4\mu - 2me_r - 1}{8}$. Otherwise, when the enhancement occurs, a self-owned platform should not be chosen if the construction cost is more than $\frac{2(m+\Delta m)^2 e_e^2 - 4((k+\mu-1)\Delta m + m(\mu-1))e_e + 2\Delta m(\mu-1)e_r + 2(me_r - k - 2)\mu - 2me_r + 3\mu^2 + 2k^2 + 2k + 1}{8}$.

If the construction cost c_p is low, a dual channel earns more than a single retail channel. However, as the construction cost continues to rise either without or with enhancement, it will be less profitable for a manufacturer. The result focuses on the construction cost. In addition, it gives managers suggestions on whether to choose a self-owned platform either with or without enhancement.

We make a comparison of the critical construction costs c_p between the conditions without and with enhancement below:

In both PR and R, the manufacturer already owns a retail channel, whether to build up a platform depends on the construction cost. As we can see in Figure 7, there is no intersection when $\Delta m \geq 0$, the junction will be found at the point where $\Delta m < 0$, but it does not exist in this paper. When there is no enhancement, it is beneficial to build up an online platform when $c_p < c_p^{O4}$. As the enhancement continues to rise, total demand goes up. To satisfy more market demand, a manufacturer is encouraged to set up a platform, so PR performs better than R and the critical construction cost becomes larger ($c_p^{W4} > c_p^{O4}$).

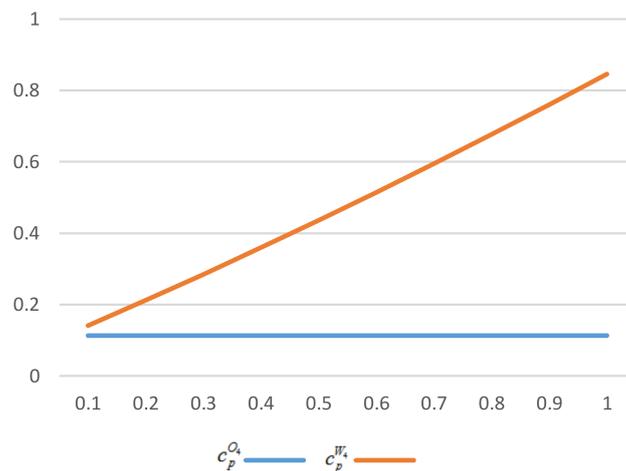


Figure 7. Comparison with critical points $\Delta m \in [0, 1]$.

4.3.2. Comparison: TPR Versus R

The manufacturer has a third-party platform and a retail channel in Scenario TPR, but just has a retail channel in Scenario R. We compare the dual channel with the single channel and get the critical revenue proportions in Scenarios TPR and R.

Theorem 8. Scenario TPR outperforms Scenario R with respect to profit if:

(1) Without enhancement

$$\theta > \theta^{O2} = \frac{(2me_r + \mu + 1)(1 - \mu)}{2(me_e - \mu + 1)^2}$$

(2) With enhancement

$$\tilde{\theta} > \theta^{W2} = \frac{2(1 - \mu)(m + \Delta m)e_r + 4k\Delta me_e - \mu^2 + 2\mu k - 2k + 1 - 2E}{4(me_e + \Delta me_e - \mu + 1)^2},$$

where

$$E = \sqrt{((\mu - 1)(m + \Delta m)e_r - (2me_e + 4\Delta me_e + 1)k + \frac{1}{2}\mu^2 + \mu k - \frac{1}{2})((\mu - 1)(m + \Delta m)e_r + 2kme_e - 3k(\mu - 1) + \frac{1}{2}\mu^2 - \frac{1}{2})}.$$

Theorem 8 illustrates two critical revenue proportions of TPR and R for a manufacturer. In addition, it demonstrates that when the proportion is high, a manufacturer will benefit from having a third-party platform. Without enhancement, when the proportion is larger than $\frac{(2me_r + \mu + 1)(1 - \mu)}{2(me_e - \mu + 1)^2}$, a third-party platform performs better. With enhancement, a single retail channel will be more profitable if the proportion is smaller than $\frac{2(1 - \mu)(m + \Delta m)e_r + 4k\Delta me_e - \mu^2 + 2\mu k - 2k + 1 - 2E}{4(me_e + \Delta me_e - \mu + 1)^2}$.

It is reasonable that adding a platform increases market demand and online revenue but deprives offline demand. When online profit covers or surpasses the offline lost, TPR performs better than

R. Therefore, if the revenue proportion is high without and with enhancement, adding a third-party platform earns more. When there is an enhancement of low-carbon preference, offline demand increases more. Therefore, a third-party platform would become less necessary.

We make a comparison of the critical revenue proportions θ between the conditions without and with enhancement below:

In Figure 8, the critical revenue proportion without enhancement is larger than that with enhancement. The enhancement of preference increases the total demand, so a dual channel would be better. Adding an online channel can satisfy more market demand. A manufacturer is encouraged to build an online channel even though the critical revenue proportion with enhancement is lower than that without enhancement, so we get $\theta^{O_2} > \theta^{W_2}$.

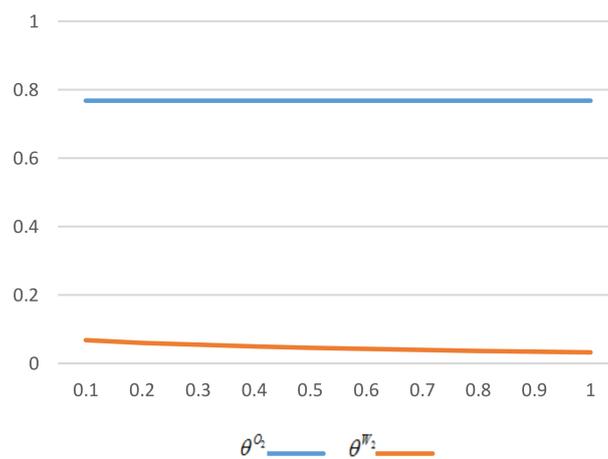


Figure 8. Comparison with critical points $\Delta m \in [0, 1]$

5. Numerical Analysis

In this section, we propose numerical examples to discuss profit changes respectively along with $\theta, \mu, c_p, \Delta m$. Similar to the parameters setting in Theorem 3, we specify that $e_r = 0.8, e_e = 0.6, m = 0.6, k = 0.2$. The proportion of manufacturer’s revenue through online platform θ changes from 0.45 to 0.9, the offline proportion of total demand μ changes from 0.05 to 0.5, the self-owned platform cost c_p changes from 0.03 to 0.3, the changes in consumers’ low-carbon preference Δm varies from 0.1 to 1. From Figure 9 to 15, we observe the profit changes in five scenarios without and with the enhancement of consumers’ low-carbon preference.

