



Carbon Emission Reduction and Pricing Decisions of Dual-Channel Closed-Loop Supply Chain with Fairness Concern Under Carbon Tax Policy

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Abstract: Considering a dual channel closed-loop supply chain composed of a manufacturer and a retailer, and the retailer establishes online direct channels, four Stackelberg game models are constructed to study the impact of carbon tax and different fairness concerns of supply chain members on the optimal strategies, such as carbon emission reduction level, recycling and pricing decisions etc. The results show that the fairness concerns of supply chain members does not affect the recycling decision of manufacturer, but increasing carbon tax will promote the manufacturer to recycle more used products to reduce carbon emissions through remanufacturing. When the retailer has fairness concern but the manufacturer ignores it, with the increase of the retailers' fairness concern, the online selling price, the retail price and the retailers' utility increase while the manufacturers' profit decreases. When the manufacturer considers retailers' fairness concern, there will be more carbon emissions in the supply chain. Manufacturer should pay attention to this fairness concern and take certain measures to prevent this behavior. Compared with fairness neutrality, whether one or both of supply chain members have fairness concerns, it will inhibit manufacturers' enthusiasm for carbon reduction investment. When both of them have fairness concerns, the higher the manufacturers' fairness concern, the lower the carbon emission reduction level is.

Keywords: Carbon Tax, Dual Channel Closed Loop Supply Chain, Fairness Concern, Carbon Reduction Investment

1. Introduction

Global climate change has posed a serious threat to human survival and development. One of the effective solutions to this problem is to curb carbon emissions. Many countries have enforced carbon tax mechanism to reduce carbon emissions. Under the carbon tax policy, more and more manufacturers have taken actions to reduce carbon emissions as much as they can. Carbon reduction technology investment and remanufacturing operations have proven to be eco-efficient, low-carbon- producing ways to save energy and reduce carbon emissions effectively [1]. For example, Gree Group has invested a lot of money in the research and development of carbon emission reduction technologies, especially focusing on the design and innovation of energy-saving products. Some giant companies, like Hewlett-Packard Corporation (HP), IBM,

Kodak, and Xerox, already engage in recycling and remanufacturing [2]. At the same time, with the rapid development of network technology and e-commerce, many major retailers have begun to introduce online channels, such as Suning, Gome, Ginza, etc, who sale their products not only from traditional channels but also from online channels to increase market share and gain more profit [3]. In this context, the dual-channel closed-loop supply chain (CLSC) is introduced. While dual-channel supply chain brings opportunities, it also raises many supply chain operation and management issues. In addition, more and more studies have found that participants in the supply chain may have fairness concerns, which will inevitably affect the benefits distribution of the supply chain members. Therefore, it is of practical significance to explore how fairness concerns of supply chain members affect the operational decisions of dual channel closed

loop supply chain under environmental protection regulations.

The literature review focuses on three main areas: low-carbon closed-loop supply chain, low-carbon dual-channel closed-loop supply chain, and the operation and coordination of supply chain with fairness concerns. In terms of low-carbon closed-loop supply chain decision-making, Liu et al. (2015) [4] presented three optimization models to investigate how the cap and trade, mandatory carbon emissions capacity and carbon tax policy affect remanufacturing decision-making. Shu et al. (2018) [5] investigated the optimal decisions of CLSC in context of social responsibility, and they discussed the impacts of carbon emission constraints and CSR strength on recycling and remanufacturing decisions. Considering different capital conditions, Wang and Chen (2017) [6] proposed three mathematical profit-maximizing models to determine the manufacturing/remanufacturing decisions under a carbon trading policy. Also researches of carbon emission reduction, recycling and remanufacturing decision-making in the closed-loop supply chain under low carbon policy have been studied [7-9]. The above studies considered carbon emission factors and mainly focused on the single channel of CLSC. However, with the development of internet and information technology, more and more enterprises are beginning to sell products from dual channels, which inevitably change the operational strategies of closed loop supply chain.

Many scholars have studied the carbon reduction and manufacturing decisions of dual channel CLSC under low carbon environment. Wang et al. (2020) [10] studied the optimal decision-making and coordination of dual-channel supply chains considering the low-carbon efforts of manufacturers. He et al. (2016) [11] evaluated the impact of consumer free-riding behavior on carbon emissions of dual-channel closed-loop supply chain and assessed the effect of governmental e-commerce tax on carbon emissions. Wang and Li (2018) [12] studied the impact of carbon emission limits on the optimal decision-making of the closed loop supply chain with dual channel sales and dual channel recycling. Considering a dual-channel closed-loop supply chain in which manufacturers sales products from online sales channels, Chen et al. (2021) [13] compared and analyzed the optimal decision-making of the supply chain before and after the implementation of the carbon trading policy. However these studies considered the supply members are fairness neutrality.

In reality, supply chain members often show strong fairness concern when determining operational decisions such as optimal pricing and carbon emission reduction levels. Li et al. (2018) [14] examined the impact of retailers' fairness concerns on the price and carbon emission reduction decisions of closed loop supply chain which is consisted of a fairness-neutral manufacturer and a fairness-concerned retailer. Jian et al. (2020) [15] examined the contract coordination between manufacturers with peer-induced and distributional fairness concerns. Cao et al. (2019) [16] studied the impact of fairness concerns on the optimal pricing decision of closed-loop supply chain. Wang et al. (2021) [17] examined the impact of government subsidy, corporate social

responsibility coefficient, and fairness concerns coefficient on decision-making of the supply chain by constructing three closed-loop supply chain (CLSC) models. Shi et al. (2016) [18] studied the impact of manufacturers' fairness concerns on optimal decisions such as carbon emission reduction and pricing in closed-loop supply chain by establishing a game model. Zhou and Liu (2017) [19] studied the impact of retailers' fairness concerns on the optimal decision-making of supply chain members in a dual channel closed-loop supply chain in which the manufacturer sales products from online channels and the retailer is responsible for recycling.

These literatures have made important contributions to the application and expansion of fairness concern theory. For example, fairness concerns have been involved in low-carbon supply chains, closed-loop supply chains, and dual-channel closed-loop supply chains, but few literatures introduces fairness concern theory into dual channel closed-loop supply chain under carbon tax policy. In addition, with the introduction of the national "14th Five-Year Plan for Carbon Emission Reduction" in China, carbon emission reduction has become an indispensable part of the production and operation of supply chain enterprises. Especially in the dual-channel closed-loop supply chain, supply chain members are faced with a complex supply chain structure and an uncertain market environment. The fairness concerns of the supply chain members have become more and more impactful on carbon emission reduction, pricing, recycling decisions and revenue in the dual-channel closed-loop supply chain.

In view of this, this paper establishes four decision-making models based on a dual channel closed loop supply chain consisting of a manufacturer and a retailer under the carbon tax policy. The aim is to study the effect of different fairness concerns of supply chain members and carbon tax on carbon emission reduction, recycling and pricing decisions in the dual channel CLSC. The results can effectively provide theoretical support for the carbon emission reduction and recycling decisions of dual channel closed loop supply chain.

The rest of the paper is organized as follows. Section 2 introduces the problem and basic assumptions. Section 3 develops and analyzes four profit-maximization models. Sections 4 provide numerical examples. Finally, Section 5 summarizes the key findings and presents future research directions.

