Pricing Decision of Dual-Channel Supply Chain Based on Carbon Emission Reduction Input Under Carbon Tax Policy

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Keywords: Tax Policy, Dual-Channel Supply Chain, Carbon Emission Reduction Input, Pricing Decision.

Abstract: This paper constructs the consumer demand function based on the low carbon preference of consumers. Considering the manufacturer's carbon emission reduction investment, the pricing models of decentralized supply chain and centralized supply chain based on consumer preference are constructed. This paper also explores the effect of consumer low carbon sensitivity coefficient on wholesale prices, retail prices, demand and profits of members. The results show that the profits and carbon emission reduction level of supply chain members under centralized decision-making are greater than those of decentralized decision-making; supply chain members' profits are positively correlated with consumer carbon emission reduction sensitivity coefficient.

1 INTRODUCTION

The international community and governments pay more attention to carbon emissions, put forward the carbon tax policy, and achieved good environmental benefits. The EU aims to reduce carbon emissions by 40 percent from 1990 levels by 2030 (Liu, 2021). On April 1, 2019, Canada introduced a nationwide carbon tax pricing, imposing a carbon tax on units (China Petrochemical News, 2019).

The formation of low carbon consumption consciousness is transformed from the concept of sustainable development in the era of low carbon economy. Consumers usually consider the price of products and services and low carbon factors when making purchase behavior. It will also become an important part of enterprises to judge customer needs. Therefore, it can effectively promote the low carbon process of supply chain incorporating consumers' preferences into product decision and network optimization of supply chain.

Companies in various fields such as IBM and Apple have begun to use third-party platform network sales channels. As a new marketing channel, online sales channel is a kind of competition or even suppression for the traditional retail channel, and the living space of offline market is getting smaller and smaller. Therefore, it is particularly important for the retail industry what joint online and offline sales channels.

In summary, this paper explores the decision-making of an online direct Dual-channel supply chain which is composed of a manufacturer and an offline retailer considering the impact of low carbon preference on channel sales prices. This paper assumes that the manufacturer invests in carbon emission reduction costs, and constructs two supply chain pricing models based on consumer preferences and carbon emission reduction investment under the carbon tax policy.

2 LITERATURE REVIEW

This article is mainly related to the following four aspects of literature: (1) Carbon tax policy, (2) Consumer preference, (3) Carbon emission reduction investment and (4) Dual-channel supply chain pricing decision.

2.1 Carbon Tax Policy

Liu et al. (2022) discuss the impact of rising energy prices caused by carbon tax policies on the welfare of Chinese residents. Xu et al. (2022) take the green marketing cost coefficient as the private information

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of retailers, and discuss the impact of information asymmetry on the optimal decision-making. Most of the current research focuses on the impact of carbon tax policy on supply chain pricing decisions.

2.2 Consumer Preference

Yalabik (2011) finds that consumers' green consumption behaviors will directly determine enterprises' willingness to produce green products and increase low carbon technology R&D. Yenipazarli et al. (2015) consider how consumers' willingness to pay affects enterprises' choice of product greenness. Hu et al. (2021) show that consumers' low carbon preferences have a significant impact on manufacturers' decisions. Some scholars explore the impact of consumer preferences on pricing decisions of products.

2.3 Carbon Emission Reduction Investment

Chen et al.(2022) build a duopoly model that considers technology R&D and technology sharing in carbon emission reduction. Liu et al.(2022) show that the R&D investment in precooling technology and carbon emission reduction reach the highest level in the centralized supply chain model. Few scholars explore the pricing decisions comprehensively considering the manufacturers' carbon emission reduction input and consumers' preferences.

2.4 Dual-Channel Supply Chain Pricing Decision

Some scholars also introduced manufacturers' carbon emission reduction input into the pricing decision of Dual-channel supply chain. Zhang et al. (2021) explore the impact of introducing online channels on supply chain network equilibrium decision-making, carbon emissions and profits. Che et al. (2021) consider the impact of manufacturers' participation in carbon trading and green financial loans on participants' profits and emission reduction decisions. Some scholars also explore the pricing decision of Dual-channel supply chain considering consumers' low carbon preferences. Xie et al. (2021) show that the profits of producer, retailer and supply chain have the same changes at different levels of consumers' low carbon preference coefficient. This paper comprehensively considers manufacturers' carbon emission reduction input and consumers' preferences under the carbon tax policy.