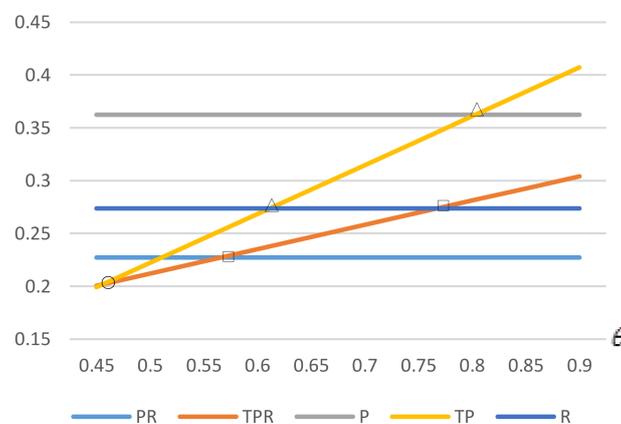


Figure 9. Profit changes without enhancement.

Among them, we use “ Δ ” represent point A (A') in the picture without (with) enhancement, “ \square ” represent point B (B') in the picture without (with) enhancement, “” represent point C (C') in the picture without (with) enhancement.

5.1. The Impact of θ on Profits ($\Delta m = 0.5$)

Figures 9 and 10 prove that Theorems 3 and 8 are consistent with the results. Firstly, we focus on modes with a third party. As we can see in both Figures 9 and 10, when the online revenue proportion is rather small, profits of TP and TPR are quite low and they are increasing along with θ . Comparing Scenarios TP (TPR) with PR, P and R, points A and A' (B and B') show the critical proportion of manufacturer's profit. As the proportion continues to rise, adopting a third-party platform earns more. Additionally, point C illustrates the comparison between TP and TPR. On the one hand, when the proportion is small, adding a retail channel will be beneficial even though an offline channel declines online demand. On the other hand, when the proportion is of a high level, TP performs better than TPR. For example, some companies simply sell product via Tmall, which is the largest e-commerce group in China, rather than open a retail channel to satisfy offline market demand mainly due to the high online revenue proportion.

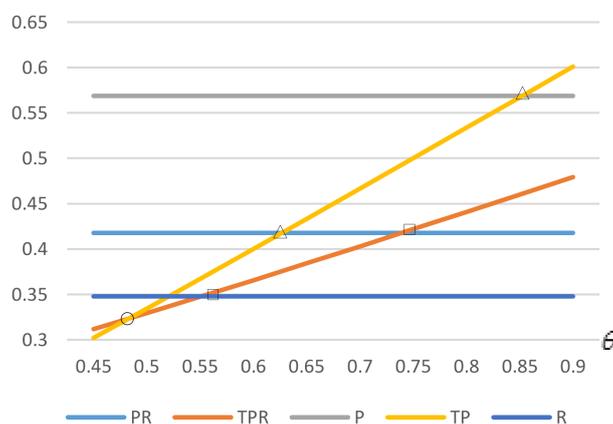


Figure 10. Profit changes with enhancement.

Secondly, when we pay attention to these three Scenarios (PR, P and R), profits remain the same along with θ since third-party platforms are not employed. Profit changes mainly rely on the specific parameters. As it shows that when an enhancement occurs, the profits of Scenarios P and PR rise to a higher extent while the profit of Scenario R increases slightly.

In conclusion, as the revenue proportion keeps on rising, using a third-party platform will be more profitable.

5.2. The Impact of μ on Profits ($\Delta m = 0.5$)

Figures 11 and 12 prove that Theorems 5 and 6 are consistent with the results. We mainly compare profits of dual channels with those of single channels. Firstly, we discuss on dual channels. As we can see in both Figures 11 and 12, profits of PR and TPR are decreasing with respect to the offline proportion of total demand. Profits of Scenario TPR are almost always higher than those of PR with and without enhancement. It mainly depends on the specific construction cost of platform and revenue proportion. The construction cost is higher than the deprived revenue by a third party, so a self-owned platform performs better. Comparing Scenarios PR and TPR with P, TP and R, points A and A' (B and B') show the critical proportion of manufacturer's profit. As the offline proportion of demand continues to rise, dual channels become less competitive than single channels. Additionally, as the online demand is shrinking, online channel becomes less attractive. This is because that a manufacturer faces the construction cost in Scenario PR and the revenue proportion derived by a third-party platform in

Scenario TPR. For example, the Xiaomi company, which mainly sells intelligent appliances and already owns a retail channel, compares a self-owned platform with a third-party platform in order to gain a higher profit. As the offline proportion becomes higher, Xiaomi would prefer a third-party platform to a self-owned platform.

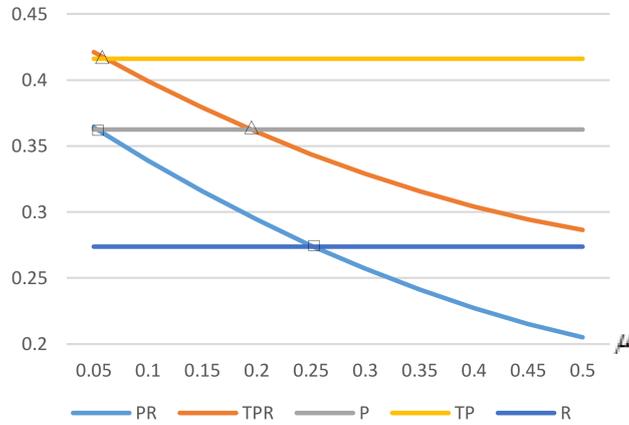


Figure 11. Profit changes without enhancement.

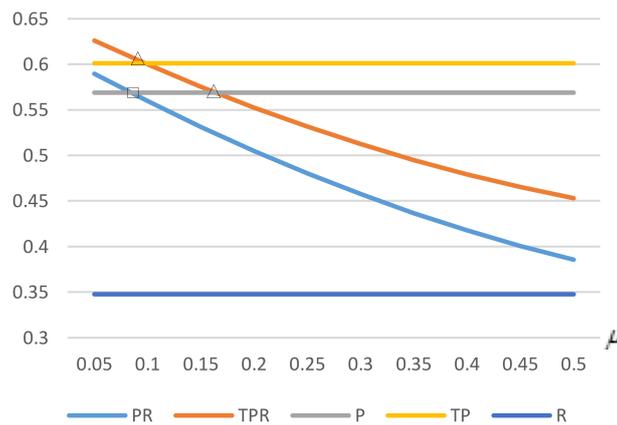


Figure 12. Profit changes with enhancement.

