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Decisions for a Retailer-Led Low-Carbon Supply Chain Considering Altruistic Preference under Carbon Quota Policy

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Abstract: With the release of the national energy-saving emission reduction policy and the improvement of consumers' awareness of environmental protection, the demand for low-carbon products is growing rapidly. In a retailer-led low-carbon supply chain, the increased cost of carbon emission reduction puts manufacturers at a disadvantage. Under the carbon quota policy, to improve manufacturers' profits as well as enhance carbon emission reduction, this paper studies the players' decisions in a low-carbon supply chain consisting of one dominant retailer and one manufacturer. To maintain the supply chain's stability and sustainability, the dominant retailer tends to employ altruistic preference policies towards the manufacturer. The optimal decision, carbon emission reduction and supply chain profit are compared and analyzed under three decision models: (i) centralized decision, (ii) decentralized decision without altruistic preference and (iii) decentralized decision with altruistic preference. The results indicate that the carbon emission reduction rate, market demand and profit in the centralized model are higher than in the decentralized model. The retailer's altruistic preference is beneficial to the improvement of carbon emission reduction, market demand and the profit of the manufacturer and the supply chain. Under certain conditions, carbon trading can effectively reduce the cost pressure of manufacturers and improve the level of carbon emission reduction and the overall profit of the supply chain. These results will guide low-carbon supply chain decision-making and provide insight into the research of irrational behaviors in supply chain decision-making under carbon policies.

Keywords: low-carbon supply chain; retailer-led; altruistic preference; carbon quota policy

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1. Introduction

Extreme weather, such as high temperatures, droughts, rainstorms, and hurricanes, has grown increasingly regular in recent years, seriously threatening human survival and health and posing a challenge to all humanity. Many governments have enacted environmental policies to combat climate change, including carbon taxes and cap-and-trade. Particularly, carbon cap-and-trade can save more energy and reduce emissions by encouraging businesses to invest more resources in low-carbon supply chains for carbon emission reduction. For example, the European Union's emissions trading scheme [1] and China's cap-and-trade scheme [2] are both effective solutions. Moreover, as public awareness of environmental protection grows, consumers are increasingly willing to pay more for low-carbon and energy-saving products [3]. For example, from 2011 to 2015, the compound growth rate of the consumers who were willing to pay a higher price for green products on the Alibaba platform exceeded 80%, and the number of green consumers on the JingDong e-commerce platform climbed by 62% year-on-year in 2017 [4]. Numerous businesses have included environmental protection and sustainable development in their strategic decisions [5–7] in response to the growing demand for low-carbon products on the market. For instance, based on the "circular economy theory", Huawei implements an environmental strategy to continuously improve the use efficiency of resources and energy. Haier establishes the strategic goals of producing green products with an emphasis on energy-efficient product design, innovation, manufacturing, management, and recycling. However, the research and development, introduction, and implementation of low-carbon technologies commonly demand substantial financial support for manufacturing firms [8], which undoubtedly increases the production costs of enterprises. This situation is not conducive to the stability and long-term development of enterprises and their supply chain, especially in the retailer-dominated supply chain. For example, Wal-Mart and Jingdong are the leading enterprises in their respective supply chains, and most of their suppliers are small and medium-sized manufacturing enterprises in vulnerable positions. Under the green economy, in order to maintain the cooperative relationship with manufacturers, increase the sales volume of products, and stabilize their positions, the leading retailers must pay attention to the profit loss suffered by upstream manufacturing enterprises in order to achieve carbon emission reduction, and to some extent, adopt the behavior of "profit concession" to improve the profits of manufacturers. For example, Walmart supports suppliers in Central America, raises their bank loan limits, and provides farmers with technical training on sustainable agricultural practices, improving suppliers' profitability and product quality [9]. Jingdong has built large-scale new energy fleets in many cities and plans to gradually replace its partners' vehicles with new energy ones through incentive measures such as subsidies [10]. This type of attention and profit-giving behavior is known as altruistic preference. "Altruistic preference" is different from "fairness concern". Fairness concern behavior refers to the irrational egoistic decision-making taken by decision-makers to protect their rights and interests [11]. In contrast, the dominant enterprise in the supply chain prioritizes its interests while considering the benefits of other participants in the system. This irrational decision-making behavior increases the enthusiasm of other enterprises to cooperate by selling part of the profits of the dominant enterprise to maintain the supply chain's stability. In the supply chain operation mode, when enterprises take social responsibility as a part of corporate decision-making, most enterprises will consider altruistic preference to varied degrees to reflect their social value and enhance their competitiveness [12].

