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Pricing and carbon emission reduction decision in dual-channel supply chain with carbon tax and consumer preference

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Abstract: With the development of society and economy, the production methods that consuming a lot of resources are gradually unable to meet the needs of modern life. And with the rise of consumers' awareness of environmental protection, more and more low-carbon production of manufacturers have been put forward. In order to encourage manufacturers to product with low carbon, the carbon tax policy is proposed. Under the pressure of the new policy and consumers' environmental awareness, manufacturers' production decisions will face many challenges. In addition, the rapid development of the Internet and the popularity of online shopping have also enabled manufacturers to engage in online direct sales, which has many impacts on traditional retail. Under such circumstances, consumers' channel preferences will also have many influences on manufacturers' production decisions. Therefore, it is necessary to study the influence of carbon tax, consumer green preference and channel preference on supply chain members. Therefore, this study constructs a dual-channel supply chain model consisting of a single manufacturer and a retailer to determine the optimal pricing of supply chain members and minimum carbon emissions of the manufacturer in the two scenarios of centralized decision-making and decentralized decision-making, respectively. The impact of consumers' environmental awareness, carbon tax rates and consumers' channel preferences on the carbon emissions of products and the profits of manufacturers and retailers are analyzed. The research results show that: when the carbon tax rate is low, with the rising of consumers' awareness of environmental protection and carbon tax, it is necessary to increase the carbon tax on clean manufacturers to enable them to take more market share, and increase the carbon tax on low carbon emission manufacturers to force them to make more efforts on clean manufacturing. Besides, low-carbon taxes should be imposed on medium carbon emission manufacturers to avoid them from going back to high-polluting production, and on high carbon emission manufacturers, so that they will have more funds to carry out cleaner production reforms. Besides, shopping online should be encouraged.

1. Introduction

In recent years, with the gradual enhancement of people's awareness of environmental protection, the traditional production mode with high pollution and consumption is more and more difficult to meet the needs of people's life. In order to promote enterprises to carry out low-carbon production, the carbon tax system emerges at the historic moment. For example, Basiri et al.'s research shows that the enhancement of consumers' low-carbon awareness will make them more willing to pay higher prices to purchase low-carbon products (Basiri et al.2017) [1]. Liu et al. studied the impact of consumers' environmental awareness on the interests of enterprises (Liu et al.2012) [2]. In addition, the popularity of online shopping provides manufacturers with the convenience of online direct selling products, which also has many impacts on the traditional supply chain and the distribution of benefits.

Many scholars have conducted a series of studies on environmental awareness and carbon tax. Du et al. analyzed a low-carbon supply chain composed of a manufacturer and a supplier, and pointed out that under the influence of different decisions, when the amount of suppliers are reduced, the manufacturer's profit increases with the carbon emission ceiling (Du et al.2013) [3]. Ghosh et al. studied the pricing coordination of low-carbon supply chain under a single traditional channel and the impact of cost sharing contract on the decision-making of supply chain participants (Ghosh et al.2015) [4]. Yang et al. studied the impact of carbon tax and carbon trading on suppliers and retailers and proposed a coordination mechanism (Yang et al.2014) [5]. Cheng Yonghong et al. has confirmed that carbon emission reduction and sales price per unit product would be affected by carbon tax rate, initial carbon dioxide emissions and supply chain decision-making mode (Cheng Yonghong et al.2015) [6]. Yang Huixiao et al. studied consumers' low-carbon preference, government carbon tax and producers' emission reduction decisions under supply chain contracts (Yang Huixiao et al.2016) [7]. Liu Mingwu et al. constructed low-carbon supply chain decision-making models under three scenarios: the manufacturer does not open online channels, the manufacturer opens online channels, and the manufacturer opens online channels and shares profits, and pointed out the optimal decisions of supply chain members under different scenarios (Liu Mingwu et al.2019) [8]. Li Yanbing et al. established a cost profit margin maximization model and compared three decision-making models, namely decentralized decision-making, centralized decision-making and repurchase contract, to solve the problems of supply chain optimization and coordination (Li Yanbing et al. 2018) [9]. Sun Jianan et al. considered consumers' low-carbon preference and channel preference, and determined the optimal carbon emission reduction boundary of the supply chain through comparative analysis of different decision-making modes (Sun Jianan et al.2018) [10]. Dai et al. found that environmental awareness can improve enterprises' green technology innovation ability and promote enterprises to carry out green production (Dai et al.2020) [11]. Wu Dan et al. studied the dynamic optimization problem of supply chain considering consumers' low-carbon preference and carbon trading policy, and gave the optimal carbon emissions under centralized decision-making and decentralized decision-making, and proposed emission reduction strategies (Wu Dan et al.2021) [12]. Cong Jing et al. showed that consumers' green preference for raw materials and finished products is conducive to promoting manufacturers' emission reduction input and profit improvement (Cong Jing et al.2020). [13]

Many scholars have also studied the dual-channel supply chain. Li Bo et al. used linear demand function to study the pricing strategy of dual-channel green products (Li Bo et al.2016) [14]. He et al. studied the impact of government taxation on enterprises on the dual-channel supply chain (He et al.2016) [15]. Xu et al. studied the impact of carbon emissions and customer loyalty on supply chain decision-making in dual-channel supply chain under carbon emission regulation (Xu et al.2018) [16]. Zhou and Ye studied the optimal equilibrium strategy in centralized and decentralized dual-channel supply chains (Zhou and Ye.2018) [17]. Ji et al. studied the supply chain decisions under four situations: whether the manufacturer conducts dual-channel sales and whether the retailer participates in the joint emission reduction of low-carbon promotion (Ji et al.2017) [18]. Li et al. studied the dual-channel pricing decision-making model when the manufacturer and the retailer make independent decisions and when the manufacturer is in a non-dominant position (Li et al. 2016) [19]. Zhou Xideng studied emission reduction and pricing decisions in the dual-channel supply chain of carbon cap and trade (Zhou Xideng. 2017) [20].