Secondly, we focus on single channels like Scenarios P, TP and R; their profits remain unchanged with respect to the offline proportion. It is obvious that there is just one channel, without competitions between two channels. Scenario TP earns the most both with and without an enhancement, P ranks second and R last. Profit of Scenario P has a drastic growth when there is an enhancement.

In conclusion, scenarios with dual channels will be less profitable as the offline proportion becomes larger, which is due to the channels' intersection and discount price.

5.3. The Impact of c_p on Profits ($\Delta m = 0.5$)

Figures 13 and 14 prove that Theorems 1, 2, 4 and 7 are consistent with the results. We mainly talk about the cost of the self-owned platform. Firstly, we focus on those channels with a self-owned platform. As we can see in both Figures 13 and 14, the profits of Scenarios P and PR are decreasing with respect to the cost of self-owned platforms. Comparing Scenarios P (PR) with TR, TPR and R, points A and A' (B and B') demonstrate the critical cost of a self-owned platform. As the cost continues to rise, using a self-owned platform will be less profitable. Profits of Scenario P are always higher than those of PR.

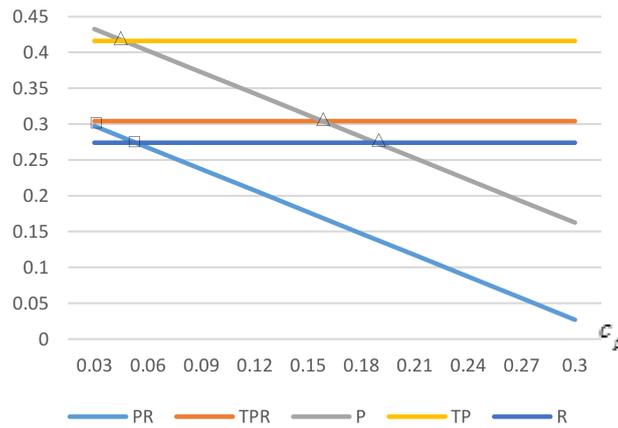


Figure 13. Profit changes without enhancement.

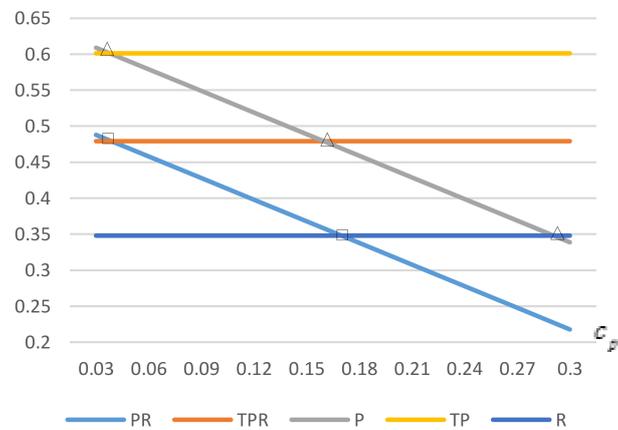


Figure 14. Profit changes with enhancement.

Secondly, we discuss those channels without a self-owned platform, such as Scenarios TPR, TP and R. Their profits remain the same with regard to the self-owned cost. Both with and without an enhancement, the profits of Scenario TP are the highest, Scenario TPR ranks second and followed by R. However, Scenario R has the smallest increasing rate and expands the profits' gap between Scenarios TP and TPR.

In conclusion, as the self-owned cost continues to drop, using a self-owned platform will be more beneficial for both with and without enhancement.

5.4. The Impact of Δm on Profits

Figure 15 proves that the enhancement of low-carbon preference is positively related to manufacturers' profits in five scenarios. With the increasing enhancement of consumers' low-carbon preference Δm , the demands of low-carbon products will also increase, thus enhancing the profitability of manufacturers.

Comparing the growth rates of profits, it can be seen that the operational modes with a retail channel are more easily influenced by the enhancement. In other words, the profits of these two scenarios with retail channels (TPR, PR and R) slump more sharply than those with online channels (P and TP). Since the environmental coefficient in retail channels is greater than direct ones, profits change more dramatically than those scenarios with direct channels, so they have poor stability.

With the growth of enhancement, retail operational modes will gain greater profits, but the stability is not high, and the three retail modes (TPR, PR and R) rely heavily on the low-carbon preference. While the online channel (P and TP) have a strong robust along with the low-carbon

preference. It may be significant that this figure provides the profits' stability and the changes of five scenarios along with Δm for managers, so that they are able to select and modify the operational modes facing the changes of consumers' low-carbon preference.

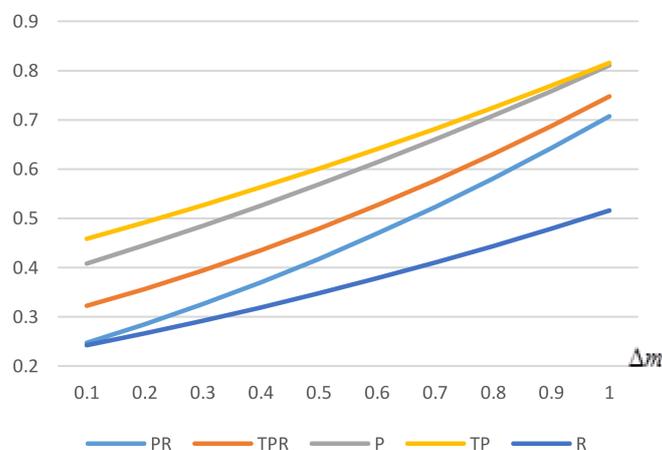


Figure 15. Profit changes with enhancement.