2. Problem Statement and Assumptions

2.1. Problem Statement

We consider a dual-channel closed-loop supply chain consisting of a single manufacturer and a single retailer, as shown in Figure 1. In the forward supply chain, manufacturer wholesales products to the retailer, and retailer sells products to consumers through traditional retail channel and online sales channel. In a reverse supply chain, the manufacturer recycles used products directly from consumers and remanufactures them. Suppose the unit carbon emission of new products is e_0 , and the unit carbon emission saving rate of remanufactured products is λ , then the unit carbon emission

of remanufactured products is $(1 - \lambda)e_0$. In order to encourage enterprises to reduce carbon emission, the government levies carbon tax. Facing consumers' preference for low-carbon products and the pressure of government's carbon tax, the manufacturer voluntarily invests in carbon reduction technologies for low-carbon operations. Considering different fairness concerns of supply chain

members, four dual-channel models are established, that is, both the manufacturer and retailer are fairness neutrality (Model N); the retailer has fairness concern, and the manufacturer considers retailer's fairness concern (Model R); the retailer has fairness concern, but the manufacturer is not aware of it (model NR); both the manufacturer and the retailer have fairness concerns (model MR).

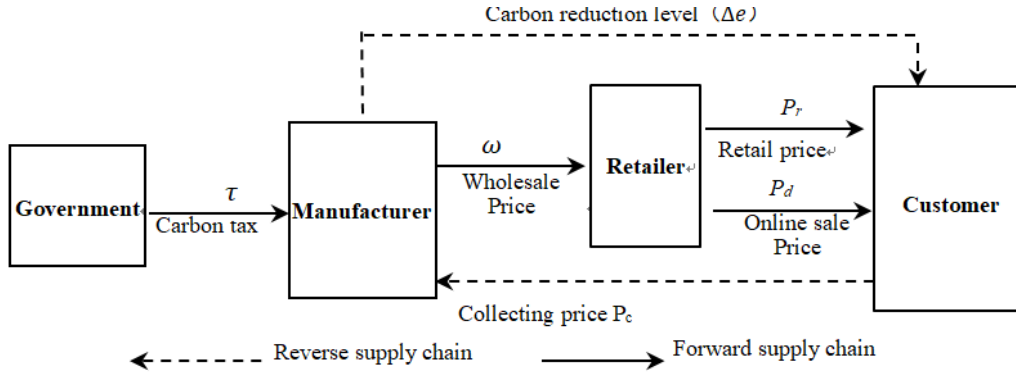


Figure 1. Basic frame of the model.

In order to formulate the problems, the following notations are used to define the sets:

Table 1. Variables and notations.

Parameters	Description
α	Size of the potential market.
c_m/c_r ($c_m > c_r$)	Unit cost to produce a new/remanufactured product.
ω	Unit wholesale price
ψ	Cost saving of remanufactured products ($\psi = c_m - c_r$)
k	the low-carbon preference coefficient of consumers
P_r/P_d	Sale price from traditional retail channel/online channel
P_c	Recycling price of used products
Q_r/Q_d	Demand for products from traditional retail channel/online sales channel
τ	Carbon tax
Δe	Carbon emission reduction level per unit product
λ	Carbon emission saving rate per unit of remanufactured product
U_m/U_r	The utility of manufacturer/retailer
$\Pi_{sc}/\Pi_m/\Pi_r$	Profit of supply chain/manufacturer/retailer

2.2. Assumptions

For the convenience of research, the following assumptions are made:

Assumption 1: There is no qualitative difference between new products and remanufactured products. All recycled products can be used for remanufacturing, that is, one unit of used products can produce one unit of remanufactured products [12, 19].

Assumption 2: The demand quantity is a function of prices and carbon emission reduction level. Then the demand functions of the two channels are as follows [20, 21]: $Q_r = \xi\alpha - P_r + \beta P_d + k\Delta e$, $Q_d = (1 - \xi)\alpha - P_d + \beta P_r + k\Delta e$, α represents the potential market share, ξ is the market demand proportion of traditional retail channel, and $1 - \xi$ is the market demand proportion of online channel. k represents

the low-carbon preference of consumers.

Assumption 3: The carbon reduction cost function is convex and increases at the carbon emission reduction level Δe , that is, $c(\Delta e) = \frac{1}{2}\gamma\Delta e^2$, γ is the carbon emission reduction investment coefficient, the larger the γ , the higher the difficulty of emission reduction [22, 23].

Assumption 4: In the reverse supply chain, the recycling quantities of used products [24]: $R(P_c) = g + \delta P_c$, g is the amount of voluntary recycling by consumers when the recycling price is zero. δ is the price-sensitive coefficient of used products, in order to make the manufacturer profitable, $\psi > P_c + c_r$.

Assumption 5: In order to encourage manufacturer to invest in carbon emission reduction and ensure that the relevant expressions in the text are economically meaningful, set $k > (1 - \beta)\tau$, $\alpha - 2(1 - \beta)(c_m + \tau e_0) > 0$.

3. Models and Analysis

3.1. Optimal Decisions of Dual Channel CLSC with Fairness Neutrality (Model N)

In this model, both manufacturer and retailer are fair neutrality, and the decision-making process is a Stackelberg game model in which the manufacturer is the leader. In the first stage, the manufacturer decides the wholesale price, carbon emission reduction level and recycling price. In the second stage, the retailer decides the offline retail price and online sales price according to the manufacturer's decision. There is no profit comparison between manufacturer and retailer, and they make decisions with the goal of maximizing their own profit. The profit functions of the manufacturer and the retailer are:

$$\Pi_m(\omega, \Delta e, P_c) = (\omega - c_m)(Q_r + Q_d) + (\psi - P_c)(g + \delta P_c) - \tau((e_0 - \Delta e)(Q_r + Q_d) - \lambda e_0(g + \delta P_c)) - \frac{1}{2}\gamma\Delta e^2 \quad (1)$$

$$\Pi_r(P_r, P_d) = (P_d - \omega)Q_d + (P_r - \omega)Q_r \quad (2)$$

On the basis of the Karush–Kuhn–Tucker (KKT) conditions, we can obtain the equilibrium decisions as presented in the following proposition.

Proposition 1. When the manufacturer and the retailer are fair

neutrality, under the condition $2(1 - \beta)\gamma > (\kappa + (1 - \beta)\tau)^2$, that is $\gamma > \frac{(\kappa + (1 - \beta)\tau)^2}{2(1 - \beta)}$, the carbon reduction, recycling and pricing decisions of manufacturer and retailer are as follows:

$$\omega^{N*} = \frac{\alpha(\gamma - A\tau) + 2((1 - \beta)\gamma - A\kappa)(c_m + \tau e_0)}{2(2(1 - \beta)\gamma - A^2)}$$

$$p_c^{N*} = \frac{\delta(\psi + \lambda\tau e_0) - g}{2\delta}$$

$$\Delta e^{N*} = \frac{A(\alpha - 2(1 - \beta)(c_m + \tau e_0))}{2(2(1 - \beta)\gamma - A^2)}$$

$$p_r^{N*} = \frac{1}{4(1 + \beta)(2(1 - \beta)\gamma - A^2)} (\alpha(B1 + A(\kappa(1 - 2\xi) - \tau - 3\beta\tau - 2(1 - \beta)\xi\tau)) + 2(1 + \beta)((1 - \beta)\gamma - 2\kappa A)(c_m + \tau e_0))$$

$$p_d^{N*} = \frac{1}{4(1 + \beta)(2(1 - \beta)\gamma - A^2)} (\alpha(B2 - A(\kappa(1 - 2\xi) + (3 + \beta + 2(\beta - 1)\xi)\tau)) + 2(1 + \beta)((1 - \beta)\gamma - 2\kappa A)(c_m + \tau e_0))$$

Here $A = \kappa + \tau - \beta\tau$, $B1 = \gamma(1 + 5\beta + 4(1 - \beta)\xi)(1 + 2\phi)$, $B2 = \gamma(5 + \beta - 4(1 - \beta)\xi)(1 + 2\phi)$.