To sum up, the current research basically considers one or both of the carbon tax, consumers' environmental awareness and consumers' channel preference, but does not comprehensively consider the joint impact of the three on the supply chain, or considers several types of factors, but does not consider the impact of carbon tax and other factors on product demand and profit per unit product. Therefore, this paper comprehensively considers the impact of carbon tax policy and consumers' dual preferences on the profits and carbon emissions of each subject in the dual-channel supply chain.

2. Description of symbolic meaning basic hypotheses

This paper constructs a dual-channel supply chain model consisting of a single manufacturer and retailer, as shown in Figure 1.

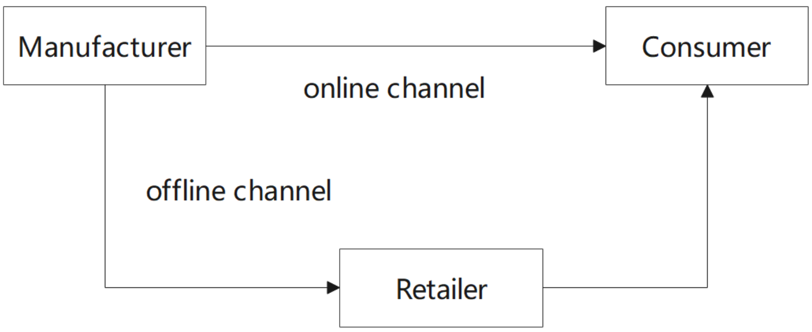

Figure 1: Dual-channel supply chain model

2.1. Description of meaning of symbol

φ: cross-sensitivity coefficient between channels
β: coefficient of consumers' preference for offline channels
θ: the sensitivity coefficient of consumers to the manufacturer's carbon emissions
e: carbon emission per unit product after technological innovation by the manufacturer
e_0: the manufacturer's initial carbon emission per unit product
w: the retailer obtains the wholesale price of the product
P_r: the selling price of traditional retail channels
P_m: the selling price of direct sales channel retail
D_r: retail demand in traditional channels
D_m: direct sales channel sales demand
t: tax rate per unit of carbon emissions imposed by the government
λ: manufacturer's unit abatement cost coefficient
π_m: manufacturer's profit
π_r: retailer's profit
π: the overall profit of the supply chain

2.2. Basic hypotheses

(1) Consumers have channel preferences, in which the proportion of consumers who prefer offline channels is, and the proportion of consumers who prefer online direct selling channels is $1-\beta$

(2) The self-price sensitivity coefficient of consumers to products is 1, and the cross-price sensitivity coefficient between channels is, which is less than the self-price sensitivity coefficient, namely $0 < \varphi < 1$

(3) We make decisions on product price and wholesale price based on unit product production cost C, without loss of generality, and let C=0

(4) Decision makers are rational

(5) Manufacturers will adopt emission reduction strategies such as production technology innovation to reduce the unit carbon emission of products

(6) It is assumed that consumers in the demand market have certain environmental awareness and are more inclined to low-carbon products, and that consumers' demand for low-carbon products increases with the increase of product greenness.

3. Model description and result analysis under different decision scenarios

3.1. Centralized decision making

It is assumed that the demand function of traditional channel and online direct selling channel is:

$$D_r = \beta - P_r + \varphi P_m - \theta e, D_m = 1 - \beta - P_m + \varphi P_r - \theta e$$

In the case of centralized decision-making, we see the manufacturer and the retailer as a whole and make decisions with the goal of maximizing the profit of the entire supply chain. Firms that make centralized decisions usually dominate the supply chain. In the case of centralized decision-making, the overall profit function of the supply chain is as follows:

$$\pi = (P_r - te)(\beta - P_r + \varphi P_m - \theta e) + (P_m - te)(1 - \beta - P_m + \varphi P_r - \theta e) - \frac{1}{2}\lambda(e_0 - e)^2$$

hence: $\frac{\partial^2 \pi}{\partial {P_m}^2} = -2, \frac{\partial^2 \pi}{\partial P_m \partial P_r} = 2\varphi, \frac{\partial^2 \pi_m}{\partial P_r \partial P_m} = 2\varphi, \frac{\partial^2 \pi_m}{\partial {P_r}^2} = -2,$

The function $\pi(P_r, P_m)$ has a maximum value. Let $\frac{\partial \pi}{\partial P_r} = 0, \frac{\partial \pi}{\partial P_m} = 0$,then

$$P_r = \frac{\varphi + (1-\varphi)\beta}{2(1-\varphi^2)} + \frac{(-\theta + (1-\varphi)t)e}{2(1-\varphi)}, P_m = \frac{1 - (1-\varphi)\beta}{2(1-\varphi^2)} + \frac{(-\theta + (1-\varphi)t)e}{2(1-\varphi)}$$

if we substituteP_r, P_m into π, and then

$$\frac{\partial \pi}{\partial e} = \frac{1}{2(1-\varphi)}(2\lambda(1-\varphi)e_0 - (\theta + (1-\varphi)t) - (2\lambda(1-\varphi) - 2(\theta + (1-\varphi)t)^2)e)$$

Let $e_1 = \frac{\theta+(1-\varphi)t}{2\lambda(1-\varphi)}$, when$e_0 > e_1$:

Let $t_1 = \frac{\sqrt{\lambda(1-\varphi)}-\theta}{1-\varphi}$, when $\lambda < \frac{(\theta+(1-\varphi)t)^2}{1-\varphi}$ that is $t > t_1$, we can know $\frac{\partial \pi}{\partial e} > 0$.That means the overall profit of the supply chain increases with the increase of carbon emissions per unit product. It is assumed that $t > t_1$ means the government carbon tax rate is at a high level, which indicates that when the carbon tax rate is high, the overall profit of the supply chain increases with the increase of unit carbon emissions, and the limit is obtained at e_0. This shows that the higher carbon tax rate will discourage manufacturers from carrying out emission reduction production, and enterprises will choose to ignore the carbon tax policy and not carry out low-carbon technological change in order to ensure their interests.