The government's carbon policy and consumers' low-carbon preference create external pressure, forcing manufacturers to transform production strategies, adopt technological innovations, or replace their equipment to control carbon emissions and reduce pollution [13]. As rational decision-makers, manufacturers would raise wholesale prices to offset the expense of reducing emissions, which would be detrimental to the interests of downstream retailers. However, manufacturers in a "weak" position are frequently exploited in a retailer-dominated supply chain. Thus, retailers, as supply chain leaders, should not only consider their profits but also pay attention to manufacturers' earnings, and create internal incentives for carbon emission reduction, to maintain the sustainable development of the supply chain. Therefore, it is of great significance to study retailer-led supply chain decisions considering altruistic preferences in the context of the carbon cap-and-trade policy. Currently, no relevant studies have integrated carbon quota policy and retailers' altruistic preferences into the supply chain decision-making process.

Recently, extensive research efforts have been devoted to the effects of the carbon cap-and-trade policy and altruistic preference behaviors on the low-carbon supply chain. However, most of the existing studies only consider the carbon cap-and-trade policy [14–18] or altruistic preference behaviors [11,19–22] on low-carbon supply chain decision-making. To the best of our knowledge, only a few papers have simultaneously studied the impact of the carbon cap-and-trade policy and the altruistic preference [23], which only discussed manufacturer-led supply chain decision-making. However, both carbon quota policy and retailers' altruistic preferences have not been studied yet in the retailer-led supply chain context. Facing the increasingly strict environmental protection requirements, manufacturers may have to adopt technological innovations or replace their equipment to control carbon emissions and reduce pollution, which means high costs of equipment replacement and technology improvement for those manufacturers. Therefore, considering the carbon cap-and-trade policy and the altruistic preference of the retailer, this study discusses the decisions of a low-carbon supply chain formed by a retailer and a manufacturer who is assumed to have less market power than the retailer. This study addresses the following three questions: (1) What are the optimal decisions when the leading retailer considers the altruistic preference under the carbon quota policy? (2) What is the relationship between the altruistic preference coefficient and system performance under the carbon quota policy, including pricing, carbon emission rate level, and profitability? (3) How do carbon trading price, carbon emission reduction cost, and consumers' low-carbon preferences affect system performance? To answer these questions, we construct three models of centralized decision, decentralized decision without altruistic preference, and decentralized decision with altruistic preference. Then, we calculate the equilibrium solutions for each model and compare them. The purpose of this study is to provide a theoretical basis and decision support not only for a low-carbon product supply chain but also for a low-carbon service supply chain.

Our study draws the following conclusions: (1) carbon trading under the carbon quota policy helps mitigate the manufacturer's cost pressures and improve carbon emission reduction levels; (2) retailer's altruistic preference contributes to carbon emission reduction, the demand for low-carbon products, and the manufacturer's profit and system profit, but decreases his interest; (3) factors such as carbon reduction cost, carbon trading price, and consumer's low-carbon preference affect the correlation between retailer's altruistic preference and price (including wholesale price and retail price).

This study contributes to the sustainability of low-carbon supply chains by helping members of retailer-led low-carbon supply chains better understand the impact of both carbon quota policies and altruistic preferences on their optimal decisions in the context of government-imposed carbon quota policies and retailers' altruistic preferences. This hitherto unexplored topic is expected to shed light on the study of irrational behavior in supply chain decision-making in the context of carbon policy.