Then, the demand for retail channel and online sales channel can be obtained as follows:

$$Q_r^{N*} = \frac{\alpha(1 - \beta)\gamma(4\xi - 1) + \alpha(1 - 2\xi)A^2 - 2(1 - \beta)^2\gamma(c_m + \tau e_0)}{4(2(1 - \beta)\gamma - A^2)}$$

$$Q_d^{N*} = \frac{\alpha((\beta - 1)\gamma(4\xi - 3) - (1 - 2\xi)A^2) - 2(1 - \beta)^2\gamma(c_m + \tau e_0)}{4(2(1 - \beta)\gamma - A^2)},$$

By substituting ω^{N*} , p_c^{N*} , p_r^{N*} , Δe^{N*} , p_d^{N*} , Q_r^{N*} and Q_d^{N*} into Eqs. (1) and (2), profits of retailer and manufacturer can be obtained.

Corollary 1. $\frac{\partial p_c^{N*}}{\partial \lambda} > 0$, $\frac{\partial p_c^{N*}}{\partial \tau} > 0$, it indicates that with the increase of carbon saving per unit remanufactured product, the recycling price of used products increases, which will lead to an increase in the recycling quantity of used products. Similarly, with the increase of carbon tax, the recycling price and quantity of used products increases. This means that the carbon tax can encourage manufacturer to reduce carbon emission by recycling more used products.

Corollary 2. when $\xi > \frac{1}{2}$, $Q_r^{N*} > Q_d^{N*}$, $p_r^{N*} > p_d^{N*}$; when $\xi < \frac{1}{2}$, $Q_r^{N*} < Q_d^{N*}$, $p_r^{N*} < p_d^{N*}$; when $\xi = \frac{1}{2}$, $Q_r^{N*} = Q_d^{N*}$, $p_r^{N*} = p_d^{N*}$. This indicates that when the potential demand of retail channels and online sales channel account for the same proportion of the market, the sale prices of the two channels are also the same; otherwise, the corresponding sale price of the channel with a larger market demand has a relatively higher price.

3.2. The Optimal Decisions of Dual Channel CLSC with Retailer's Fairness Concern

Considering that manufacturer who is the leader tends to make more profits than the retailer, the retailer may have

fairness concern, so it will not only care about its own profit, but also care about the profit gap with the manufacturer. Therefore, this section studies the optimal decision-making problem of dual-channel CLSC in which the manufacturer is fair-neutral and the retailer has fairness concern.

3.2.1. The Analysis of Model R

In model R, we consider the retailer has fairness concern and manufacturer has felt the existence of retailers' fairness concern. At this point, the retailer makes decisions with the goal of maximizing utility, while the manufacturer makes decision with the goal of maximizing profit. Referring to [19, 25], the retailer's utility function is:

$$\mu_r(\Pi_r) = \Pi_r(P_r, P_d) - \phi(\Pi_m(\omega, \Delta e, P_c) - \Pi_r(P_r, P_d)) \quad (3)$$

Here, ϕ ($0 \leq \phi \leq 1$) is the fairness concern coefficient of retailer, the larger the ϕ , the higher the retailer's attention to the fairness of system profit distribution.

Combining Eqs. (1), (2) and (3), the following proposition can be obtained by using the backward induction methods.

Proposition 2. When the manufacturer considers retailer's fairness concern, under the condition $(\kappa + \tau - \beta\tau)^2 - \frac{2(1 - \beta)\gamma(1 + 2\phi)}{1 + \phi} < 0$, the optimal decisions of manufacturer and retailer are as follows:

$$\omega^{R*} = \frac{\alpha(\gamma - A\tau)(1 + \phi) - 2(\kappa A(1 + \phi) - (1 - \beta)\gamma(1 + 3\phi))(c_m + \tau e_0)}{2(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}$$

$$\omega^{R*} = \frac{\alpha(\gamma - A\tau) + 2((1 - \beta)\gamma - A\kappa)(c_m + \tau e_0)}{2(2(1 - \beta)\gamma - A^2)}$$

$$\Delta e^{R^*} = \frac{(\kappa + \tau - \beta\tau)(1 + \phi)(\alpha - 2(1 - \beta)(c_m + \tau e_0))}{2(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}$$

$$p_c^{R^*} = -\frac{g - \delta\psi - \delta\lambda\tau e_0}{2\delta}$$

$$p_r^{R^*} = \frac{1}{4(1 + \beta)(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}(\alpha(A * B3 - B1) - 2(1 + \beta)(2\kappa A(1 + \phi) - (1 - \beta)\gamma(1 + 2\phi))(c_m + \tau e_0))$$

$$p_d^{R^*} = \frac{1}{4(1 + \beta)(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}(\alpha(A * B4 + B2) - 2(1 + \beta)(2\kappa A(1 + \phi) - (1 - \beta)\gamma(1 + 2\phi))(c_m + \tau e_0))$$

Here, $A = \kappa + (1 - \beta)\tau$, $B1 = \gamma(1 + 5\beta + 4(1 - \beta)\xi)(1 + 2\phi)$, $B2 = \gamma(5 + \beta - 4(1 - \beta)\xi)(1 + 2\phi)$, $B3 = (\kappa(1 - 2\xi) - (1 + 3\beta + 2(1 - \beta)\xi)\tau)(1 + \phi)$, $B4 = (\kappa(2\xi - 1) - (3 + \beta - 2(1 - \beta)\xi)\tau)(1 + \phi)$.

Similarly, the demand for retail channel and online sales channel can be obtained as follows:

$$Q_r^{R^*} = \frac{1}{4(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}(\alpha((1 - 2\xi)A^2(1 + \phi) - (1 - \beta)\gamma(1 - 4\xi)(1 + 2\phi)) - 2(1 - \beta)^2\gamma(1 + 2\phi)(c_m + \tau e_0))$$

$$Q_d^{R^*} = \frac{1}{4(2(1 - \beta)\gamma(1 + 2\phi) - A^2(1 + \phi))}(\alpha((2\xi - 1)A^2(1 + \phi) + (1 - \beta)\gamma(3 - 4\xi)(1 + 2\phi)) - 2(1 - \beta)^2\gamma(1 + 2\phi)(c_m + \tau e_0))$$

By substituting ω^{R^*} , $p_c^{R^*}$, $p_r^{R^*}$, Δe^{R^*} , $p_d^{R^*}$, $Q_r^{R^*}$ and $Q_d^{R^*}$ into Eqs. (2) and (3), the manufacturer's profit and retailer's utility can be obtained.