When $\lambda > \frac{(\theta+(1-\varphi)t)^2}{1-\varphi}$, that is $0 < t < t_1$,this means the carbon tax rate is low:

now the Hessian matrix of π with respect to P_r, P_m, e is negative definite, and the Hessian matrix is as follows:

$$\begin{bmatrix} -2 & 2\varphi & -\theta+(1-\varphi)t \\ 2\varphi & -2 & -\theta+(1-\varphi)t \\ -\theta+(1-\varphi)t & -\theta+(1-\varphi)t & 4t\theta-\lambda \end{bmatrix}$$

At this time, there is optimal ${P_r}^*, {P_m}^*$and e^* that maximize the profit of the supply chain.

Let $\frac{\partial\pi}{\partial P_r}=0, \frac{\partial\pi}{\partial P_m}=0, \frac{\partial\pi}{\partial e}=0$, and then we can get ${P_r}^*, {P_m}^*$and e^* as follows, and we can know that in the case of centralized decision-making, the manufacturer's optimal carbon emission has nothing to do with consumer channel preference.

$$P_r^*=\frac{\varphi+(1-\varphi)\beta}{2(1-\varphi^2)}+\frac{(-\theta+(1-\varphi)t)e^*}{2(1-\varphi)}, P_m^*=\frac{1-(1-\varphi)\beta}{2(1-\varphi^2)}+\frac{(-\theta+(1-\varphi)t)e^*}{2(1-\varphi)},$$

$$e^*=\frac{2\lambda(1-\varphi)e_0-(\theta+(1-\varphi)t)}{2\lambda(1-\varphi)-2(\theta+(1-\varphi)t)^2}$$

Let $e_2=\frac{(\theta+(1-\varphi)t)}{\lambda(1-\varphi)+(\theta+(1-\varphi)t)^2}, e_3=\frac{(\theta+(1-\varphi)t)^2+(1-\varphi)\lambda}{4(1-\varphi)\lambda(\theta+(1-\varphi)t)}, e_4=\frac{1}{2(\theta+(1-\varphi)t)}$and then:

Proposition 1: when $e_1<e_0<e_2$, we can get the following result:

$$\frac{\partial e^*}{\partial\theta}<0, \frac{\partial e^*}{\partial t}=(1-\varphi)\frac{\partial e^*}{\partial\theta}<0, \frac{\partial\pi}{\partial\theta}<0, \frac{\partial\pi}{\partial t}<0,$$

and then we can infer that the following values are all greater than 0

$$\frac{\partial D_r}{\partial\theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial\theta}, \frac{\partial D_m}{\partial t}, \frac{\partial(P_m-te^*)}{\partial\theta}, \frac{\partial(P_m-te^*)}{\partial t}$$

$$\frac{\partial(P_r-te^*)}{\partial\theta}, \frac{\partial(P_r-te^*)}{\partial t}, \frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial\theta}, \frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t}$$

Statement of proposition 1: when the initial carbon emissions of the manufacturer satisfies $e_1<e_0<e_2$, we define this kind of manufacturer as 'Clean type manufacturer', and we can draw the conclusion that when the government carbon tax rate is low, for clean manufacturers, the strengthening of consumers' environmental awareness and the increase of government carbon tax will be conducive to the reduction of their carbon emissions, but the overall profit of the supply chain will decrease with the strengthening of consumers' environmental awareness and the increase of carbon tax. This is because although the strengthening of consumers' awareness of environmental protection and the increase of government carbon tax can increase the demand for manufacturers' online and offline products and increase the profit of a single product, the increase in profit is not enough to make up for the cost of investment in emission reduction, so the overall profit will decline, but it is conducive to the clean manufacturers to seize more markets. Therefore, the government should increase the carbon tax for such enterprises while trying to improve consumers' environmental awareness.

Proposition 2: when$e_2<e_0<e_3$, we can get the following result:

$$\frac{\partial e^*}{\partial\theta}<0, \frac{\partial e^*}{\partial t}=(1-\varphi)\frac{\partial e^*}{\partial\theta}<0, \frac{\partial\pi}{\partial\theta}<0, \frac{\partial\pi}{\partial t}<0$$

and then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial\theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial\theta}, \frac{\partial D_m}{\partial t}, \frac{\partial(P_m-te^*)}{\partial\theta}, \frac{\partial(P_m-te^*)}{\partial t}, \frac{\partial(P_r-te^*)}{\partial\theta}, \frac{\partial(P_r-te^*)}{\partial t}$$

and the following values are greater than 0:

$$\frac{\partial(\frac{1}{2}\lambda(e_0-e)^2)}{\partial\theta},\frac{\partial(\frac{1}{2}\lambda(e_0-e)^2)}{\partial t}$$

Statement of proposition 2: when the initial carbon emissions of the manufacturer satisfies$e_2 < e_0 < e_3$, we define this kind of manufacturer as 'Low carbon emission manufacturer', and we can draw the conclusion that for manufacturers with low carbon emissions, when the carbon tax rate is low, the strengthening of consumers' environmental awareness and the increase of government carbon tax will be conducive to the reduction of their carbon emissions, but the overall profit of the supply chain will decrease with the strengthening of consumers' environmental awareness and the increase of carbon tax. This is because the product competitiveness of such manufacturers has declined. With the enhancement of consumers' environmental awareness and the increase of carbon tax, the product demand and single product profit of such manufacturers will decline. At the same time, due to the incomplete green technology innovation, the profit of such manufacturers will decline along with the increase of emission reduction cost, so they are at a disadvantage in the competition. For such manufacturers, the government should increase carbon taxes on such manufacturers to force them to make more radical cleaner production changes.

