Optimization decision of cooperative emission reduction of clothing supply chain based on carbon tax

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Abstract. Clothing products will cause environmental pollution while promoting economic development. The government collects carbon tax on clothing products to restrict the carbon emission of enterprises. In order to protect the environment and reduce the carbon tax penalty, Stackelberg model is established to compare the optimal decision-making and profit under the centralized decision-making and decentralized decision-making. It is found that no matter whether it is centralized decision or decentralized decision making, the retail price of clothing, carbon emission reduction and clothing demand increase with the increase of carbon tax, while the profit of supply chain system shows a downward trend. We can also get manufacturers and retailers can get higher supply chain system profits under centralized decision-making, and can meet the needs of environment, market and enterprises at the same time.

1. Introduction

The problem of climate warming caused by carbon dioxide emissions is a hidden danger of human long-term living environment. In order to reduce carbon emissions, many countries have adopted policies. Carbon tax is widely used as a fast, convenient and effective emission reduction measure, while the clothing industry, as the main enterprise producing carbon emissions, is under more pressure of carbon emissions. Therefore, in order to reduce carbon tax constraints, the collaborative emission reduction of clothing supply chain is a problem worthy of study.

On the basis of establishing the equilibrium model, Cai D L et al. investigated the possible impact on the environment caused by the government's carbon tax policy, subsidy policy, carbon tax and subsidy policy, and sought the best way to solve the environmental pollution [1]. According to the trend of carbon pricing, Hanna et al. used the emission sources that are not emphasized by carbon tax to balance the carbon emission constraints, reduce the pressure of carbon tax on enterprises, and improve the enthusiasm of enterprises to reduce emissions [2]. Wei S D et al. established a supply chain composed of two manufacturers with different emission reduction efficiency. Considering the three-stage decision-making game model composed of the government and the manufacturers under the carbon trading, the paper analyzed the results of the manufacturers' choice of competition or cooperation in emission reduction [3]. Shi C D and others established a closed-loop supply chain consist of manufacturers, retailers and recyclers, and used the game model to explore the optimal profits of each member of the low-carbon supply chain under the non cooperative game [4]. Li Hui et al. built a closed-loop supply chain which include manufacturers, retailers and consumers. Considering the impact of consumer demand on carbon emission reduction and on the enthusiasm of carbon emission reduction, based on three cooperation structures and one non cooperation structure, the
decision-making and performance of the supply chain system were studied [5]. The sustainability of clothing is the main concern of the industry. Based on understanding the development background, motivation and obstacles of clothing supply chain, Laura et al. studied the strategic methods of clothing supply chain management [6]. Under the background of emerging technology development, Zheng Fei and others integrated the concept of online and offline common development into the development and upgrading of clothing supply chain, and provided ideas for the improvement of clothing enterprise supply chain by using intelligent technology and strategic alliance ideas [7]. Lu Z N et al. established a closed-loop supply chain made up of manufacturers and retailers, reprocessed and utilized recycled products to reduce environmental pollution, and compared product prices under decentralized and centralized decision-making [8]. In order to reduce the carbon tax pressure of textile enterprises, Wang X F and others constructed a three-level supply chain composed of manufacturing enterprises, brand makers and recyclers, and explored the optimization of price, profit and emission reduction under the game model [9].

Through literature review, we find that the research on different subsidy policies of carbon tax, cooperative game model under closed-loop supply chain, sustainable development of clothing supply chain and supply chain research under intelligent technology have achieved certain results. However, there are few literatures on collaborative emission reduction of clothing supply chain under the constraint of carbon tax.

2. Model description and symbol explanation

2.1. Model description
Taking apparel supply chain as the research object, this paper considers enterprises how to reduce the carbon emissions of clothing in the manufacturing process when facing the carbon tax pressure. As shown in Figure 1, under the consideration of carbon tax constraints and enterprise cooperation, the supply chain formed by clothing manufacturers, clothing retailers and customers is constructed. The manufacturers occupy the dominant position, and the retailers change comprehensively according to factors such as the manufacturer's wholesale price. In the case of considering carbon tax, this paper compares the optimal decision and profit of retailers and manufacturers under centralized or decentralized decision-making, and mainly solves the following problems:

(1) Establish models under decentralized and centralized decision-making, and select the optimal decision.
(2) Reduce the carbon emission of clothing in the manufacturing process.
(3) The impact of carbon tax policy on enterprise emission reduction.