Corollary 3. $\frac{\partial \Delta e^{R^*}}{\partial \phi} < 0$, $\frac{\partial \omega^{R^*}}{\partial \phi} < 0$, $\frac{\partial p_r^{R^*}}{\partial \phi} < 0$, $\frac{\partial p_d^{R^*}}{\partial \phi} < 0$, it is obviously that the carbon emission reduction level, wholesale price, offline retail price and online sales price are inversely related to retailer's fairness concern, but the recycling price is not affected by the retailer's fair concern.

Corollary 3 shows that when the manufacturer pays attention to the retailer's fairness concern, with the enhancement of the retailer's fairness concern, the manufacturer has to wholesale products to the retailer at a lower wholesale price. Therefore, the retailer can use this fairness preference as a negotiating weight to improve its bargaining power with the manufacturer. Correspondingly, the retailer sells more products by lowering retail and online channel prices, so as to obtain more profit.

Corollary 4. When the manufacturer pays attention to the retailer's fairness concern, it has the same effect as Corollary 2.

$$p_d^{NR^*} = \frac{\alpha(A * B4 + C1) + 2(1 + \beta)((1 - \beta)\gamma - 2\kappa A(1 + \phi))(c_m + \tau e_0)}{4(1 + \beta)(2(1 - \beta)\gamma - (\kappa + \tau - \beta\tau)^2)(1 + \phi)}$$

$$p_r^{NR^*} = \frac{\alpha(A * B3 + C2) + 2(1 + \beta)((1 - \beta)\gamma - 2\kappa A(1 + \phi))(c_m + \tau e_0)}{4(1 + \beta)(2(1 - \beta)\gamma - A^2)(1 + \phi)}$$

Here, $C1 = \gamma(5 + \beta - 4\xi + 4\beta\xi + 2(3 + \beta - 2(1 - \beta)\xi)\phi)$, $C2 = \gamma(1 + 2\phi + 4\xi(1 + \phi) + \beta(5 + 6\phi - 4\xi(1 + \phi)))$, $B3 = (\kappa(1 - 2\xi) - (1 + 3\beta + 2(1 - \beta)\xi)\tau)(1 + \phi)$, $B4 = (\kappa(2\xi - 1) - (3 + \beta - 2(1 - \beta)\xi)\tau)(1 + \phi)$.

Similarly, the demand quantities for retail channel and online sales channel can be obtained as follows:

$$Q_d^{NR^*} = \frac{1}{4(2(1 - \beta)\gamma - A^2)(1 + \phi)}((2\xi - 1)A^2(1 + \phi) + \alpha(1 - \beta)\gamma(3 + 2\phi - 4\xi(1 + \phi)) - 2(1 - \beta)^2\alpha\gamma(c_m + \tau e_0))$$

$$Q_r^{NR^*} = \frac{1}{4(2(1 - \beta)\gamma - A^2)(1 + \phi)}(\alpha((1 - 2\xi)A^2(1 + \phi) - (1 - \beta)\gamma(1 + 2\phi - 4\xi(1 + \phi))) + 2(1 - \beta)^2\gamma(c_m + \tau e_0))$$

By substituting ω^{NR^*} , $p_c^{NR^*}$, $p_r^{NR^*}$, Δe^{NR^*} , $p_d^{NR^*}$, $Q_r^{NR^*}$, $Q_d^{NR^*}$ into Eqs.(1), (2) and (3), the manufacturer's profit and retailer's utility can be obtained.

Corollary 5. When the manufacturer doesn't pay attention to the retailer's fairness concern, it also has the same effect as Corollary 2.

3.2.2. The Analysis of Model NR

In this case, the retailer has fairness concern behavior, but the manufacturer does not perceive it, and the manufacturer believes that the retailer does not have fairness concern. In the decision-making process, manufacturers make decisions on wholesale prices, carbon reduction level and recycling prices based on the fact that retailer has no fairness concerns, while retailers make pricing decisions with the goal of maximizing fair utility. Then, the optimal decision of the manufacturer is the same as the model N, namely: $\omega^{NR^*} = \omega^{N^*}$, $p_c^{NR^*} = p_c^{N^*}$, $\Delta e^{NR^*} = \Delta e^{N^*}$.

On the basis of the manufacturer's decision, the retailer further makes decisions on the retail price and online price with the goal of maximizing utility.

Substituting ω^{N^*} , $p_c^{NR^*}$, Δe^{NR^*} into Eqs.(1) and (2), the profits of the manufacturer and retailer can be obtained. Then combining Eqs (1), (2) and (3), the retailer's optimal decisions can be obtained according to the KKT conditions.

Corollary 6. $\frac{\partial p_r^{NR^*}}{\partial \phi} = \frac{\partial p_d^{NR^*}}{\partial \phi} > 0$. The retail price and online sales price increase with the increase of retailer's fairness concern. It shows that the retailer tries to increase retail prices and online selling prices to obtain more profit. At this time, the retailer's utility increases, but the manufacturer's profit decreases. In this case, the manufacturer's wholesale price and

carbon emission reduction level are not affected by the retailer's fairness concern.

Corollary 7. Comparing the retail price, online selling price, wholesale price and carbon emission reduction level in model R, model N and model NR, it is obviously, $p_d^{NR^*} > p_d^{N^*} > p_d^{R^*}$, $\omega^{N^*} = \omega^{NR^*} > \omega^{R^*}$, $\Delta e^{N^*} = \Delta e^{NR^*} > \Delta e^{R^*}$.

It can be seen that, compared with fair neutrality, when manufacturers pay attention to retailers' fairness concern, retailers' fair concerns will lead to lower wholesale price, and

manufacturers' enthusiasm for carbon emission reduction is low.

3.3. Optimal Decisions of Dual-Channel CLSC When Both Manufacturer and Retailer Have Fairness Concerns

In this model, both manufacturer and retailer make decisions with the goal of maximizing utility. The manufacturer's fair utility function:

$$\mu_m(\Pi_m) = \Pi_m(\omega, \Delta e, P_c) - t(\Pi_r(P_r, P_d) - \Pi_m(\omega, \Delta e, P_c)) \quad (4)$$

Similarly, t is manufacturer's fairness concern degree. The larger the t is, the more the manufacturer pays attention to the fairness of system profit distribution.

Combining Eqs. (1) - (4), the following propositions can be obtained by using the reverse solution method.