Proposition 3: when$e_3 < e_0 < e_4$, we can get the following result:

$$\frac{\partial e^*}{\partial\theta}>0,\frac{\partial e^*}{\partial t}=(1-\varphi)\frac{\partial e^*}{\partial\theta}>0,\frac{\partial\pi}{\partial\theta}<0,\frac{\partial\pi}{\partial t}<0$$

and then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial\theta},\frac{\partial D_r}{\partial t},\frac{\partial D_m}{\partial\theta},\frac{\partial D_m}{\partial t},\frac{\partial(P_m-te^*)}{\partial\theta},\frac{\partial(P_m-te^*)}{\partial t},\frac{\partial(P_r-te^*)}{\partial\theta},\frac{\partial(P_r-te^*)}{\partial t}$$

$$\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial\theta},\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t}$$

Statement of proposition 3: when the initial carbon emissions of the manufacturer satisfies$e_3 < e_0 < e_4$, we define this kind of manufacturer as 'Medium carbon emission manufacturer', and we can draw the conclusion that for such manufacturers, when the government's carbon tax rate is low, the carbon emissions of products produced by such manufacturers will also increase with the increase of carbon tax rate and the improvement of consumers' environmental awareness. Moreover, the supply chain profit will also decrease with the increase of consumer environmental awareness and carbon tax rate. This is because its market share will be further compressed by the clean type, while the profit per unit product is reduced, and it is also at a disadvantage in the competition. Although it reduces its own emission reduction cost, the reduction in emission reduction cost is not enough to make up for the profit reduction caused by the lost market share, so the overall profit decreases. If the carbon tax rate on such manufacturers is further increased, it will force them to further reduce their input in emission reduction costs in order to make up for the lost profits, and eventually return to the old way of high-pollution manufacturing. Therefore, the government should reduce the carbon tax for such enterprises, which can not only stabilize the market share of such manufacturers, but also promote them to invest more in emission reduction costs, and finally achieve the reduction of carbon emissions and the increase of profits at the same time.

Proposition 4: when $e_0 > e_4$, we can get the following result:

$$\frac{\partial e^*}{\partial\theta}>0,\frac{\partial e^*}{\partial t}=(1-\varphi)\frac{\partial e^*}{\partial\theta}>0,\frac{\partial\pi}{\partial\theta}>0,\frac{\partial\pi}{\partial t}>0$$

and then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial \theta},\frac{\partial D_r}{\partial t},\frac{\partial D_m}{\partial \theta},\frac{\partial D_m}{\partial t},\frac{\partial (P_m-te^*)}{\partial \theta},\frac{\partial (P_m-te^*)}{\partial t},\frac{\partial (P_r-te^*)}{\partial \theta},\frac{\partial (P_r-te^*)}{\partial t}$$

$$\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial \theta},\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t}$$

Statement of proposition 4: when the initial carbon emissions of the manufacturer satisfies $e_0 > e_4$, we define this kind of manufacturer as 'High carbon emission manufacturer', and we can draw the conclusion that for such manufacturers, with the increase of consumers' environmental awareness and the increase of carbon tax, their carbon emissions will increase while their profits will increase. This is because although the market share of such manufacturers will gradually decrease with the increase of consumers' environmental awareness, due to their low emission reduction costs, the emission reduction costs saved can make up for the loss of market share, but this is not a benign state. Therefore, for the government, it is necessary to reduce the carbon tax rate of such manufacturers, so that they can invest more funds in emission reduction technologies. It can also be seen that the driving force for such manufacturers to reduce emissions is not the increase of consumers' environmental awareness, but the reduction of the government's carbon tax rate.

Proposition 5: when$0 < \beta < \frac{1}{2}$, we can infer that $\frac{\partial e^*}{\partial \theta} > 0$ $\frac{\partial \pi}{\partial \beta} < 0, P_m > P_r, D_m > D_r$; when $\frac{1}{2} < \beta < 1$, we can infer that $P_m < P_r$,$D_m < D_r$,$\frac{\partial \pi}{\partial \beta} > 0$

Procedure of proof:$P_m - P_r = \frac{1-2\beta}{2(1+\varphi)}$,$D_m - D_r = \frac{1-2\beta}{2}$,$\frac{\partial \pi}{\partial \beta} = \frac{2\beta-1}{2(1+\varphi)}$,

Hence when $0 < \beta < \frac{1}{2}$, we can infer that $P_m > P_r, D_m > D_r$,$\frac{\partial \pi}{\partial \beta} < 0$, and when$\frac{1}{2} < \beta < 1$, we can infer that $P_m < P_r$,$D_m < D_r$,$\frac{\partial \pi}{\partial \beta} > 0$.

$$\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial \theta},\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t}$$

Statement of proposition 5: if we assume that when $0 < \beta < \frac{1}{2}$, consumers tend to shop online, and when $\frac{1}{2} < \beta < 1$, consumers tend to shop offline. Therefore, for manufacturers, when consumers prefer online channels, direct selling price is greater than retail price, direct sales volume is greater than retail volume, and direct selling profit is greater than retail profit. When consumers prefer offline channels, direct selling price is lower than retail price, direct sales volume is lower than retail volume, and direct selling profit is lower than retail profit. For manufacturers that can control the supply chain, they should try their best to increase consumers' online consumption intention or offline consumption intention, and choose one of them. However, with the gradual improvement of consumers' desire for online shopping, manufacturers that can control the supply chain should enhance consumers' willingness for online consumption.

3.2. Decentralized decision making

When the manufacturer and the retailer make decentralized decisions, the manufacturer and the retailer respectively pursue the maximization of their own profits. It is assumed that in decentralized decision-making, the supply chain is still dominated by the manufacturer and followed by the retailer.

Profit of retailer:

$$\pi_r = (P_r - w)(\beta - P_r + \varphi P_m - \theta e)$$

Profit of manufacturer:

$$\pi_m = (w - te)(\beta - P_r + \varphi P_m - \theta e) + (P_m - te)(1 - \beta - P_m + \varphi P_r - \theta e) - \frac{1}{2}\lambda(e_0 - e)^2$$

Hence,

$$\frac{\partial \pi_r}{\partial P_r} = \beta - P_r + \varphi P_m - \theta e - P_r + w, \frac{\partial^2 \pi_r}{\partial {P_r}^2} = -2 < 0$$

For the retailer, there is an optimal P_r^* that makes the retailer profit the most: let $\frac{\partial \pi_r}{\partial P_r} = 0$, and we can infer that $P_r^* = \frac{1}{2}(\beta + \varphi P_m - \theta e + w)$