6. Conclusions and Future Research

This paper mainly investigates the influences of five channel structures, including three single channels and two dual channels. Consumers' low-carbon preference and its enhancement are both considered in our models to analyze how they influence channel selections. We further compare five scenarios in terms of pricing, profits and the changes of some critical points. When the construction cost is low, a self-owned platform (P) performs better than a retail channel (R) and a third-party platform (TP); Scenario PR is more profitable than Scenarios TPR and R. When the offline proportion is high, a retail channel (R) would be better than an online channel (TP and P); Scenario PR (TPR) earns more than P (TP). When the revenue proportion is high, Scenario TP would be more profitable compared to Scenarios R and P; Scenario TPR performs better than R. Moreover, critical points are drawn in our paper to identify higher profits, such as the offline proportion of the total demand, manufacturer's revenue proportion through third-party platform and the construction cost. As the offline proportion continues to fall, profits will reduce in those scenarios with retail channels. By comparing those three critical factors, we find that the critical offline proportion and revenue proportion become smaller while the construction cost becomes larger under enhancement. When it comes to the consumer implications, it is reasonable that they always prefer a lower price. We find the price in the both online and offline will increase after the enhancement of consumers' low-carbon preference (in Appendix C). This means that consumers should pay more to buy low-carbon products, which may be unfavorable to them. However, as for manufacturers, it is so necessary for them to adopt environmental-friendly technologies to satisfy consumers' low-carbon preference and increase their competitiveness. At the same time, the retail price will be higher than that in online channel, when these three factors (retail environmental coefficient, offline-demand proportion, low-carbon preference and enhancement) are relatively high or those two (direct environmental coefficient and the unit procurement cost) are low. Otherwise, the online price will be higher. This can help consumers to make the optimal purchase decisions. In addition, numerous parameter analysis is provided to attain more managerial insights for manufacturers. With the aim to get profit changes without and with enhancement, we draw figures along with the changes of offline demand, platform's commission and construction cost. Furthermore, since the manufacturers really care about robustness and trend changes among five scenarios when consumers' low-carbon preference changes, the profit trends along with preference are drawn in numerical analysis. It is reasonable that the scenarios with retail channels are more sensitive than those without as low-carbon preference grows.

This paper has its limitations. In fact, there are many types of low-carbon factors that affect the decision-making of channel operation. However, it is rather difficult to take all low-carbon factors on channel management into consideration. Among them, former scholars are less concerned about consumers' low-carbon preference, so this paper has carried out the thorough research analysis on channel selections while considering preference. However, we simply focus on market demands from the economic perspective, without taking reduction technologies into consideration to alleviate greenhouse effect. We find it is hard to comprehensively analyze the impacts from both economic and technological aspects in one article. In future studies, the impact of other low-carbon factors on channel selection should be considered, such as carbon trading system, carbon tax, new production technologies, recycling policies, and so on.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Optimal Decisions without Enhancement of Consumers' Low-Carbon Preference

(1) In Scenario PR, the retailer's profit is $\pi_r = (p_r - w)(\mu - p_r + me_r)$, the manufacturer's profit is $\pi_m = w(\mu - p_r + me_r) + p_e((1 - \mu) - p_e + me_e) - c_p$. Let $\frac{\partial \pi_r}{\partial p_r} = 0$, we get $p_r^{PR} = \frac{me_r + \mu + w}{2}$. Substitute p_r^* into π_m , and let $\frac{\partial \pi_m}{\partial w} = 0$, $\frac{\partial \pi_m}{\partial p_e} = 0$, we get $w^{PR} = \frac{\mu + me_r}{2}$, $p_e^{PR} = \frac{me_e - \mu + 1}{2}$. So $p_r^{PR} = \frac{3(me_r + \mu)}{4}$. Then the maximum profit of manufacturer is $\pi_m^{PR} = \frac{(2e_e^2 + e_r^2)m^2 + 2((e_r - 2e_e)\mu + 2e_e)m + 3\mu^2 - 4\mu + 2}{8} - c_p$.

(2) In Scenario TPR, the retailer's profit is $\pi_r = (p_r - w)(\mu - p_r + me_r)$, the manufacturer's profit is $\pi_m = w(\mu - p_r + me_r) + \theta p_e((1 - \mu) - p_e + me_e)$. Let $\frac{\partial \pi_r}{\partial p_r} = 0$, we get $p_r^{TPR} = \frac{me_r + \mu + w}{2}$. Substitute p_r^* into π_m , and let $\frac{\partial \pi_m}{\partial w} = 0$, $\frac{\partial \pi_m}{\partial p_e} = 0$, we get $w^{TPR} = \frac{\mu + me_r}{2}$, $p_e^{TPR} = \frac{me_e - \mu + 1}{2}$. So $p_r^{TPR} = \frac{3(me_r + \mu)}{4}$. Then the maximum profit of manufacturer is $\pi_m^{TPR} = \frac{(me_r + \mu)^2 + 2\theta(me_e - \mu + 1)^2}{8}$.

(3) In Scenario P, the manufacturer's profit is $\pi_m = p_e(1 - p_e + me_e) - c_p$. Let $\frac{\partial \pi_m}{\partial p_e} = 0$, we get $p_e^P = \frac{me_e + 1}{2}$. Substitute p_e^* into π_m , then the maximum profit of manufacturer is $\pi_m^P = \frac{(me_e + 1)^2}{4} - c_p$.

(4) In Scenario TP, the manufacturer's profit is $\pi_m = \theta p_e(1 - p_e + me_e)$. Let $\frac{\partial \pi_m}{\partial p_e} = 0$, we get $p_e^{TP} = \frac{me_e + 1}{2}$. Substitute p_e^* into π_m , then the maximum profit of manufacturer is $\pi_m^{TP} = \frac{\theta(me_e + 1)^2}{4}$.

(5) In Scenario R, the retailer's profit is $\pi_r = (p_r - w)(1 - p_r + me_r)$, the manufacturer's profit is $\pi_m = w(1 - p_r + me_r)$. Let $\frac{\partial \pi_r}{\partial p_r} = 0$, we get $p_r^R = \frac{me_r + w + 1}{2}$. Substitute p_r^* into π_m , and let $\frac{\partial \pi_m}{\partial w} = 0$, we get $w^R = \frac{me_r + 1}{2}$. So $p_r^R = \frac{3(me_r + 1)}{4}$. Then the maximum profit of manufacturer is $\pi_m^R = \frac{(me_r + 1)^2}{8}$.