3 DUAL-CHANNEL SUPPLY CHAIN PRICING MODEL

3.1 Problem Description and Parameter Assumption

Under the background of carbon tax policy, considering consumers' channel preference and low carbon preference, the research objects of this paper are a manufacturer and an offline retailer considering the manufacturer's carbon emission reduction input. Assume that the manufacturer establish an online direct sale channel and an offline retail channel.

This paper assumes the supply and demand balance in the supply chain market. Assume that the manufacturer's carbon emission reduction input is $\frac{1}{2}kg^2$. Assume that μ represents the value of the product purchased by consumers; θ represents consumer preference coefficient for online channels; f represents the cross price elasticity coefficient; c represents production cost; w_1 represents wholesale price; P_i represents retail prices of online direct sales channels and offline retailers; D_i represents sales volumes of online direct marketing channels and offline retailers; k represents the carbon emission reduction level coefficient of the manufacturer; g represents the carbon emission reduction level of the manufacturer; φ represents consumer carbon emission reduction sensitivity coefficient; e represents the unit carbon emission of the product; y represents the tax price of unit carbon emissions; E represents carbon emission difference; Π_M^j , Π_R^j and Π^j represent profits of manufacturers, retailers and the whole supply chain respectively; $i=1,2$ represent online direct sales channels and offline retailers respectively; $j=D,C$ represent decentralized supply chain pricing models and centralized supply chain pricing models respectively.

3.2 Pricing Model of Decentralized Supply Chain

This section explores the pricing decision of online direct sales Dual-channel supply chain under the carbon tax policy considering the carbon emission reduction investment which is to improve the carbon emission reduction level of products through technical means. At this time, the demand functions of online direct sales channels and offline retailers are as follows:

$$D_1^D = \theta\mu - P_1 + fP_2 + \varphi g \tag{1}$$

$$D_2^D = (1-\theta)\mu - P_2 + fP_1 + \varphi g \tag{2}$$

The profit functions are as follows:

$$\Pi_M^D = \left(p_1^D - c\right)D_1^D + \left(w_1^D - c\right)D_2^D - yE^D - \frac{1}{2}k\left(g^D\right)^2 \tag{3}$$

$$\Pi_R^D = \left(P_2^D - w_1^D\right)D_2^D \tag{4}$$

$$\Pi^D = \left(p_1^D - c\right)D_1^D + \left(p_1^D - c\right)D_2^D - yE^D - \frac{1}{2}k\left(g^D\right)^2 \tag{5}$$

Where $E^D = (e-g)\left(D_1^D + D_2^D\right)$.

Proposition 3.1 There are optimal wholesale price, retail prices, sales volumes and profits for the manufacturer and offline retailer:

$$\begin{cases} w_1^{D*} = \dfrac{\left(1+(f-1)\theta\right)\mu + \left((f+1)\varphi + y\left(f^2-1\right)\right)g + \left(1-f^2\right)(c+ye)}{2\left(1-f^2\right)} \\ p_1^{D*} = \dfrac{\left(f+(1-f)\theta\right)\mu + \left((f+1)\varphi + y\left(f^2-1\right)\right)g + \left(1-f^2\right)(c+ye)}{2\left(1-f^2\right)} \\ p_2^{D*} = \dfrac{1}{4\left(1-f^2\right)}\Big[\left(3-f^2+\left(f^2+2f-3\right)\theta\right)\mu + (f+1)\left(1-f^2\right)(c+ye) \\ +\left(\left(-f^2+2f+3\right)\varphi + (f+1)\left(f^2-1\right)y\right)g\Big] \end{cases} \tag{6}$$

$$\begin{cases} D_1^{D*} = \dfrac{\left(f+(2-f)\theta\right)\mu + (f-1)(f+2)(c+ye) + \left((f+2)\varphi + (1-f)(f+2)y\right)g}{4} \\ D_2^{D*} = \dfrac{(1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g}{4} \end{cases} \tag{7}$$