Proposition 3: When both of manufacturer and retailer have fairness concerns, under the condition $(\kappa + \tau - \beta\tau)^2 - \frac{2(1-\beta)\gamma(1+2\phi)}{1+\phi} < 0$, the optimal decisions of manufacturer and retailer are as follows:

$$\omega^{MR^*} = \frac{1}{2\Delta_1} (\alpha((1+t)(1+2t)\gamma(1+\phi)^2 - \tau A(1+t+\phi)^2) - 2(\kappa A(1+t+\phi)^2 - \Delta_0)(c_m + \tau e_0))$$

$$\Delta e^{MR^*} = \frac{(\kappa + \tau - \beta\tau)(1+t+\phi)^2(\alpha - 2(1-\beta)(c_m + \tau e_0))}{2\Delta_1}$$

$$p_r^{MR^*} = \frac{1}{4(1+\beta)\Delta_1} (\alpha((\kappa + \tau - \beta\tau)(\kappa(1-2\xi) - \tau - 3\beta\tau - 2(1-\beta)\xi\tau)(1+t+\phi)^2 + \Delta_2) - 2(1+\beta)(1+t+\phi)(c_m + \tau e_0)\Delta_3)$$

$$p_d^{MR^*} = \frac{1}{4(1+\beta)\Delta_1} (\alpha(A(\kappa(1-2\xi) + (3+\beta-2(1-\beta)\xi)\tau)(1+t+\phi)^2) - \Delta_4) - 2(1+\beta)(1+t+\phi)(c_m + \tau e_0)\Delta_3$$

Then, the demand quantities for retail channel and online sales channel can be obtained as follows:

$$Q_d^{MR^*} = \frac{1}{4\Delta_1} (\alpha((2\xi-1)A^2(1+t+\phi)^2 - \Delta_5) - 2(1+t)(1-\beta)^2\gamma(1+t+\phi)(1+2\phi)(c_m + \tau e_0))$$

$$Q_r^{MR^*} = \frac{1}{4\Delta_1} (\alpha((1-2\xi)A^2(1+t+\phi)^2 + \Delta_6)) + 2(1+t)(1-\beta)^2\gamma(1+t+\phi)(1+2\phi)(c_m + \tau e_0))$$

Here $\Delta_0 = (1+t)(1-\beta)\gamma(t+2t\phi(2+\phi) + (1+\phi)(1+3\phi))$, $\Delta_1 = (1+t)(1-\beta)\gamma(1+2\phi)(2+3t+2(1+t)\phi) - (\kappa + \tau - \beta\tau)^2(1+t+\phi)^2$, $\Delta_2 = (1+t)\gamma(1+2\phi)((1+5\beta+4(1-\beta)\xi)(1+\phi) + t(2(1+3\xi+\phi+2\xi\phi) + \beta(8-6\xi+6\phi-4\xi\phi)))$, $\Delta_3 = (2\kappa(\kappa + \tau - \beta\tau)(1+t+\phi) - (1+t)(1-\beta)\gamma(1+2\phi))$, $\Delta_4 = (1+t)\gamma(1+2\phi)((5+\beta-4(1-\beta)\xi)(1+\phi) + 2t(4+\beta-3\xi(1-\beta) + (3+\beta-2(1-\beta)\xi)\phi))$, $\Delta_5 = (1+t)(1-\beta)\gamma(1+2\phi)((4\xi-3)(1+\phi) - 2t(2+\phi) + t\xi(6+4\phi))$, $\Delta_6 = (1+t)(1-\beta)\gamma(1+2\phi)((4\xi-1)(1+\phi) - 2t(1+\phi) + t\xi(6+4\phi))$.

$$\text{Corollary 8. } \frac{\partial \Delta e^{MR^*}}{\partial \phi} < 0, \frac{\partial \Delta e^{MR^*}}{\partial t} < 0, \frac{\partial \Delta e^{MR^*}}{\partial \gamma} < 0, \frac{\partial Q^{MR^*}}{\partial \gamma} < 0, \frac{\partial Q^{MR^*}}{\partial \gamma} < 0.$$

It shows that when both manufacturer and retailer have fairness concerns, the carbon emission reduction level is inversely related to their fairness concerns. At the same time, with increase of the carbon emission reduction coefficient, carbon emission reduction level and demand quantities under the two sales channels decrease.

Considering that the model MR involves the fairness concern coefficient of retailer and manufacturer, the optimal decision will be affected by multiple parameters. In the next section, numerical examples are used to explore the influence of retailer and manufacturer's fairness concerns on the

optimal decisions and seek their change rule.

4. Numerical Examples

In this section, numerical examples are used to investigate comparatively the effects of carbon tax and different fairness concerns of the supply chain members on the optimal decisions in the proposed models. According to the problem description and analysis above, the parameters are as follows:

$$\alpha = 100, \gamma = 20, \xi = 0.5, \psi = 5, k = 3, \beta = 0.4, g = 20, \delta = 3, \lambda = 0.3, \tau = 1.2, c_m = 8, c_r = 3$$

4.1. Effect of Retailer's Fairness Concern on the Optimal Decisions of Dual Channel CLSC

To study the impact of retailer's fairness concern on

wholesale prices, carbon emission reduction levels, retail prices, online sales prices, profits and utility of supply chain members. The retailer's fairness concern coefficient ϕ varies from 0.1 to 0.9, indicating that the fairness concern degree varies from weak to strong. Under the model MR, the manufacturer's

fairness concern ($t=0.6$) is considered for analysis.

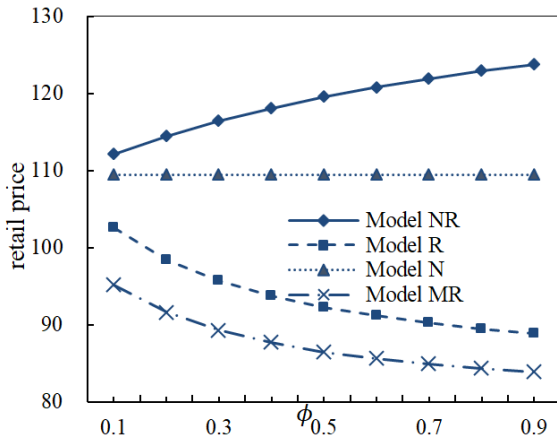


Figure 2. The effect of ϕ on retail price.

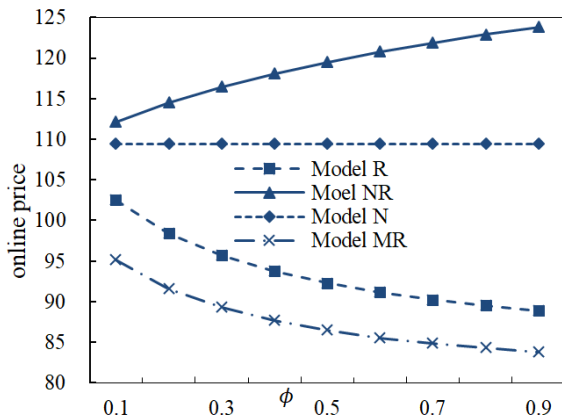


Figure 3. The effect of ϕ on online selling price.

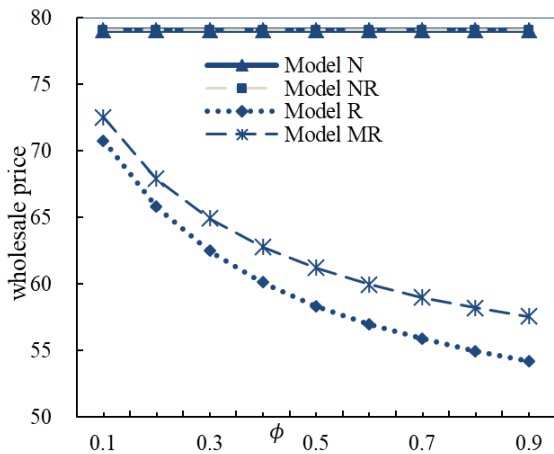


Figure 4. The effect of ϕ on wholesale price.