Appendix A.2. Optimal Decisions with Enhancement of Consumers' Low-Carbon Preference

(1) In Scenario PR, the retailer's profit is $\tilde{\pi}_r = (\tilde{p}_r - \tilde{w})(\mu - \tilde{p}_r + (m + \Delta m)e_r) - k(\tilde{D}_r - D_r^*)$, the manufacturer's profit is $\tilde{\pi}_m = \tilde{w}(\mu - \tilde{p}_r + (m + \Delta m)e_r) + \tilde{p}_e((1 - \mu) - \tilde{p}_e + (m + \Delta m)e_e) - c_p - k(\tilde{D} - D^*)$. Let $\frac{\partial \tilde{\pi}_r}{\partial \tilde{p}_r} = 0$, we get $\tilde{p}_r^{PR} = \frac{(m + \Delta m)e_r + \mu + w + k}{2}$. Substitute \tilde{p}_r^* into $\tilde{\pi}_m$, and let $\frac{\partial \tilde{\pi}_m}{\partial \tilde{w}} = 0$, $\frac{\partial \tilde{\pi}_m}{\partial \tilde{p}_e} = 0$, we get $\tilde{w}^{PR} = \frac{(m + \Delta m)e_r + \mu}{2}$, $\tilde{p}_e^{PR} = \frac{1 + (m + \Delta m)e_e - \mu + k}{2}$. So $\tilde{p}_r^{PR} = \frac{3(m + \Delta m)e_r + 3\mu + 2k}{4}$. Then the maximum profit of manufacturer is $\tilde{\pi}_m^{PR} = \frac{(2e_e^2 + e_r^2)\Delta m^2 + (4me_e^2 - 4(k_2 + \mu - 1)e_e + 2e_r(me_r - 2k + \mu))\Delta m + 2m^2e_e^2 - 4m(\mu - 1)e_e + m^2e_r^2 + 2e_r(\mu - k)m + 3\mu^2 - (2k + 4)\mu + 6k^2 + 2}{8} - c_p$.

(2) In Scenario TPR, the retailer's profit is $\tilde{\pi}_r = (\tilde{p}_r - \tilde{w})(\mu - \tilde{p}_r + (m + \Delta m)e_r) - k(\tilde{D}_r - D_r^*)$, the manufacturer's profit is $\tilde{\pi}_m = \tilde{w}(\mu - \tilde{p}_r + (m + \Delta m)e_r) + \theta \tilde{p}_e((1 - \mu) - \tilde{p}_e + (m + \Delta m)e_e) - k(\tilde{D} - D^*)$. Let $\frac{\partial \tilde{\pi}_r}{\partial \tilde{p}_r} = 0$, we get $\tilde{p}_r^{TPR} = \frac{(m + \Delta m)e_r + \mu + w + k}{2}$. Substitute \tilde{p}_r^* into

$\tilde{\pi}_m$, and let $\frac{\partial \tilde{\pi}_m}{\partial \tilde{w}} = 0$, $\frac{\partial \tilde{\pi}_m}{\partial \tilde{p}_e} = 0$, we get $\tilde{w}^{TPR} = \frac{(m+\Delta m)e_r + \mu}{2}$, $\tilde{p}_e^{TPR} = \frac{(m+\Delta m)\theta e_e + (1-\mu)\theta + k}{2\theta}$. So $\tilde{p}_r^{TPR} = \frac{3(m+\Delta m)e_r + 3\mu + 2k}{4}$. Then the maximum profit of manufacturer is $\tilde{\pi}_m^{TPR} = \frac{2(me_e + \Delta me_e - \mu + 1)^2 \theta^2 + (\Delta m^2 e_r^2 - (4ke_e - 2e_r(me_r - 2k + \mu))\Delta m + \mu^2 + (2me_r - 2k)\mu + m^2 e_r^2 - 2me_r k + 4k^2)\theta + 2k^2}{8\theta}$.

(3) In Scenario P, the manufacturer's profit is $\tilde{\pi}_m = \tilde{p}_e(1 - \tilde{p}_e + (m + \Delta m)e_e) - c_p - k(\tilde{D} - D^*)$. Let $\frac{\partial \tilde{\pi}_m}{\partial \tilde{p}_e} = 0$, we get $\tilde{p}_e^P = \frac{1+(m+\Delta m)e_e+k}{2}$. Substitute \tilde{p}_e^* into $\tilde{\pi}_m$, then the maximum profit of manufacturer is $\tilde{\pi}_m^P = \frac{(m+\Delta m)^2 e_e^2 + 2((-k+1)\Delta m + m)e_e + k^2 + 1}{4} - c_p$.

(4) In Scenario TP, the manufacturer's profit is $\tilde{\pi}_m = \theta \tilde{p}_e(1 - \tilde{p}_e + (m + \Delta m)e_e) - k(\tilde{D} - D^*)$. Let $\frac{\partial \tilde{\pi}_m}{\partial \tilde{p}_e} = 0$, we get $\tilde{p}_e^{TP} = \frac{(m+\Delta m)\theta e_e + \theta + k}{2\theta}$. Substitute \tilde{p}_e^* into $\tilde{\pi}_m$, then the maximum profit of manufacturer is $\tilde{\pi}_m^{TP} = \frac{(1+(m+\Delta m)e_e)^2 \theta^2 - 2\theta \Delta m e_e k + k^2}{4\theta}$.

(5) In Scenario R, the retailer's profit is $\tilde{\pi}_r = (\tilde{p}_r - \tilde{w})(1 - \tilde{p}_r + (m + \Delta m)e_r) - k(\tilde{D}_r - D_r^*)$, the manufacturer's profit is $\tilde{\pi}_m = \tilde{w}(1 - \tilde{p}_r + (m + \Delta m)e_r) - k(\tilde{D} - D^*)$. Let $\frac{\partial \tilde{\pi}_r}{\partial \tilde{p}_r} = 0$, we get $\tilde{p}_r^R = \frac{(m+\Delta m)e_r + \tilde{w} + k + 1}{2}$. Substitute \tilde{p}_r^* into $\tilde{\pi}_m$, and let $\frac{\partial \tilde{\pi}_m}{\partial \tilde{w}} = 0$, we get $\tilde{w}^R = \frac{1+(m+\Delta m)e_r}{2}$. So $\tilde{p}_r^R = \frac{3(m+\Delta m)e_r + 3\mu + 2k}{4}$. Then the maximum profit of manufacturer is $\tilde{\pi}_m^R = \frac{(m+\Delta m)^2 e_r^2 + 2((1-2k)\Delta m - m(k-1))e_r + 4k^2 - 2k + 1}{8}$.