$$\begin{cases} \Pi_M^{D*} = \dfrac{1}{8\left(1-f^2\right)}\Big[\Big(\left(f+(2-f)\theta\right)\mu + (f-1)(f+2)(c+ye) \\ +\left((f+2)\varphi + (1-f)(f+2)y\right)g\Big) \\ \left(\left(f+(1-f)\theta\right)\mu + \left((f+1)\varphi + y\left(1-f^2\right)\right)g + \left(f^2-1\right)(c+ye)\right) \\ +\left((1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g\right) \\ \left(\left(1+(f-1)\theta\right)\mu + \left(f^2-1\right)(c+ye) + \left((f+1)\varphi + \left(1-f^2\right)y\right)g\right)\Big] \\ -\dfrac{1}{2}kg^2 \\ \Pi_R^{D*} = \dfrac{1}{16}\left[(1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g\right]^2 \\ \Pi^{D*} = \dfrac{1}{8\left(1-f^2\right)}\Big[\Big(\left(f+(2-f)\theta\right)\mu + (f-1)(f+2)(c+ye) \\ +\left((f+2)\varphi + (1-f)(f+2)y\right)g\Big) \\ \left(\left(f+(1-f)\theta\right)\mu + \left((f+1)\varphi + y\left(1-f^2\right)\right)g + \left(f^2-1\right)(c+ye)\right) \\ +\left((1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g\right) \\ \left(\left(1+(f-1)\theta\right)\mu + \left(f^2-1\right)(c+ye) + \left((f+1)\varphi + \left(1-f^2\right)y\right)g\right)\Big] \\ +\dfrac{1}{16}\left[(1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g\right]^2 - \dfrac{1}{2}kg^2 \end{cases} \tag{8}$$

Proposition 3.2 (1) When $\theta_p^{D*} < \theta < 1$, there has $p_1^{D*} > p_2^{D*}$; when $0 < \theta < \theta_p^{D*}$, there has $p_1^{D*} < p_2^{D*}$;

(2) When $\theta_d^{D*} < \theta < 1$, there has $D_1^{D*} > D_2^{D*}$; when $0 < \theta < \theta_d^{D*}$, there has $D_1^{D*} < D_2^{D*}$.

Among them, $\theta_p^{D*} = \dfrac{1}{\left(-f^2-4f+5\right)\mu}\Big[-\Big((f+3)(f-1)\mu + \left(\left(f^2-1\right)\varphi + \left(1-f^2\right)(f-1)y\right)g + \left(1-f^2\right)(1-f)(c+ye)\Big)\Big]$,

$$\theta_d^{D*} = \frac{-\left((f-1)\mu + \left((f+1)\varphi + \left(1-f^2\right)y\right)g + \left(f^2-1\right)(c+ye)\right)}{(3-f)\mu},$$

$\Delta\theta = \theta_p^{D*} - \theta_d^{D*} \neq 0$.

Proposition 3.2 shows that when $0 < \theta < \theta_p^{D*}$, that is, when consumer's preference for online channels θ is at a small value, the retail prices of online direct selling channels will be lower than that of offline retailers, and the manufacturer's online direct selling channels can obtain greater price advantages in the Dual-channel supply chain of online direct selling. When $\theta_d^{D*} < \theta < 1$ is greater, the demands for online direct selling channels is higher than that of offline retailers; otherwise, the opposite is true.

Proposition 3.3 When $k > k_g^{D*}$, the manufacturer has optimal carbon emission reduction level g^{D*}, and $\dfrac{\partial g^{D*}}{\partial \varphi} > 0$. It makes manufacturer's profit achieve Pareto optimal.

Among them, $k_g^{D*} = \dfrac{y\left((f+3)\varphi + \left(-f^2-2f+3\right)y\right)}{4}$,

$$g^{D*} = \frac{y\left(\left((f+1)+(1-f)\theta\right)\mu + \left(f^2+2f-3\right)(c+ye)\right)}{4k + y\left(\left(f^2+2f-3\right)y - (f+3)\varphi\right)}.$$

Proposition 3.3 when $k > \dfrac{y\left((f+3)\varphi + \left(-f^2-2f+3\right)y\right)}{4}$, the manufacturer obtain the optimal carbon emission reduction level and maximize its profit. In addition, manufacturer's carbon emission reduction level increases with the increase of the consumer's carbon emission reduction sensitivity coefficient φ, which indicates that increasing the consumer's carbon emission reduction sensitivity coefficient can enable manufacturer to increase the carbon emission reduction level.