It can be seen from Figures 2 and 3 that in Model NR, the retail price and online sales price increase with the increase of the retailer's fairness concern (consistent with Corollary 6). Under model R and model MR, that is, when the manufacturer considers retailer's fairness concern, regardless of whether the manufacturer has the fairness concern behavior or not, the retail price, online selling price are inversely related with the

retailer's fairness concern degree. It shows that when the manufacturer considers the retailer's fairness concern, the retailer will reduce the retail price and increase the demand quantities to narrow the profit gap with the manufacturer. For retail price and online selling price, when the manufacturer does not consider the retailer's fairness concern, the online selling price is the highest, and when the manufacturer has a high fairness concern, the online selling price is the lowest.

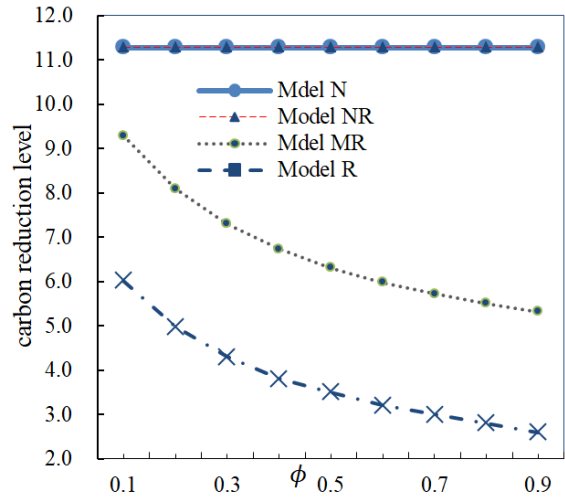


Figure 5. The effect of ϕ on carbon reduction level.

It can be seen from Figure 4 and Figure 5 that in model R and model MR, wholesale prices and carbon emission reduction level have an inverse relationship with the retailer's fairness concern. The higher the retailer's fairness concern, the lower the wholesale price and carbon emission reduction level. In Model MR, with the enhancement of the manufacturer's fairness concern, the wholesale price and the level of carbon emission reduction decrease. This is because the manufacturer reduces carbon emissions by investing in carbon reduction technologies, and carbon reduction investments will inevitably increase its costs, so it passes part of the costs on to the retailer by raising wholesale prices to obtain fair utility. If only the retailer has a unilateral fairness concern, it will use the lower wholesale price as a bargaining chip, so as to reduce the profit gap with the manufacturer by reducing the selling price and increasing the demand quantities to obtain greater utility. Compared with fairness neutrality, the supply chain members' fairness concerns will inhibit the enthusiasm of the manufacturer to invest in carbon reduction technology.

Figures 6-7 illustrate the impact of a retailer's fairness concern on its utility and manufacturer's profit. As can be seen from Figure 6, in the model NR, the retailer's fairness utility increases with the increase of its fairness concern; in model R, that is, when the manufacturer considers the retailer's fairness concern, the retailer's utility will first decrease and then increase, indicating that when the retailer makes decisions with the goal of maximizing utility, the retailer aggressively pursues fairness concerns. When the fairness concern is low, the profit gap with the manufacturer increases. When the fairness concern is high, the profit gap decreases. When the

manufacturer also has fairness concerns, the retailer's utility will decrease and the higher the manufacturer's fairness concern, the lower the retailer's utility. This shows that if the manufacturer ignores the retailer's fairness concern, the retailer will pursue fairness concern more aggressively and find ways to increase its own profit and narrow the profit gap between them. The higher the level of fairness concern for the manufacturer, the more unfavorable it is for the retailer.

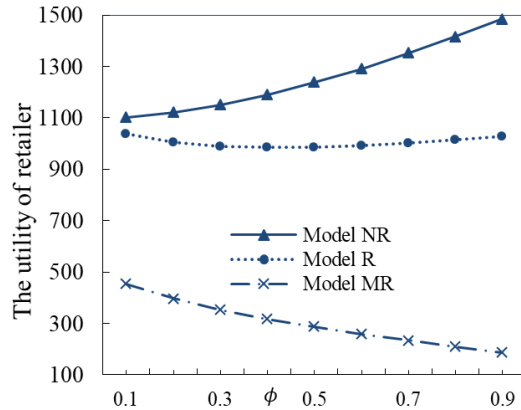


Figure 6. The effect of ϕ on utility of retailer.

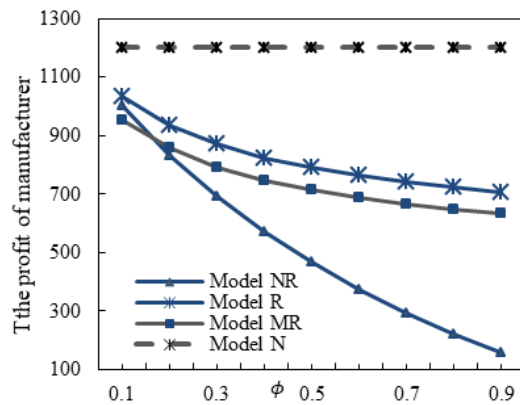


Figure 7. The effect of ϕ on the profit of manufacturer.

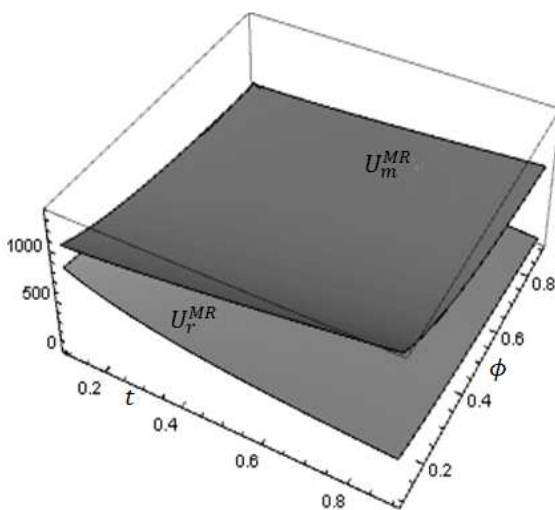


Figure 8. The effect of ϕ and t on the utility of manufacturer and retailer.

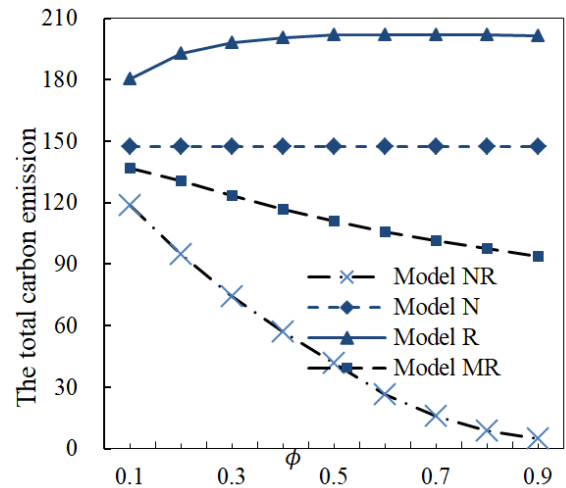


Figure 9. The effect of ϕ on the total carbon emission.