Appendix B

Proof of Theorem 1: For TP and P cases, we compare the manufacturer's optimal profit and find out the critical condition. Without enhancement, if $c_p > \frac{(me_e+1)^2(1-\theta)}{4}$, we have $\frac{\theta(me_e+1)^2}{4} > \frac{(me_e+1)^2}{4} - c_p$, then $\pi_m^{TP} - \pi_m^P > 0$. Therefore, $\pi_m^{TP} > \pi_m^P$. Otherwise if $c_p \leq \frac{(me_e+1)^2(1-\theta)}{4}$, $\pi_m^{TP} \leq \pi_m^P$. With enhancement, if $c_p > \frac{((1+(m+\Delta m)e_e)^2 \theta - k^2)(1-\theta)}{4\theta}$, we have $\frac{(1+(m+\Delta m)e_e)^2 \theta^2 - 2\theta \Delta m e_e k + k^2}{4\theta} > \frac{(m+\Delta m)^2 e_e^2 + 2((-k+1)\Delta m + m)e_e + k^2 + 1}{4} - c_p$. Therefore, $\tilde{\pi}_m^{TP} > \tilde{\pi}_m^P$. Otherwise, if $c_p \leq \frac{((1+(m+\Delta m)e_e)^2 \theta - k^2)(1-\theta)}{4\theta}$, $\tilde{\pi}_m^{TP} \leq \tilde{\pi}_m^P$. When $\Delta m > \frac{\sqrt{\theta(\theta(me_e+1)^2+k^2)}-\theta}{\theta e_e} - m$, we have $\frac{(me_e+1)^2(1-\theta)}{4} > \frac{((1+(m+\Delta m)e_e)^2 \theta - k^2)(1-\theta)}{4\theta}$, so $c_p^{W1} > c_p^O1$.

Proof of Theorem 2: For P and R cases, we compare the manufacturer's optimal profit and find out the critical condition. Without enhancement, if $c_p < \frac{2(me_e+1)^2 - (me_r+1)^2}{8}$, we have $\frac{(me_e+1)^2}{4} - c_p > \frac{(me_r+1)^2}{8}$, then $\pi_m^P - \pi_m^R > 0$. Therefore, $\pi_m^P > \pi_m^R$. Otherwise if $c_p \geq \frac{2(me_e+1)^2 - (me_r+1)^2}{8}$, $\pi_m^P \leq \pi_m^R$. With enhancement, if $c_p < \frac{2(m+\Delta m)^2 e_e^2 - (m+\Delta m)^2 e_r^2 + 2e_r((m+2\Delta m)k - (m+\Delta m)) + 4e_e(m - \Delta m(k-1)) - 2k^2 + 2k + 1}{8}$, we have $\frac{(m+\Delta m)^2 e_e^2 + 2((-k+1)\Delta m + m)e_e + k^2 + 1}{4} - c_p > \frac{(m+\Delta m)^2 e_r^2 + 2((1-2k)\Delta m - m(k-1))e_r + 4k^2 - 2k + 1}{8}$. Therefore, $\tilde{\pi}_m^P > \tilde{\pi}_m^R$. Otherwise, if $c_p \geq \frac{2(m+\Delta m)^2 e_e^2 - (m+\Delta m)^2 e_r^2 + 2e_r((m+2\Delta m)k - (m+\Delta m)) + 4e_e(m - \Delta m(k-1)) - 2k^2 + 2k + 1}{8}$, $\tilde{\pi}_m^P \leq \tilde{\pi}_m^R$.

Proof of Theorem 3: For TP and R cases, we compare the manufacturer's optimal profit and find out the critical condition. Without enhancement, if $\theta > \frac{(me_r+1)^2}{2(me_e+1)^2}$, we have $\frac{\theta(me_e+1)^2}{4} > \frac{(me_r+1)^2}{8}$, then $\pi_m^{TP} - \pi_m^R > 0$. Therefore, $\pi_m^{TP} > \pi_m^R$. Otherwise if $\theta \leq \frac{(me_r+1)^2}{2(me_e+1)^2}$, $\pi_m^{TP} \leq \pi_m^R$. With enhancement, if $\theta > \frac{\sqrt{(A+4kme_e+8k\Delta me_e+2k)(A-4kme_e-6k)+A+4\Delta mke_e-2k}}{4(me_e+\Delta me_e+1)^2}$, where $A = (m + \Delta m)^2 e_r^2 - 2((m + 2\Delta m)k - m - \Delta m)e_r + 1 + 4k^2$, we have $\frac{(1+(m+\Delta m)e_e)^2 \theta^2 - 2\theta \Delta m e_e k + k^2}{4\theta} > \frac{(m+\Delta m)^2 e_r^2 + 2((1-2k)\Delta m - m(k-1))e_r + 4k^2 - 2k + 1}{8}$. Therefore, $\tilde{\pi}_m^{TP} > \tilde{\pi}_m^R$. Otherwise, if $\theta \leq \frac{\sqrt{(A+4kme_e+8k\Delta me_e+2k)(A-4kme_e-6k)+A+4\Delta mke_e-2k}}{4(me_e+\Delta me_e+1)^2}$, $\tilde{\pi}_m^{TP} \leq \tilde{\pi}_m^R$.

Proof of Theorem 4: For PR and TPR cases, we compare the manufacturer's optimal profit and find out the critical condition. Without enhancement, if $c_p < \frac{(me_e-\mu)(me_e-\mu+2)(1-\theta)}{4}$,