3.3 Pricing Model of Centralized Supply Chain

In the centralized supply chain pricing model, manufacturers and offline retailers regard the entire supply chain system as an enterprise, they strive to the win-win situation.

The profit function of centralized supply chain system is:

$$\Pi_C^C = \left(p_1^C - c\right)D_1^C + \left(w_1^C - c\right)D_2^C - yE^C + \left(P_2^{C1} - w_1^C\right)D_2^C - \frac{1}{2}k\left(g^C\right)^2$$

$$= \left(p_1^C - c\right)D_1^C + \left(P_2^C - c\right)D_2^C - yE^C - \frac{1}{2}k\left(g^C\right)^2 \quad (9)$$

Proposition 3.4 There are optimal retail prices, sales volumes and profits for the manufacturer and offline retailer:

$$\begin{cases} p_1^{C*} = \dfrac{\left(f + (1-f)\theta\right)\mu + \left((f+1)\varphi + y\left(f^2-1\right)\right)g + \left(1-f^2\right)(c+ye)}{2\left(1-f^2\right)} \\ p_2^{C*} = \dfrac{\left(1 + (f-1)\theta\right)\mu + \left((f+1)\varphi + y\left(f^2-1\right)\right)g + \left(1-f^2\right)(c+ye)}{2\left(1-f^2\right)} \end{cases} \quad (10)$$

$$\begin{cases} D_1^{C*} = \dfrac{\theta\mu + \left(\varphi + y(1-f)\right)g + (f-1)(c+ye)}{2} \\ D_2^{C*} = \dfrac{(1-\theta)\mu + \left(\varphi + y(1-f)\right)g + (f-1)(c+ye)}{2} \end{cases} \quad (11)$$

$$\Pi_C^{C*} = \frac{1}{4\left(1-f^2\right)}\Big[\left(\left(f+(1-f)\theta\right)\mu + \left((f+1)\varphi + y\left(1-f^2\right)\right)g + \left(f^2-1\right)(c+ye)\right)\left(\theta\mu + \left(\varphi + y(1-f)\right)g + (f-1)(c+ye)\right) + \left(\left(1+(f-1)\theta\right)\mu + \left((f+1)\varphi + y\left(1-f^2\right)\right)g + \left(f^2-1\right)(c+ye)\right)\left((1-\theta)\mu + \left(\varphi + y(1-f)\right)g + (f-1)(c+ye)\right)\Big] - \frac{1}{2}kg^2 \quad (12)$$

Proposition 3.5 (1) When $\theta_p^{C*} < \theta < 1$, there has $p_1^{C*} > p_2^{C*}$; when $0 < \theta < \theta_p^{C*}$, there has $p_1^{C*} < p_2^{C*}$;

(2) When $\theta_d^{C*} < \theta < 1$, there has $D_1^{C*} > D_2^{C*}$; when $0 < \theta < \theta_d^{C*}$, there has $D_1^{C*} < D_2^{C*}$.

Among them, $\theta_p^{C*} = \frac{1}{2}, \theta_d^{C*} = \frac{1}{2}$.

Proposition 3.6 When $k > k_g^{C*}$, manufacturer has optimal carbon emission reduction level g^{C*}. It makes the profit of manufacturer achieve Pareto optimal, and $\frac{\partial g^{C*}}{\partial \varphi} > 0$.

Among them, $k_g^{C*} = \varphi + (1-f)y$, $g^{C*} = \dfrac{y\left(\mu + 2(1-f)(c+ye)\right)}{2\left(k - y\left(\varphi + (1-f)y\right)\right)}$.

The proof process of Propositions 3.5 and 3.6 is similar to Propositions 3.2 and 3.3.