And then we can know that:

$$\pi_m = \frac{1}{2}(w - te)(\beta + \varphi P_m - \theta e - w) + (P_m - te)(1 - \beta - P_m + \frac{1}{2}\varphi(\beta + \varphi P_m - \theta e + w) - \theta e) - \frac{1}{2}\lambda(e_0 - e)^2$$

$$\frac{\partial \pi_m}{\partial P_m} = \varphi w + (\varphi^2 - 2)P_m - \frac{1}{2}\varphi te + 1 + (\frac{1}{2}\varphi - 1)\beta - (\frac{1}{2}\varphi + 1)\theta e - (\frac{1}{2}\varphi^2 - 1)te$$

$$\frac{\partial \pi_m}{\partial w} = \varphi P_m - w + \frac{1}{2}\beta - \frac{1}{2}\theta e + \frac{1}{2}(1 - \varphi)te$$

$$\frac{\partial^2 \pi_m}{\partial {P_m}^2} = \varphi^2 - 2, \frac{\partial^2 \pi_m}{\partial w^2} = -1, \frac{\partial^2 \pi_m}{\partial P_m \partial w} = \varphi, \frac{\partial^2 \pi_m}{\partial w \partial P_m} = \varphi$$

Now the Hessian matrix of π_m with respect to P_m, w is negative definite, therefore there are optimal P_m and w that maximize manufacturer's profit.

Let $\frac{\partial \pi_m}{\partial w} = 0, \frac{\partial \pi_m}{\partial P_m} = 0$,

Therefore, in the decentralized decision scenario, the optimal pricing of the manufacturer's online direct selling price and wholesale price are as follows:

$$ {P_m}^* = \frac{1-(1-\varphi)\beta}{2(1-\varphi^2)} + \frac{(-\theta+(1-\varphi)t)e}{2(1-\varphi)}, w^* = \frac{\varphi+(1-\varphi)\beta}{2(1-\varphi^2)} + \frac{(-\theta+(1-\varphi)t)e}{2(1-\varphi)}$$

and then we can know that ${P_r}^* = \frac{2\varphi+(3-2\varphi-\varphi^2)\beta}{4(1-\varphi^2)} + \frac{(\varphi-3)\theta e+(1-\varphi^2)te}{4(1-\varphi)}$

We substitute ${P_r}^*, {P_m}^*$ and w^* into π_m and we can infer that

$$\frac{\partial \pi_m}{\partial e} = -\frac{\theta+(1-\varphi)t}{4(1-\varphi)}(2 - (1-\varphi)\beta - (3+\varphi)\theta e - (1-\varphi)(3+\varphi)te) - \lambda(e - e_0).$$

Let $e_5 = \frac{(2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi)}$, when $e_0 > e_5$,

Let $t_2 = \frac{\sqrt{\frac{4\lambda(1-\varphi)}{3+\varphi}}-\theta}{1-\varphi}$, when $\lambda < \frac{(3+\varphi)[\theta+(1-\varphi)t]^2}{4(1-\varphi)}$ that is $t > t_2$, we can know $\frac{\partial \pi_m}{\partial e} > 0$, this means manufacturer's profits increase with the increase in carbon emissions per unit of product.

It is assumed that $t > t_2$, this means the carbon tax rate is at a high level, which indicates that when the carbon tax rate is high, the manufacturer's profit increases with the increase of unit carbon emissions, and the limit is obtained at e_0. At this time, the profit obtained by the emission reduction production is less than the profit obtained by the initial non-emission reduction, which indicates that the high carbon tax rate will discourage the manufacturer's enthusiasm for emission reduction production, and the enterprise will choose to ignore the carbon tax policy in order to ensure the profits.

When $\lambda > \frac{(3+\varphi)[\theta+(1-\varphi)t]^2}{4(1-\varphi)}$, that is $0 < t < t_2$,π_m has a maximum value.

Let $\frac{\partial \pi_m}{\partial e} = 0$, the optimal carbon emission is as follows:

$$e^* = \frac{4\lambda(1-\varphi)e_0 - (2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi) - (3+\varphi)(\theta+(1-\varphi)t)^2}$$

Then we can know that:

$$P_m{}^* = \frac{1-(1-\varphi)\beta}{2(1-\varphi^2)} + \frac{-\theta+(1-\varphi)t}{2(1-\varphi)} \cdot \frac{4\lambda(1-\varphi)e_0 - (2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi) - (3+\varphi)(\theta+(1-\varphi)t)^2}$$

$$w^* = \frac{\varphi+(1-\varphi)\beta}{2(1-\varphi^2)} + \frac{-\theta+(1-\varphi)t}{2(1-\varphi)} \cdot \frac{4\lambda(1-\varphi)e_0 - (2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi) - (3+\varphi)(\theta+(1-\varphi)t)^2}$$

$$P_r{}^* = \frac{2\varphi+(3-2\varphi-\varphi^2)\beta}{4(1-\varphi^2)} + \frac{(\varphi-3)\theta+(1-\varphi^2)t}{4(1-\varphi)} \cdot \frac{4\lambda(1-\varphi)e_0 - (2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi) - (3+\varphi)(\theta+(1-\varphi)t)^2}$$

Hence,

$$\frac{\partial e^*}{\partial \theta} = \frac{8\lambda(1-\varphi)(3+\varphi)(\theta+(1-\varphi)t)e_0 - (2-(1-\varphi)\beta)(4\lambda(1-\varphi)+(3+\varphi)(\theta+(1-\varphi)t)^2)}{(4\lambda(1-\varphi)-(3+\varphi)(\theta+(1-\varphi)t)^2)^2}.$$

$$\frac{\partial D_r}{\partial \theta} = -\frac{1}{4}(e^* + (\theta+(1-\varphi)t)\frac{\partial e^*}{\partial \theta}), \frac{\partial D_r}{\partial t} = (1-\varphi)\frac{\partial D_r}{\partial \theta}$$

$$\frac{\partial D_m}{\partial \theta} = -\frac{3+\varphi}{4}(e^* + (\theta+(1-\varphi)t)\frac{\partial e^*}{\partial \theta}), \frac{\partial D_m}{\partial t} = (1-\varphi)\frac{\partial D_m}{\partial \theta}$$

$$\frac{\partial (w-te^*)}{\partial \theta} = \frac{\partial (P_m-te^*)}{\partial \theta} = -\frac{1}{2(1-\varphi)}(e^* + (\theta+(1-\varphi)t)\frac{\partial e^*}{\partial \theta}),$$

$$\frac{\partial (w-te^*)}{\partial t} = \frac{\partial (P_m-te^*)}{\partial t} = -\frac{1}{2}(e^* + (\theta+(1-\varphi)t)\frac{\partial e^*}{\partial \theta})$$

$$\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial \theta} = -\lambda(e^*-e_0)\frac{\partial e^*}{\partial \theta}, \frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t} = (1-\varphi)\frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial \theta}$$