2.2. Symbol explanation
The cost for the manufacturer to produce a single garment is \( c \). After the price is increased, the garment is supplied to the retailer at the price \( w \) in batches, and then the retailer sells the garment to the customer at the price \( p \). Suppose that the demand for clothing in the whole consumer market is \( q \), \( q = d - ap + bd \), \( d \) is the maximum demand in the potential market, \( a \) is the sensitivity coefficient of customers to clothing price, \( b \) is the sensitivity coefficient of customers to clothing carbon emission
reduction in manufacturing, and \( \theta \) is the carbon emission reduction. \( e \) is used to represent the carbon emissions generated during the garment manufacturing process. This paper will collect carbon tax according to the final carbon emission and charge \( \lambda \) yuan per unit of carbon emissions. The main body of social responsibility clothing manufacturers must bear the responsibility of carbon emission reduction, the manufacturer's cost of emission reduction is \( \ell(\theta) = \frac{\theta^2}{2} \). Because of the high pressure of emission reduction cost, manufacturers seek cooperation from retailers to share the carbon tax cost, and set the proportion of retailers to bear carbon tax as \( w \).

3. Construction and solution of cooperative emission reduction model

3.1. cooperative emission reduction model of manufacturers and retailers under decentralized decision
Under the constraint of carbon tax, carbon tax is charged according to the final carbon emissions. In order to relieve the pressure, garment manufacturers seek the help of garment retailers. Suppose retailers share the manufacturer's carbon tax in proportion to \( m \). At this point, you can get:

\[
\pi_r = (p - w)q - m\lambda(e - \theta) \\
\pi_a = (w - c)q - (1 - m)\lambda(e - \theta) - \ell(\theta)
\]

Under the constraint of carbon tax, retailers share the pressure of carbon tax borne by manufacturers under decentralized decision-making. The second-order partial derivative \( \frac{\partial^2 \pi_r}{\partial(p^2)} = -2a < 0 \) of retailer's profit function is obtained by the reverse induction method, so there is only one optimal pricing decision for clothing retailers. Let \( \frac{\partial \pi_r}{\partial p} = 0 \), the optimal function expression of clothing retail price after retailers and manufacturers reach a cooperation is

\[
p(w, \theta) = \frac{d + b\theta + aw}{2a}
\]

Then, the function formula of \( p \) is substituted into (2), and the partial derivatives of the function with respect to wholesale price \( w \) and carbon emission reduction \( \theta \) are obtained as follows:

\[
\frac{\partial^2 \pi_a}{\partial w^2} = -a, \quad \frac{\partial^2 \pi_a}{\partial w\partial \theta} = \frac{b}{2}, \quad \frac{\partial^2 \pi_a}{\partial \theta^2} = \frac{b}{2}, \quad \frac{\partial^2 \pi_a}{\partial \theta} = -1, \quad \text{so we can get the Hess matrix determinant of manufacturer's profit as} \quad |\partial| = a - b^2 \frac{4}{4a - b^2}
\]

But \( \frac{\partial^2 \pi_a}{\partial w^2} = -a < 0 \), so if \( 4a - b^2 > 0 \), Hess matrix is negative definite, then the manufacturer has only one optimal wholesale price \( w \) and carbon emission reduction \( \theta \), as follows:

\[
w = \frac{2\lambda b(1 - m) + 2(d - ac)}{4a - b^2} + c \\
\theta = \frac{b(d - ac) + 4\lambda a(1 - m)}{4a - b^2}
\]

After substituting \( w \) and \( \theta \), the retail price, product demand, retailer profit and supplier profit are obtained as follows:

\[
p = \frac{3(d - ac) + 3\lambda b(1 - m) + c}{4a - b^2} \\
q = \frac{\lambda b[(d - ac) + \lambda b(1 - m)]}{4a - b^2} \\
\pi_r = \frac{\lambda(b(d - ac) + 2am + 2a - b^2)}{4a - b^2} + \lambda b(1 + m) (d - ac) + 2\lambda b(1 + m) (d - ac) + \lambda b(1 - 5m)(1 - m) - \lambda e \omega \\
\pi_a = \frac{(d - ac)^2 + 4\lambda^2 a (m - 1)^2 + 2\lambda b(d - ac)(1 - m) - \lambda e (1 - m)}{2(4a - b^2)}
\]
3.2. cooperative emission reduction model of manufacturers and retailers under centralized decision

Under the constraint of centralized decision-making carbon tax, clothing retailers and manufacturers try their best to maximize the overall benefits, and then we can get the function of the overall profits of the supply chain.

\[ \pi_{sc} = (p - c)q - f'(\theta) - \lambda(e - \theta) \]  \hspace{1cm} (9)

The first and second order partial derivatives of \( p^* \) and \( \theta^* \) in equation (9) are obtained respectively, and then we can get the determinant \( \left| f' \right| = 2a - b^2 \) of Hess matrix. Because \( \frac{\partial^2 \pi_{sc}}{\partial p^2} = -2a < 0 \), when \( 2a - b^2 > 0 \), Hess matrix is negative qualitative, the supply chain system has unique optimal retail price \( p^* \) and carbon emission reduction \( \theta^* \).