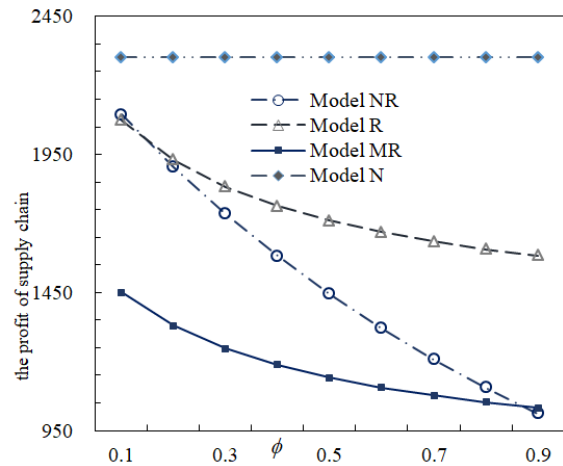


Figure 10. The effect of ϕ on the profit of supply chain.

As can be seen from Figure 9, with the increase of retailer's fairness concern, the total carbon emissions of the supply chain increase in Model R, while that in models MR and NR decrease. We also can see that the total carbon emissions are the greatest when manufacturers consider retailer's fairness concern. From the previous analysis, it is known that the retailer's fairness concern inhibit the enthusiasm of manufacturer to invest in carbon reduction technology. In Model NR, the total carbon emission of supply chain is the smallest, because the retailer increases retail and online selling prices to obtain more utility. The increase of selling prices will inevitably lead to a decrease in demand. However the manufacturer is unaware of the existence of such fairness concern, carbon reduction investment is still very high, so the carbon emission is the smallest in this case.

It can be seen from Figure 10 that the total profit of the supply chain is the largest in model N. In Model NR, when the manufacturer does not consider the retailer's fairness concern, the total profit of the supply chain drops rapidly with the increase retailer's fairness concern. When the retailer's fairness concern is high, the manufacturer should pay attention to this phenomenon and take necessary measures to actively respond to

retailer's fairness concern. When both of them are fairness concerns, the higher the fairness concern, the lower the total supply chain profit. From an economic point, the fairness concern behavior of supply chain members will have a negative impact on the system profit.

4.2. Effect of Carbon Tax on Optimal Decisions of Dual Channel CLSC

In this subsection, we analyze the effects of carbon tax on the equilibrium decisions of supply chain members. Here we consider that $\phi = t = 0.5$ is fixed. According to the previous analysis, τ Value range $[0.5, 2.5]$ to ensure the economic significance.

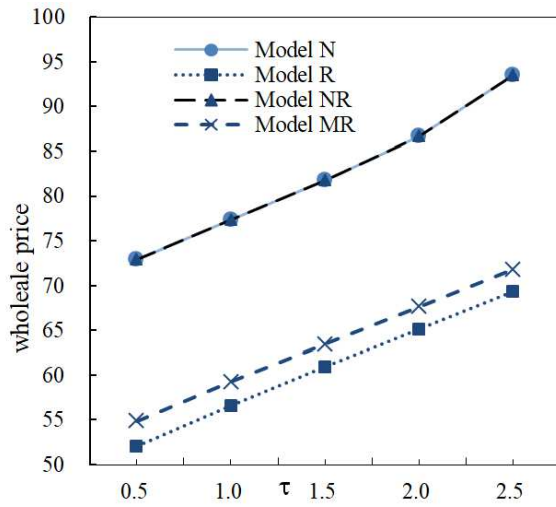


Figure 11. The effect of τ on the profit of supply chain.

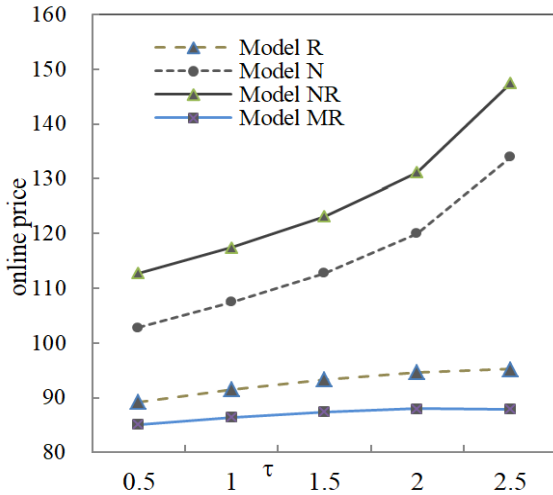


Figure 12. The effect of τ on the online selling price.

From figures 11-14, we can see that wholesale price, retail price, online selling price and carbon reduction level increase with the increase of carbon tax. This is because with the increase of carbon tax, the manufacturer has to increase carbon reduction investment to reduce carbon emissions. The carbon reduction investment will inevitably increase manufacturers' costs, which will make manufacturer enhance

wholesale prices, and then the retailer has to raise retail and online selling prices to gain more profit. Comparing these models, it is found that in the model MR, the carbon emission reduction level and wholesale price are the lowest, so the retail price and online selling price are the lowest. In models NR and N, the wholesale price, the retail price and online selling price are the highest. In the model MR, the retail price, online selling prices and the carbon reduction level are the lowest, also the wholesale price is higher in model MR than that in model NR. This shows that when the manufacturer has fairness concern, the manufacturer reduces the carbon reduction level and increases the wholesale price to obtain more profits.

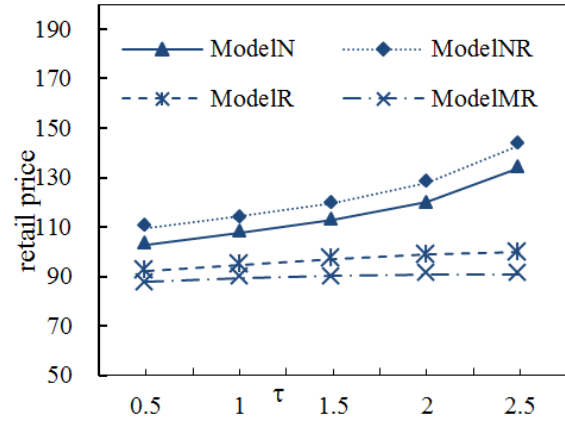


Figure 13. The effect of τ on the retail price.

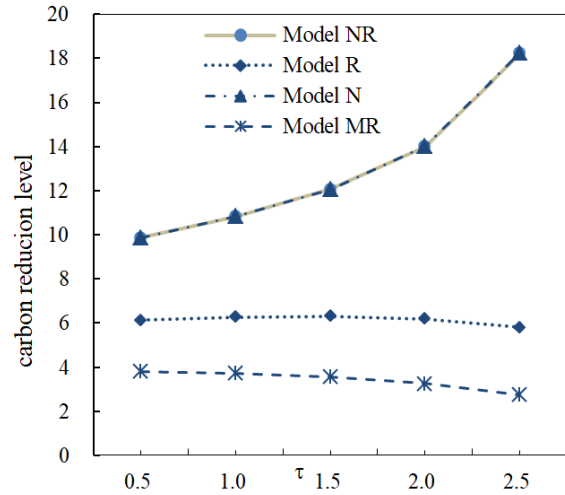


Figure 14. The effect of τ on carbon reduction level.