we have $\frac{(2e_e^2+e_r^2)m^2+2((e_r-2e_e)\mu+2e_e)m+3\mu^2-4\mu+2}{8} - c_p > \frac{(me_r+\mu)^2+2\theta(me_e-\mu+1)^2}{8}$, then $\pi_m^{PR} - \pi_m^{TPR} > 0$. Therefore, $\pi_m^{PR} > \pi_m^{TPR}$. Otherwise if $c_p \geq \frac{(me_e-\mu)(me_e-\mu+2)(1-\theta)}{4}$, $\pi_m^{PR} \leq \pi_m^{TPR}$. With enhancement, if $c_p < \frac{(((m+\Delta m)e_e-\mu+1)^2\theta-k^2)(1-\theta)}{4\theta}$, we have $\frac{(2e_e^2+e_r^2)\Delta m^2+(4(me_e-k-\mu+1)e_e+2e_r(me_r-2k+\mu))\Delta m+2m^2e_e^2-4m(\mu-1)e_e+m^2e_r^2+2e_r(\mu-k)m+3\mu^2-(2k+4)\mu+6k^2+2}{8} - c_p > \frac{2(me_e+\Delta me_e-\mu+1)^2\theta^2+(\Delta m^2e_r^2-(4ke_e-2e_r(me_r-2k+\mu))\Delta m+\mu^2+(2me_r-2k)\mu+m^2e_r^2-2me_rk+4k^2)\theta+2k^2}{8\theta}$. Therefore, $\tilde{\pi}_m^{PR} > \tilde{\pi}_m^{TPR}$. Otherwise, if $c_p \geq \frac{(((m+\Delta m)e_e-\mu+1)^2\theta-k^2)(1-\theta)}{4\theta}$, $\tilde{\pi}_m^{PR} \leq \tilde{\pi}_m^{TPR}$. When $\Delta m > \frac{\sqrt{\theta(\theta(me_e-\mu)(me_e-\mu+2)+k^2)-(me_e-\mu+1)\theta}}{\theta e_e}$, we have $\frac{(((m+\Delta m)e_e-\mu+1)^2\theta-k^2)(1-\theta)}{4\theta} > \frac{(me_e-\mu)(me_e-\mu+2)(1-\theta)}{4}$, so $c_p^{W3} > c_p^{O3}$.

Proof of Theorem 5: For PR and P cases, we compare the manufacturer’s optimal profit and find out the critical condition. Without enhancement, if $\mu > \frac{2me_e-me_r+2+2\sqrt{m^2e_e^2-m^2e_e e_r-\frac{1}{2}m^2e_r^2+2me_e-me_r+1}}{3}$, we have $\frac{(2e_e^2+e_r^2)m^2+2((e_r-2e_e)\mu+2e_e)m+3\mu^2-4\mu+2}{8} - c_p > \frac{(me_e+1)^2}{4} - c_p$, then $\pi_m^{PR} - \pi_m^P > 0$. Therefore, $\pi_m^{PR} > \pi_m^P$. Otherwise if $\mu \leq \frac{2me_e-me_r+2+2\sqrt{m^2e_e^2-m^2e_e e_r-\frac{1}{2}m^2e_r^2+2me_e-me_r+1}}{3}$, $\pi_m^{PR} \leq \pi_m^P$. With enhancement, if $\mu > \frac{(2e_e-e_r)\Delta m+2me_e-me_r+k+2+B}{3}$, where $B = \sqrt{4(m+\Delta m)^2e_e^2-4(m+\Delta m)(me_r+\Delta me_r-k-2)e_e-2\Delta m^2e_r^2-(4me_r^2-10ek+4e_r)\Delta m-11k^2+4(me_r+1)k-2(me_r+1)^2+2}$, we have $\frac{(2e_e^2+e_r^2)\Delta m^2+(4(me_e-k-\mu+1)e_e+2e_r(me_r-2k+\mu))\Delta m+2m^2e_e^2-4m(\mu-1)e_e+m^2e_r^2+2e_r(\mu-k)m+3\mu^2-(2k+4)\mu+6k^2+2}{8} - c_p > \frac{(m+\Delta m)^2e_e^2+2((-k+1)\Delta m+m)e_e+k^2+1}{4} - c_p$. Therefore, $\tilde{\pi}_m^{PR} > \tilde{\pi}_m^P$. Otherwise, if $\mu \leq \frac{(2e_e-e_r)\Delta m+2me_e-me_r+k+2+B}{3}$, $\tilde{\pi}_m^{PR} \leq \tilde{\pi}_m^P$.

Proof of Theorem 6: For TPR and TP cases, we compare the manufacturer’s optimal profit and find out the critical condition. Without enhancement, if $\mu > \frac{2m\theta e_e-me_r+2\theta+2X}{2\theta+1}$, where $X = \sqrt{\theta^2m^2e_e^2-\theta m^2e_e e_r-\frac{1}{2}\theta m^2e_r^2+2\theta^2me_e-\theta me_r+\theta^2}$, we have $\frac{(me_r+\mu)^2+2\theta(me_e-\mu+1)^2}{8} > \frac{\theta(me_e+1)^2}{4}$, then $\pi_m^{TPR} - \pi_m^{TP} > 0$. Therefore, $\pi_m^{TPR} > \pi_m^{TP}$. Otherwise if $\mu \leq \frac{2m\theta e_e-me_r+2\theta+2X}{2\theta+1}$, $\pi_m^{TPR} \leq \pi_m^{TP}$. With enhancement, if $\mu > \frac{2m\theta e_e+2\Delta m\theta e_e-me_r-\Delta me_r+2\theta+k+Y}{2\theta+1}$, where $Y = \sqrt{4\theta(m+\Delta m)^2e_e^2-4\theta(m+\Delta m)(me_r-\Delta me_r-k-2)e_e-2\theta(m+\Delta m)^2e_r^2+((4\theta+\theta+2\Delta m)k-4\theta(m+\Delta m)e_e-(\theta+3)k^2+4k+4\theta^2)}$, we have $\frac{2(me_e+\Delta me_e-\mu+1)^2\theta^2+(\Delta m^2e_r^2-(4ke_e-2e_r(me_r-2k+\mu))\Delta m+\mu^2+(2me_r-2k)\mu+m^2e_r^2-2me_rk+4k^2)\theta+2k^2}{8\theta} > \frac{(1+(m+\Delta m)e_e)^2\theta^2-2\theta\Delta me_e k+k^2}{4\theta}$. Therefore, $\tilde{\pi}_m^{TPR} > \tilde{\pi}_m^{TP}$. Otherwise, if $\mu \leq \frac{2m\theta e_e+2\Delta m\theta e_e-me_r-\Delta me_r+2\theta+k+Y}{2\theta+1}$, $\tilde{\pi}_m^{TPR} \leq \tilde{\pi}_m^{TP}$.