\[ p^* = \frac{d + ac + \lambda h - b^2 c}{2a - b^2} \]
\[ \theta = \frac{b(d - ac) + 2\lambda a}{2a - b^2} \]
\[ q^* = \frac{a(d - ac + \lambda b)}{2a - b^2} \]
\[ \pi_{sc} = \frac{(ac - d)^2 + 2\lambda (a + bd - abc)}{2(2a - b^2)} - \lambda e \]  \hspace{1cm} (13)

4. Numerical analysis

According to the conditions obtained in the process of building the model: \( 2a - b^2 > 0 \) and \( 0 < m < 1 - \frac{b^2}{4a} \), select the value of \( a \), \( b \), \( m \), and set other parameters as: \( c = 40 \), \( e = 500 \), \( d = 500 \), \( a = 0.4 \), \( b = 0.5 \), \( m = 0.5 \). Through numerical analysis, the optimal decision, supply chain member profit and system profit of decentralized decision and centralized decision under carbon tax are compared.

4.1. The influence of carbon tax constraints on decentralized decision making

According to the value of carbon tax \( \lambda \), parameter values under decentralized decision-making can be obtained as shown in Table 1:

| Carbon tax | 2   | 4   | 6   | 8   | 10  |
|------------|-----|-----|-----|-----|-----|
| Wholesale price | 757.78 | 758.52 | 759.26 | 760.00 | 760.74 |
| Retail price | 1116.70 | 1117.80 | 1118.90 | 1120.00 | 1121.10 |
| Carbon emission reduction | 180.44 | 181.63 | 182.81 | 184.00 | 185.19 |
| Demand quantity | 143.56 | 143.70 | 143.85 | 144.00 | 144.15 |
| Retailer profit | 51201 | 50990 | 50782 | 50576 | 50373 |
| Manufacturer's profit | 86441 | 86122 | 85805 | 85488 | 85173 |
| Supply chain system profit | 137642 | 137112 | 136587 | 136064 | 135546 |

It can be seen from Table 1 that in order to ensure profits, the wholesale and retail prices of clothing increase with the increase of carbon tax. Driven by the pressure of carbon tax, manufacturers will increase their enthusiasm for carbon emission reduction, increase carbon emission reduction, reduce carbon emissions of clothing, and clothing demand is also increasing due to consumers'
low-carbon sensitivity. The cost of emission reduction and carbon tax increases with the increase of carbon tax, which leads to the decrease of profits of manufacturers and retailers, and the decrease of profits of supply chain system.

4.2. The influence of carbon tax constraints on centralized decision making
According to the value of carbon tax \( \lambda \), the parameter values under centralized decision-making can be obtained as shown in Table 2:

| Carbon tax | 2    | 4    | 6    | 8    | 10   |
|------------|------|------|------|------|------|
| Retail price | 921.82 | 923.64 | 925.45 | 927.27 | 929.09 |
| Carbon emission reduction | 442.91 | 445.82 | 448.73 | 451.64 | 454.55 |
| Demand quantity | 352.73 | 353.45 | 354.18 | 354.91 | 355.64 |
| Supply chain system profit | 212840 | 212730 | 212630 | 212530 | 212430 |

Compared with Table 1, it can be found that with the increase of carbon tax, the parameters of the two models basically have the same trend: with the increase of carbon tax, the retail price, carbon emission reduction and demand increase, while the profits of the supply chain system decrease. According to Table 1 and Table 2, Figure 2 can be obtained as follows.
According to the comparison of the pictures in Figure 2, we can find that whether centralized or decentralized decision-making, clothing price, carbon emission reduction and demand are increasing with carbon tax, while supply chain system profit is declining. At the same time, we find that the carbon emission reduction under the centralized decision-making is far greater than that under the decentralized decision-making, but the retail price is lower, which can not only satisfy consumers' low-carbon preferences, but also purchase products at a cheaper price. The demand of consumers is also far higher than that under the decentralized decision-making, and manufacturers and retailers can get higher supply chain system profits under the centralized decision-making.

5. Conclusion
In this paper, Stackelberg model is established to compare the optimal decision and profit under centralized and decentralized decision-making, and to study the decision-making optimization of manufacturers and retailers' cooperative emission reduction under the constraint of carbon tax. Through numerical analysis, it can be found that under the constraint of carbon tax, whether centralized decision-making or decentralized decision-making, in order to ensure profits, the retail price of clothing will increase with the increase of carbon tax, manufacturers will improve the enthusiasm of carbon emission reduction, the demand for clothing will also rise under the influence of low carbon sensitivity of consumers, while the profit of supply chain system will decline. We can also get the carbon emission reduction under the centralized decision-making is far greater than the decentralized decision-making, but the retail price is lower, which can not only satisfy consumers' low-carbon preferences, but also purchase products at a cheaper price. The demand of consumers is far higher than the decentralized decision-making, and manufacturers and retailers can get higher supply chain system profits under the centralized decision-making. Therefore, the centralized supply chain of clothing manufacturers and retailers is the best choice, which can better protect the environment, meet the needs of customers and maximize the interests of enterprises.

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