Let

$$e_6 = \frac{(2-(1-\varphi)\beta)(4\lambda(1-\varphi)+(3+\varphi)(\theta+(1-\varphi)t)^2)}{8\lambda(1-\varphi)(3+\varphi)(\theta+(1-\varphi)t)}, e_7 = \frac{2-(1-\varphi)\beta}{(3+\varphi)(\theta+(1-\varphi)t)}, e_8 = \frac{2(2-(1-\varphi)\beta)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi)+(3+\varphi)(\theta+(1-\varphi)t)^2}$$

Proposition 6: when$e_5 < e_0 < e_8$, we can infer that $\frac{\partial e^*}{\partial \theta} < 0, \frac{\partial e^*}{\partial t} = (1-\varphi)\frac{\partial e^*}{\partial \theta} < 0,$

$$\frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_m}{\partial t} = (1-\varphi)\frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial \theta} > 0, \frac{\partial \pi_r}{\partial t} = (1-\varphi)\frac{\partial \pi_r}{\partial \theta} > 0,$$

And now $e^* + (\theta+(1-\varphi)t)\frac{\partial e^*}{\partial \theta} < 0$, hence the following values are all greater than 0:

$$\frac{\partial D_r}{\partial \theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial \theta}, \frac{\partial D_m}{\partial t}, \frac{\partial (w-te^*)}{\partial \theta}, \frac{\partial (w-te^*)}{\partial t}, \frac{\partial (P_m-te^*)}{\partial \theta}, \frac{\partial (P_m-te^*)}{\partial t},$$

$$\frac{\partial (P_r-w)}{\partial \theta}, \frac{\partial (P_r-w)}{\partial t}, \frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial \theta}, \frac{\partial(\frac{1}{2}\lambda(e_0-e^*)^2)}{\partial t}$$

Statement of proposition 6: when the initial carbon emission of the manufacturer satisfies $e_5 < e_0 < e_8$, we define this kind of manufacturer as 'Clean type manufacturer', and we can draw the conclusion that When the government's carbon tax rate is low, for clean manufacturers, although the increase of carbon tax rate and consumers' awareness of environmental protection has brought the increase of product sales and the increase of single product profits, the cost of emission reduction also increases with the increase of carbon tax rate and consumers' awareness of environmental protection. On the contrary, the overall profit decreases with the increase of carbon tax and the increase of consumer awareness of environmental protection. This means that even though some profits are lost, the products of cleaner manufacturers have more market. For the government, by increasing carbon tax, clean manufacturers can further reduce carbon emissions, and at the same time increase the market share of such manufacturers, forcing other manufacturers to carry out low-carbon production. For retailers working with cleaner manufacturers, retail profits have increased as carbon tax rates and consumer awareness have increased. Therefore, for retailers, they should actively cooperate with clean manufacturers, which will benefit retailers to achieve profits.

Proposition 7: when$e_8 < e_0 < e_6$, we can get the following result:

$$\frac{\partial e^*}{\partial \theta} < 0, \frac{\partial e^*}{\partial t} = (1-\varphi)\frac{\partial e^*}{\partial \theta} < 0, \frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_m}{\partial t} = (1-\varphi)\frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial t} = (1-\varphi)\frac{\partial \pi_r}{\partial \theta} < 0,$$

and now $e^* + (\theta + (1-\varphi)t)\frac{\partial e^*}{\partial \theta} < 0$,

then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial \theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial \theta}, \frac{\partial D_m}{\partial t}, \frac{\partial (w - te)}{\partial \theta}, \frac{\partial (w - te^*)}{\partial t}, \frac{\partial (P_m - te^*)}{\partial \theta}, \frac{\partial (P_m - te^*)}{\partial t}, \frac{\partial (P_r - w)}{\partial \theta}, \frac{\partial (P_r - w)}{\partial t}$$

and the following values are greater than 0:

$$\frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial \theta}, \frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial t}$$

Statement of proposition 7: when the initial carbon emission of the manufacturer satisfies $e_8 < e_0 < e_6$, we define this kind of manufacturer as 'Low carbon emission manufacturer', and we can draw the conclusion that When the government controls the carbon tax rate is low, for such manufacturers, with the increase of carbon tax rate and consumer awareness of environmental protection, manufacturers' profits will decrease. This is because in this case, the living space of such manufacturers will be compressed. Although they have achieved the reduction of carbon emissions, they are in a very disadvantageous competitive position due to the decrease of product sales and profit per unit product, and the further increase of emission reduction costs. For such manufacturers, they should increase their efforts in clean manufacturing. Implement more radical cleaner production changes. The government should impose a carbon tax on such manufacturers to speed up cleaner production changes. Retailers that work with such manufacturers will see their profits squeezed as consumers become more environmentally conscious.