Proposition 3.7 The profit and carbon emission reduction level of centralized decision are higher than that of decentralized decision.

$$\Delta g = g^{C*} - g^{D*} = \frac{y(1-f)}{2\left(k - y\left(\varphi + (1-f)y\right)\right)\left(4k + y\left(\left(f^2+2f-3\right)y - (f+3)\varphi\right)\right)}\Big[\left(\left(2k - y\left(\varphi + (1-f)y\right)\right) + \left(2\left(k - y\left(\varphi+(1-f)y\right)\right)\right)\theta\right)\mu + \left(2(f+7)k + 4\left(f^2+2f-3\right)y^2 - 4(f+3)\varphi y\right)(c+ye)\Big] > 0$$

When $g^{D*} = g^{C*}$, there is $\Delta\Pi = \Pi_C^{C*} - \left(\Pi_M^{D*} + \Pi_R^{D*}\right) = \frac{1}{16}\left[(1-\theta)\mu + (f-1)(c+ye) + \left(\varphi + (1-f)y\right)g\right]^2 > 0$.

Proposition 3.7 shows that when manufacturer invests the same carbon emission reduction level, the manufacturer and retailer jointly set the wholesale price and retail prices under centralized decision-making, aiming at making the profit of the entire system to maximize and pursue a win-win situation. The sales prices of retailers increase, which leads to the decrease of profits under the decentralized decision.

Proposition 3.8 In two decision-making models, there are following conclusions $(j = D, C)$:

(1) $\frac{\partial w_1^{D*}}{\partial e} > 0$, $\frac{\partial p_1^{j*}}{\partial e} > 0$, $\frac{\partial p_2^{j*}}{\partial e} > 0$, $\frac{\partial D_1^{j*}}{\partial e} < 0$, $\frac{\partial D_2^{j*}}{\partial e} < 0$, $\frac{\partial \Pi_M^{D*}}{\partial e} < 0$, $\frac{\partial \Pi_R^{D*}}{\partial e} < 0$, $\frac{\partial \Pi_C^{C*}}{\partial e} < 0$;

(2) $\frac{\partial w_1^{D*}}{\partial g} > 0$, $\frac{\partial p_1^{j*}}{\partial g} > 0$, $\frac{\partial p_2^{j*}}{\partial g} > 0$, $\frac{\partial D_1^{j*}}{\partial g} > 0$, $\frac{\partial D_2^{j*}}{\partial g} > 0$, $\frac{\partial \Pi_M^{D*}}{\partial g} > 0$, $\frac{\partial \Pi_R^{D*}}{\partial g} > 0$, $\frac{\partial \Pi_C^{C*}}{\partial g} > 0$;

(3) $\frac{\partial w_1^{D*}}{\partial \varphi} > 0$, $\frac{\partial p_1^{j*}}{\partial \varphi} > 0$, $\frac{\partial p_2^{j*}}{\partial \varphi} > 0$, $\frac{\partial D_1^{j*}}{\partial \varphi} > 0$, $\frac{\partial D_2^{j*}}{\partial \varphi} > 0$, $\frac{\partial \Pi_M^{D*}}{\partial \varphi} > 0$, $\frac{\partial \Pi_R^{D*}}{\partial \varphi} > 0$, $\frac{\partial \Pi_C^{C*}}{\partial \varphi} > 0$;

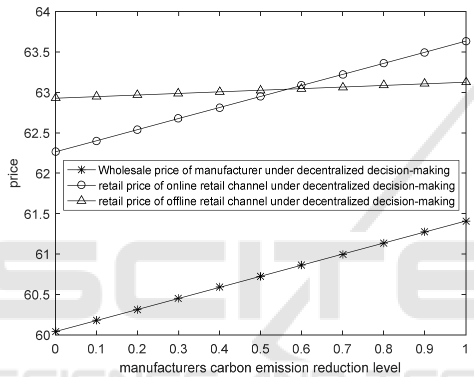
(4) $\frac{\partial w_1^{D*}}{\partial y} > 0$, $\frac{\partial p_1^{j*}}{\partial y} > 0$, $\frac{\partial p_2^{j*}}{\partial y} > 0$, $\frac{\partial D_1^{j*}}{\partial y} < 0$, $\frac{\partial D_2^{j*}}{\partial y} < 0$, $\frac{\partial \Pi_M^{D*}}{\partial y} < 0$, $\frac{\partial \Pi_R^{D*}}{\partial y} < 0$, $\frac{\partial \Pi_C^{C*}}{\partial y} < 0$.