Proof of Theorem 7: For PR and R cases, we compare the manufacturer’s optimal profit and find out the critical condition. Without enhancement, if $c_p < \frac{2(me_e+1)^2+2m\mu e_r-4m\mu e_e+3\mu^2-4\mu-2me_r-1}{8}$, we have $\frac{(2e_e^2+e_r^2)m^2+2((e_r-2e_e)\mu+2e_e)m+3\mu^2-4\mu+2}{8} - c_p > \frac{(me_r+1)^2}{8}$, then $\pi_m^{PR} - \pi_m^R > 0$. Therefore, $\pi_m^{PR} > \pi_m^R$. Otherwise if $c_p \geq \frac{2(me_e+1)^2+2m\mu e_r-4m\mu e_e+3\mu^2-4\mu-2me_r-1}{8}$, $\pi_m^{PR} \leq \pi_m^R$. With enhancement, if $c_p < \frac{2(m+\Delta m)^2e_e^2-4((k+\mu-1)\Delta m+m(\mu-1))e_e+2\Delta m(\mu-1)e_r+2(me_r-k-2)\mu-2me_r+3\mu^2+2k^2+2k+1}{8}$, we have $\frac{(2e_e^2+e_r^2)\Delta m^2+(4(me_e-k-\mu+1)e_e+2e_r(me_r-2k+\mu))\Delta m+2m^2e_e^2-4m(\mu-1)e_e+m^2e_r^2+2e_r(\mu-k)m+3\mu^2-(2k+4)\mu+6k^2+2}{8} - c_p > \frac{(m+\Delta m)^2e_e^2+2((1-2k)\Delta m-m(k-1))e_r+4k^2-2k+1}{8}$. Therefore, $\tilde{\pi}_m^{PR} > \tilde{\pi}_m^R$. Otherwise, if $c_p \geq \frac{2(m+\Delta m)^2e_e^2-4((k+\mu-1)\Delta m+m(\mu-1))e_e+2\Delta m(\mu-1)e_r+2(me_r-k-2)\mu-2me_r+3\mu^2+2k^2+2k+1}{8}$, $\tilde{\pi}_m^{PR} \leq \tilde{\pi}_m^R$.

Proof of Theorem 8: For TPR and R cases, we compare the manufacturer’s optimal profit and find out the critical condition. Without enhancement, if $\theta > \frac{2(me_r+\mu+1)(1-\mu)}{2(me_e-\mu+1)^2}$, we have $\frac{(me_r+\mu)^2+2\theta(me_e-\mu+1)^2}{8} > \frac{(me_r+1)^2}{8}$, then $\pi_m^{TPR} - \pi_m^R > 0$. Therefore, $\pi_m^{TPR} > \pi_m^R$. Otherwise if $\theta \leq \frac{2(me_r+\mu+1)(1-\mu)}{2(me_e-\mu+1)^2}$,

$\pi_m^{TPR} \leq \pi_m^R$. With enhancement, if $\theta > \frac{2(1-\mu)(m+\Delta m)e_r+4k\Delta me_e-\mu^2+2\mu k-2k+1+2E}{4(me_e+\Delta me_e+1)^2}$, where $E = \sqrt{(\mu-1)(m+\Delta m)e_r - (2me_e+4\Delta me_e+1)k + \frac{1}{2}\mu^2 + \mu k - \frac{1}{2}}((\mu-1)(m+\Delta m)e_r + 2kme_e - 3k(\mu-1) + \frac{1}{2}\mu^2 - \frac{1}{2})$, we have $\frac{2(me_e+\Delta me_e-\mu+1)^2\theta^2+(\Delta m^2e_r^2-(4ke_e-2e_r(me_r-2k+\mu))\Delta m+\mu^2+(2me_r-2k)\mu+m^2e_r^2-2me_rk+4k^2)\theta+2k^2}{8\theta} > \frac{(m+\Delta m)^2e_r^2+2((1-2k)\Delta m-m(k-1))e_r+4k^2-2k+1}{8}$. Therefore, $\tilde{\pi}_m^{TPR} > \tilde{\pi}_m^R$. Otherwise, if $\theta \leq \frac{2(1-\mu)(m+\Delta m)e_r+4k\Delta me_e-\mu^2+2\mu k-2k+1+2E}{4(me_e+\Delta me_e+1)^2}$, $\tilde{\pi}_m^{TPR} \leq \tilde{\pi}_m^R$.

Appendix C

The comparisons of direct/retail channel price without and with the enhancement of consumers' low-carbon preference:

Table A1. The price without and with enhancement in five scenarios.

Scenario	p_r	\tilde{p}_r	p_e	\tilde{p}_e
PR	$\frac{3(me_r+\mu)}{4}$	$\frac{3(m+\Delta m)e_r+3\mu+2k}{4}$	$\frac{me_e-\mu+1}{2}$	$\frac{1+(m+\Delta m)e_e-\mu+k}{2}$
TPR	$\frac{3(me_r+\mu)}{4}$	$\frac{3(m+\Delta m)e_r+3\mu+2k}{4}$	$\frac{me_e-\mu+1}{2}$	$\frac{(m+\Delta m)\theta e_e+(1-\mu)\theta+k}{2\theta}$
P	—	—	$\frac{me_e+1}{2}$	$\frac{1+(m+\Delta m)e_e+k}{2}$
TP	—	—	$\frac{me_e+1}{2}$	$\frac{(m+\Delta m)\theta e_e+\theta+k}{2\theta}$
R	$\frac{3(me_r+1)}{4}$	$\frac{3(m+\Delta m)e_r+3+2k}{4}$	—	—

We compare the direct channel price p_r and \tilde{p}_r . In Scenarios PR and TPR, $\tilde{p}_r - p_r = \frac{3(m+\Delta m)e_r+3\mu+2k}{4} - \frac{3(me_r+\mu)}{4} = \frac{3\Delta me_r+2k}{4} > 0$; In Scenario R, $\tilde{p}_r - p_r = \frac{3(m+\Delta m)e_r+3+2k}{4} - \frac{3(me_r+1)}{4} = \frac{3\Delta me_r+2k}{4} > 0$.

We compare the retail channel price p_e and \tilde{p}_e . In Scenario PR, $\tilde{p}_e - p_e = \frac{1+(m+\Delta m)e_e-\mu+k}{2} - \frac{me_e-\mu+1}{2} = \frac{\Delta me_e+k}{2} > 0$; In Scenario TPR, $\tilde{p}_e - p_e = \frac{(m+\Delta m)\theta e_e+(1-\mu)\theta+k}{2\theta} - \frac{me_e-\mu+1}{2} = \frac{\Delta me_e\theta+k}{2\theta} > 0$; In Scenario P, $\tilde{p}_e - p_e = \frac{1+(m+\Delta m)e_e+k}{2} - \frac{me_e+1}{2} = \frac{\Delta me_e+k}{2} > 0$; In Scenario TP, $\tilde{p}_e - p_e = \frac{(m+\Delta m)\theta e_e+\theta+k}{2\theta} - \frac{me_e+1}{2} = \frac{\Delta me_e\theta+k}{2\theta} > 0$.

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