Proposition 8: when $e_6 < e_0 < e_7$, we can get the following result:

$$\frac{\partial e^*}{\partial \theta} > 0, \frac{\partial e^*}{\partial t} = (1-\varphi)\frac{\partial e^*}{\partial \theta} > 0, \frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_m}{\partial t} = (1-\varphi)\frac{\partial \pi_m}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial t} = (1-\varphi)\frac{\partial \pi_r}{\partial \theta} < 0$$

and then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial \theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial \theta}, \frac{\partial D_m}{\partial t}, \frac{\partial (w - te^*)}{\partial \theta}, \frac{\partial (w - te^*)}{\partial t}, \frac{\partial (P_m - te^*)}{\partial \theta}, \frac{\partial (P_m - te^*)}{\partial t}$$

$$\frac{\partial (P_r - w)}{\partial \theta}, \frac{\partial (P_r - w)}{\partial t}, \frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial \theta}, \frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial t}$$

Statement of proposition 8: when the initial carbon emission of the manufacturer satisfies $e_6 < e_0 < e_7$, we define this kind of manufacturer as 'Medium carbon emission manufacturer', and we can draw the conclusion that When the government carbon tax rate is low, the carbon emission will increase with the increase of the carbon tax rate and the improvement of consumers' awareness of environmental protection. And its profits will fall as consumers become more environmentally conscious and carbon taxes increase. This is because its market share will be further compressed by the clean type, and the profit per unit product will be reduced, and it is also at a disadvantage in the competition. Although it reduces its own emission reduction costs, the reduction of emission reduction costs is not enough to make up for the profit reduction brought by the lost market share, so the overall profit decreases. A further increase in the carbon tax rate for such manufacturers would force them to make up for lost profits by further reducing the cost of their emissions, and eventually return to their old ways of polluting. Therefore, the government should reduce the carbon tax on such enterprises, which can not only stabilize the market share of such manufacturers, but also promote them to make more investment in emission reduction costs, and finally achieve the reduction of their carbon emissions and increase their profits.

Proposition 9: when$e_0 > e_7$, we can get the following result:

$$\frac{\partial e^*}{\partial \theta} > 0, \frac{\partial e^*}{\partial t} = (1-\varphi)\frac{\partial e^*}{\partial \theta} > 0, \frac{\partial \pi_m}{\partial \theta} > 0, \frac{\partial \pi_m}{\partial t} = (1-\varphi)\frac{\partial \pi_m}{\partial \theta} > 0, \frac{\partial \pi_r}{\partial \theta} < 0, \frac{\partial \pi_r}{\partial t} = (1-\varphi)\frac{\partial \pi_r}{\partial \theta} < 0$$

and then we can infer that the following values are all less than 0:

$$\frac{\partial D_r}{\partial \theta}, \frac{\partial D_r}{\partial t}, \frac{\partial D_m}{\partial \theta}, \frac{\partial D_m}{\partial t}, \frac{\partial (w - te^*)}{\partial \theta}, \frac{\partial (w - te^*)}{\partial t}, \frac{\partial (P_m - te^*)}{\partial \theta}, \frac{\partial (P_m - te^*)}{\partial t}$$

$$\frac{\partial (P_r - w)}{\partial \theta}, \frac{\partial (P_r - w)}{\partial t}, \frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial \theta}, \frac{\partial (\frac{1}{2}\lambda (e_0 - e^*)^2)}{\partial t}$$

Statement of proposition 9: when the initial carbon emission of the manufacturer satisfies $e_0 > e_7$ we define this kind of manufacturer as 'High carbon emission manufacturer', and we can draw the conclusion that For such manufacturers, when the government's carbon tax rate is low, with the increase of consumers' awareness of environmental protection and the increase of carbon tax, their carbon emissions will increase while their profits will increase. This is because although the market share of such manufacturers will gradually decrease with the increase of consumers' awareness of environmental protection, the cost of emission reduction can make up for the loss of market share due to the low cost of emission reduction. However, this is not a benign situation. Therefore, the government should reduce the carbon tax rate for such manufacturers, so that they can invest more money in emission-reduction technologies. It can also be seen that the driving force for such manufacturers to reduce emissions is not the increase of consumers' awareness of environmental protection, but the reduction of the government's carbon tax rate.

Proposition 10:

let $\beta_1 = \frac{\lambda(1-\varphi)^2(2-(1+\varphi)(\theta+(1-\varphi)t)e_0-(1-\varphi)(\theta+(1-\varphi)t)^2)}{\lambda(1-\varphi)(3-\varphi)-2(\theta+(1-\varphi)t)^2}$, we can infer that$0 < \beta_1 < 1$.

when $e_0 < \frac{1}{(1+\varphi)(\theta+(1-\varphi)t)}$,we can infer that $\frac{\partial e^*}{\partial \beta} = \frac{(1-\varphi)(\theta+(1-\varphi)t)}{4\lambda(1-\varphi)-(3+\varphi)(\theta+(1-\varphi)t)^2} > 0$,

$$\frac{\partial \pi_m}{\partial \beta}=\frac{(\lambda(1-\varphi)(3-\varphi)-2(\theta+(1-\varphi)t)^2)\beta-(\lambda(1-\varphi)^2(2-(1+\varphi)(\theta+(1-\varphi)t)e_0)-(1-\varphi)(\theta+(1-\varphi)t)^2)}{(1-\varphi^2)(4\lambda(1-\varphi)-(3+\varphi)(\theta+(1-\varphi)t)^2)}<0$$

Statement of proposition 10: As the offline preference increases, so does the optimal carbon emission per unit product. So online purchases should be encouraged. And there is an offline channel preference degree; When the preference of goods purchased through offline channels is less than, the manufacturer can gain higher profits with the decrease of offline preference. Therefore, manufacturers should make efforts to improve consumers' preference for online consumption, which can not only reduce the carbon emission of their products, but also gain increased profits.

4. Numerical simulation

4.1. Centralized decision making

Firstly, the situation of dual channel supply chain when making centralized decision is analyzed. Suppose the parameters in the model are set as follows: $\beta=0.30$,$\varphi=0.50$,λ=8.0, the initial carbon emissions of the four types of manufacturers are 0.15, 0.25, 0.42 and 0.72 respectively. Under the centralized decision, the optimal carbon emissions of different types of manufacturers and the changes of manufacturers' profits along with the government's carbon tax and consumers' environmental awareness are shown in Table 1 and Table 2.

Table 1 shows when t=1, the optimal carbon emissions of various manufacturers and the changes of supply chain profits with the environmental awareness of consumers under the carbon tax rate. Table 2 shows when θ=0.2, the optimal carbon emissions of various manufacturers and the changes of supply chain profits with the carbon tax rate.