Proposition 3.8 shows that (1) It will increase wholesale price and retail prices with the increase of unit carbon emissions of products, resulting in the decrease of demands and profits; (2) When carbon emission reduction level increases, manufacturer and offline retailer have pricing initiative, which ultimately increase their profit; (3) When consumer carbon emission reduction sensitivity coefficient is higher, the profit of the whole supply chain will be higher; (4) When the tax price of unit carbon emissions increases, the wholesale price and retail price increases.

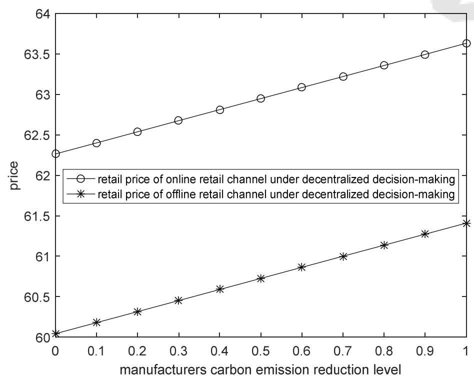
4 DUAL-CHANNEL SUPPLY CHAIN PRICING DECISION ANALYSIS

This paper uses MATLAB to further analyze the impact of relevant parameters on pricing and supply chain members' profits. Refer to the parameter assignment in the study of xie et al. (2021), the parameter values used in this paper are: $\mu=40, \theta=0.6, \varphi=0.6, f=0.8, c=21, k=3.5, y=0.265, e=4.93$.

4.1 Impact of Manufacturers' Carbon Emission Reduction Level on Pricing Strategy



(1) Decentralized decision

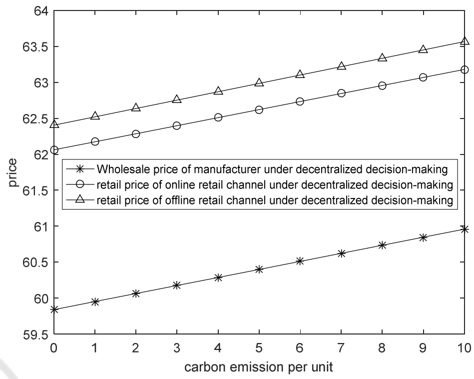


(2) Centralized decision

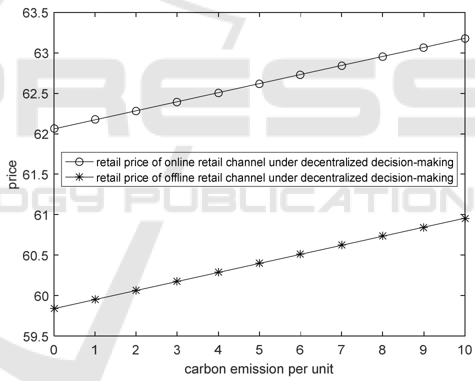
Figure 1: Impact of manufacturers' carbon emission reduction level on pricing strategy.

It can be seen from Figure 1 that whether it is decentralized decision-making or centralized decision-making, the retail prices of offline retail channels are greater than those of online direct selling channels. When the manufacturers' carbon emission reduction level improve, the wholesale prices, retail prices and the sales volumes increase, ultimately increasing profits of manufacturers and the offline retailers.