As shown in Figure 15, with the increase of carbon tax, the total carbon emission in the supply chain decreases in all of these cases, the total carbon emission in model NR is the smallest, and it is the largest in model R. Combining with Figures 15-18, it can be seen that under Model R, the total carbon emission is the largest, but the profit of the manufacturer and the utility of the retailer are not the largest. Under model NR, although the total carbon emission is the smallest, the profit of the manufacturer is also the smallest, and the utility of the retailer is the largest. This means that it

is extremely disadvantageous to the manufacturer if it does not consider the retailer's fairness concern. Therefore, if the retailer has fairness concern, the manufacturer should pay attention to such fairness concern and take certain measures to prevent such behaviors.

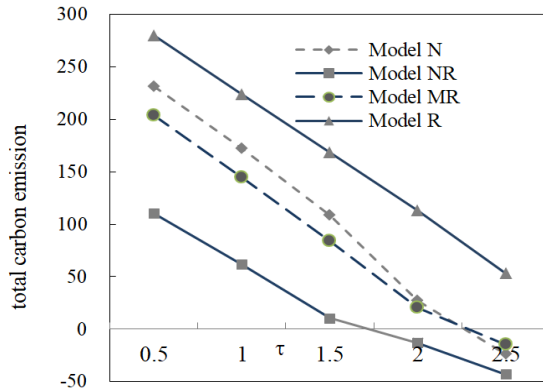


Figure 15. The effect of τ on carbon reduction level.

From Figure 16, as the carbon tax increases, the manufacturer's profit decreases in all four cases. Combining Figures 11, 14 and 16, it can be known that in models NR and N, there are the same wholesale price and emission reduction level, but manufacturer's profit in model NR is much smaller than that in model N. This is because if the manufacturer does not consider the retailer's fairness concern, the retailer increases retail and online selling price to obtain greater fair utility, the increasing selling price results in a decrease in demand, which has an extremely negative impact on the manufacturer's profits.

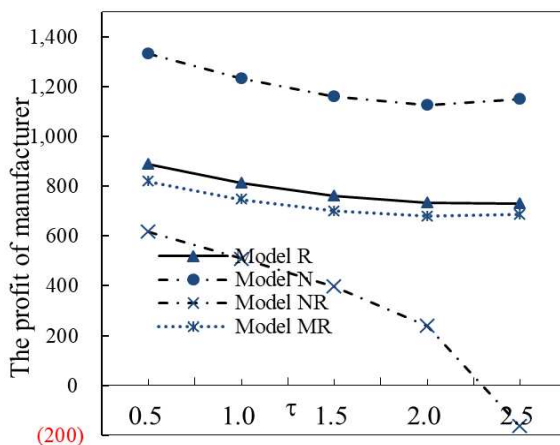


Figure 16. The effect of τ on the profit of manufacturer.

From Figures 17–18, we can conclude that the retailer's utility increases with the increase of carbon tax in model NR, and it is greater than that in model MR. When both the manufacturer and retailer have fairness concerns, with the increase of carbon tax, manufacturer's utility increases, while retailer's utility decreases, and the profit gap is becoming larger and larger. This is because when the manufacturer has fairness concern, with the carbon tax increases, the manufacturer will reduce carbon reduction level, and

strengthen the squeeze on retailer by raising wholesale price to ensure its own profit, which will ultimately reduce the utility of the retailer.

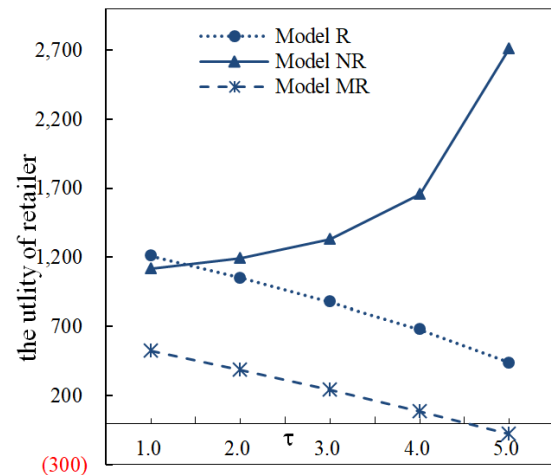


Figure 17. The effect of τ utility of retailer.

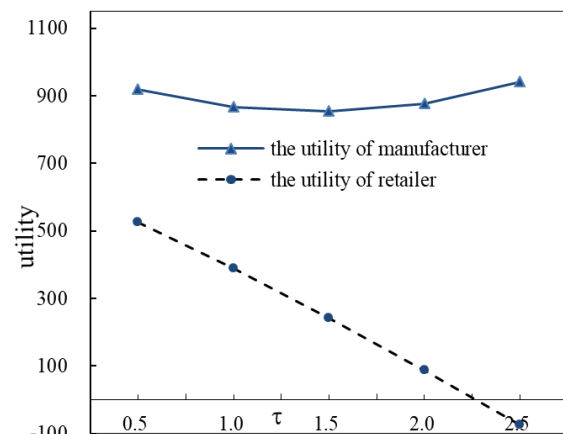


Figure 18. The effect of τ on the utility of manufacturer and retailer in model MR.

5. Conclusion

Aiming at a dual channel closed-loop supply chain, four game models are established to study the influence of carbon tax and the different fairness concerns of supply chain members on carbon reduction, price and recycling decisions of dual-channel closed-loop supply chain. In this dual channel closed loop supply chain, the retailer sales products from two channels (offline and online channels), and the manufacturer is responsible for collecting used products from customers for remanufacturing. By comparing and analyzing the equilibrium results of the four models, the following conclusions are drawn:

- (1) Manufacturer's recycling decision is not affected by the fairness concerns of supply chain members, but raising carbon tax can promote manufacturer to recycle more used products and reduce carbon emissions through remanufacturing.
- (2) If the retailer has fairness concern behavior, the

manufacturer should not ignore it, but should take active measures to deal with this behavior, so as to achieve win-win results for both of them and maximize the profit of the supply chain system.

- (3) Compared with the fair neutrality case, no matter who has fairness concern or regardless of the degree of fairness concern, it will inhibit the enthusiasm of manufacturer to invest in carbon reduction technology. When both of them have fairness concerns, the higher the manufacturer's fairness concern, the lower carbon emission reduction level is. At the same time, the fairness concerns of supply chain members will reduce the profit of the supply chain system.
- (4) In case of both manufacturer and retailer have fairness concerns, as the retailer's fairness concern increases, the utility of both the manufacturer and the retailer decreases; as the degree of manufacturer's fairness concern increases, the utility of the retailer decreases, while the utility of the manufacturer increases, which indicates that the manufacturer as a leader has an advantage and obtains greater utility.

This study only focuses on the dual channel closed-loop supply chain in which retailer sales products from two channels. In the future work, we can study what about the impacts of the fairness concerns of supply chain members on the carbon emission reduction and recycling decisions with dual channel supply chain in which the manufacturer establishes online direct channels and the retailer is responsible for recycling.

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