Table 1: The impact of consumer environmental awareness on supply chain profits and optimal carbon emissions

	Clean type manufacturer		Low carbon emission manufacturer		Medium carbon emission manufacturer		High carbon emission manufacturer	
θ	e^*	π	e^*	π	e^*	π	e^*	π
0.20	0.07	0.19	0.19	0.13	0.38	0.06	0.72	0.01
0.40	0.05	0.18	0.17	0.11	0.39	0.03	0.76	0.04
0.60	0.02	0.17	0.16	0.09	0.41	0.02	0.84	0.14

Table 1 shows that with the strengthening of consumers' environmental awareness: (1) The optimal carbon emission of clean manufacturers decreases, and the supply chain profits decrease; (2) the optimal carbon emission of low carbon manufacturers decreases, and the supply chain profits decrease; (3) the optimal carbon emission of medium carbon manufacturers increases, and the supply chain profits decrease; (4) the optimal carbon emission of high carbon manufacturers increases, but the supply chain profits increase.

Table 2: Effects of carbon tax on supply chain profits and optimal carbon emissions

	Clean type manufacturer		Low carbon emission manufacturer		Medium carbon emission manufacturer		High carbon emission manufacturer	
t	e^*	π	e^*	π	e^*	π	e^*	π
1.00	0.07	0.19	0.19	0.13	0.38	0.06	0.72	0.01
1.40	0.05	0.18	0.17	0.11	0.39	0.03	0.76	0.04
1.80	0.02	0.17	0.16	0.09	0.41	0.02	0.84	0.14

Table 2 shows that with the increase of carbon tax rate: (1) The decrease of the optimal carbon emission of clean manufacturers will reduce the profits of the supply chain; (2) the decrease of the optimal carbon emission of low carbon manufacturers will reduce the profits of the supply chain; (3) the increase of the optimal carbon emission of medium carbon manufacturers will reduce the profits of the supply chain; (4) the increase of the optimal carbon emission of high carbon manufacturers will increase the profits of the supply chain.

4.2. Decentralized decision making

Suppose the parameters in the model are as follows: the initial carbon emissions of the four types of manufacturers are respectively 0.13, 0.21, 0.43 and 0.78. In the case of decentralized decision-making, the optimal carbon emissions of different types of manufacturers and their profits change with the carbon tax rate and consumers' environmental awareness, as shown in Table 3 and Table 4.

Table 3 shows the optimal carbon emissions of various manufacturers and the changes of manufacturers' profits with consumers' environmental awareness when the carbon tax rate t=0.9. Table 4 shows the optimal carbon emissions of various manufacturers and the changes of manufacturers' profits with the carbon tax rate when θ=0.2 is taken.

Table 3: The impact of consumer environmental awareness on manufacturers' profits and manufacturers' optimal carbon emissions

	Clean type manufacturer		Low carbon emission manufacturer		Medium carbon emission manufacturer		High carbon emission manufacturer	
θ	e^*	π_m	e^*	π_m	e^*	π_m	e^*	π_m
0.20	0.06	0.17	0.15	0.13	0.40	0.05	0.78	0.00
0.40	0.04	0.16	0.14	0.11	0.40	0.02	0.82	0.03
0.60	0.02	0.15	0.13	0.09	0.42	0.00	0.88	0.12

Table 3 shows that with the strengthening of consumers' environmental awareness: (1) The optimal carbon emission of clean manufacturers decreases, which is accompanied by the decrease of their own profits. (2) The optimal carbon emission of low carbon manufacturers decreases, and their profits will decrease. (3) The optimal carbon emission of medium carbon manufacturers increases, and their profits will decrease accordingly. (4) The optimal carbon emission of high-carbon manufacturers will increase, but their profits will increase.

Table 4: The effect of carbon tax on manufacturers' profits and manufacturers' optimal carbon emissions

	Clean type manufacturer		Low carbon emission manufacturer		Medium carbon emission manufacturer		High carbon emission manufacturer	
t	e^*	π_m	e^*	π_m	e^*	π_m	e^*	π_m
0.90	0.06	0.17	0.15	0.13	0.40	0.05	0.78	0.00
1.40	0.04	0.16	0.14	0.10	0.40	0.01	0.83	0.04
1.90	0.01	0.15	0.12	0.08	0.43	0.00	0.92	0.19

Table 4 shows that with the increase of carbon tax rate: (1) the optimal carbon emission of clean manufacturers decreases, and their profits will decrease; (2) the optimal carbon emission of low carbon manufacturers decreases, and their profits will decrease; (3) the optimal carbon emission of medium carbon manufacturers increases, and their profits will decrease; (4) the optimal carbon emission of high carbon manufacturers increases, but their profits will increase.

5. Conclusion

This paper constructs a pricing and emission reduction model of the dual-channel supply chain considering the dual preferences of consumers and the influence of the government's carbon tax policy. It considers the emission reduction decision-making behaviors of different types of manufacturers under the two situations of centralized decision-making and decentralized decision-making, and draws the following main conclusions:

In either case, when the government's carbon tax rate is high, manufacturers' profits will be damaged if they carry out emission-reduction manufacturing. The profits after emission-reduction production are lower than those without emission-reduction production, so they are not willing to invest more funds in low-carbon production reform.

When the government's carbon tax rate is relatively low: (1) For clean manufacturers, the government should raise consumers' awareness of environmental protection and at the same time increase the carbon tax rate for such manufacturers. This can increase the manufacturers' demand for products online and offline, and increase the profit of each product. Although the overall profit declines, it is conducive for clean manufacturers to seize more markets. (2) For low-carbon emission manufacturers, they should increase their own efforts in clean manufacturing and implement more thorough clean production reform. While raising consumer awareness, governments should also increase carbon taxes on such manufacturers to speed up cleaner production changes. (3) For medium carbon emission manufacturers, the government should reduce the carbon tax on such enterprises to prevent them from returning to the old road of high-pollution production. (4) For high-carbon emission manufacturers, the government should reduce the carbon tax rate of such manufacturers, so that they can have more funds to invest in emission reduction technologies. Moreover, the driving force for such manufacturers to reduce emissions is not the increase of consumers' awareness of environmental protection, but the reduction of the government's carbon tax rate. (5) Online consumption should be encouraged, which will not only help reduce the carbon emission per unit product, but also make manufacturers gain more profits.

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