4.2 Impact of Carbon Emission per Unit Product on Pricing Strategy



(1) Decentralized decision

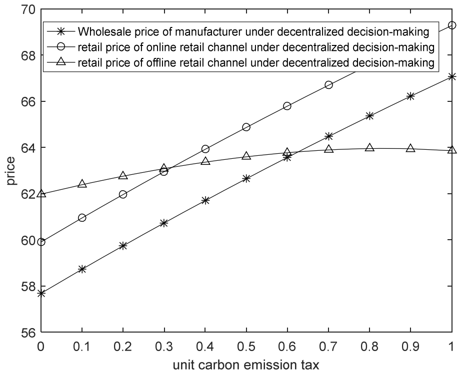


(2) Centralized decision

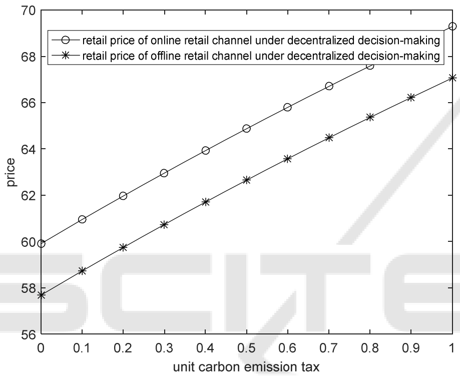
Figure 2: Impact of carbon emission per unit product on pricing strategy.

It can be seen from Figure 2 that whether it is decentralized decision-making or centralized decision-making, the increase of carbon emission per unit product will increase the wholesale price of manufacturers and retail price of online direct sales channels and offline retailers. Due to the existence of consumer carbon emission reduction sensitivity coefficient, the demands for online direct sales channels and offline retailers will decrease, and profits of manufacturers and offline retailers will decrease.

4.3 Impact of Unit Carbon Emission Tax on Pricing Strategy



(1) Decentralized decision



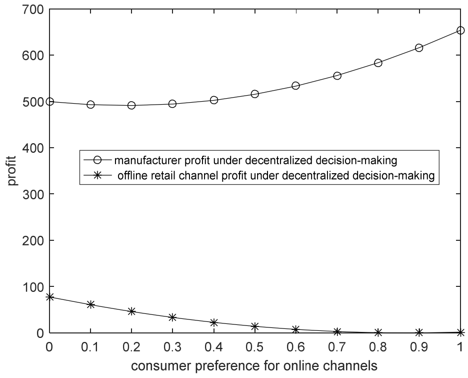
(2) Centralized decision

Figure 3. Impact of unit carbon emission tax on pricing strategy.

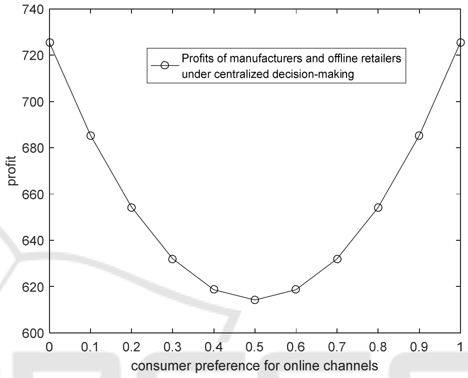
As can be seen from Figure 3, the wholesale prices of manufacturers, the retail prices will increase with the increase of unit carbon emission tax prices. This shows that the collection of carbon tax makes manufacturers raise wholesale prices and retailers raise retail prices to reduce the cost of carbon tax policy.

4.4 Profit Comparison Analysis

It can be seen from Figure 4 that the profits of manufacturers and offline retailers under centralized decision-making are greater than those of decentralized decision-making. When making centralized decisions, it can narrow the profits gap between manufacturers and offline retailers.



(1) Decentralized decision



(2) Centralized decision

Figure 4. Profit comparison between decentralized decision and centralized decision.

5 CONCLUSIONS

The main conclusions of our paper are as follows: (1) The profits and carbon emission reduction level under centralized decision making are higher than those under decentralized decision making. (2) When the consumer carbon emission reduction sensitivity coefficient is higher, the profit of the whole supply chain will be higher. (3) Supply chain members' profits are positively correlated with the tax price of unit carbon emissions and unit carbon emission of the product; they are negatively correlated with consumer carbon emission reduction sensitivity coefficient.

Manufacturers should increase the cost of carbon emission reduction and reduce the unit carbon emissions of products. The government can encourage manufacturers to invest in carbon emission reduction through carbon tax discounts and other ways.

Future research can explore the pricing strategies from the perspective of government subsidies. The asymmetric carbon information also should be considered in the future. The pricing decisions and channel selection problems for these complex channel structures also can be further studied.

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