The rest of the paper is organized as follows. Section 2 comprehensively reviews carbon quotas and altruistic preferences based on low-carbon supply chains. Section 3 describes the notation and assumptions of the model and analyzes different models. Section 4 presents a numerical analysis. The conclusion and research prospects are provided in Section 5.

2. Literature Review

The theory of the supply chain is well known, and numerous papers have reviewed it from various directions (such as [24,25]). Focus on carbon cap-and-trade policy and altruistic preference for low-carbon supply chain, the previous studies related to our research, can be classified into two categories. The first category is the impact of carbon quota policy on low-carbon supply chain management decisions. The second category is the impact of altruistic preferences on low-carbon supply chain management decisions.

2.1. The Impact of Carbon Quota Policy on Low-Carbon Supply Chain Decision-Making

In order to effectively reduce carbon emissions, many countries and regions have implemented a carbon tax and cap-and-trade policy. Compared with carbon tax control, the carbon cap-and-trade policy is more economical and realizable [26]. The carbon cap-and-trade policy has recently become a hot topic in academic research. Taking manufacturing enterprises as research objects, scholars have discussed the decision-making of production and carbon trading by using the classical newsvendor model [27], the economic order quantity model [28], and the duopoly model [2]. Some scholars studied the effect of consumers' low-carbon preference [18] and government low-carbon subsidy [19,20] on the optimal production and carbon emission reduction level. Although low-carbon production is the key factor to the sustainability of the economy and environment, it is not enough to achieve low-carbon goals only relying on manufacturing. The other players in the supply chain also needs to be considered [29,30]. Therefore, the different supply chains with different influencing factors are discussed under carbon cap and trade.

Du et al. [14] studied the impact of the carbon cap-and-trade system on the decisions and profits of emission-dependent supply chain players and the distributional equity of social welfare and also discussed the issue of supply chain coordination. For "make-to-order" supply chains, Xu et al. [31] studied the production- and emission-reduction decision-making of supply chain members and proposed optimal wholesale prices and cost-sharing contracts. Bai et al. [32] further investigated the optimal decision-making in the case of one manufacturer producing and selling two products under cap-and-trade regulation and designed a coordination contract based on revenue- and investment-sharing. Meanwhile, the rapid development of e-commerce has encouraged numerous companies to open online sales channels [33]. On this background, Ji et al. [15] investigated the effects of carbon cap-and-trade regulation on supply chain decision-making, profits, and social welfare, considering retailers with the dual-channel green supply chain. Xu et al. [34] studied the decision-making and coordination issues in the dual-channel supply chain where manufacturers added direct online sales under cap-and-trade control. Some scholars have also focused on the impact of the carbon cap-and-trade policy on the operation of supply chains with different power structures. Zhang et al. [16] studied the carbon reduction decisions of manufacturers and the changes of government's emission caps under three kinds of supply chain power structures. Jiang et al. [35] studied supply chain decisions simultaneously considering different supply chain power structures and flexible cap and trade. With the enhancement of consumers' environmental awareness, consumers' low carbon preference becomes an important factor influencing market demand. Mondal et al. [17] extended supply chain coordination, including both manufacturer and retailer environmental awareness, while using the revenue-sharing contract to coordinate the supply chain. To promote enterprises investing in green technology, the government usually provides subsidies to enterprises. Li et al. [18] studied and compared the effects of government subsidies on green technology investment and emission reduction amounts of supply chains under the carbon cap-and-trade mechanism. In business management, decision-makers' behavioral and cognitive factors cannot be ignored [36]. Therefore, in recent years, some scholars have introduced behavioral factors into the study of the supply chain under the carbon cap-and-trade policy. Considering the social preferences of supply chain members and consumers' low-carbon awareness, Xia et al. [37] explored the optimal decision and coordination of the supply chain. Meanwhile, Zou et al. [38] studied the impact of fairness on a sustainable low-carbon supply chain and analyzed the optimal decision of pricing and carbon emission reduction rate. Zhang et al. [23] studied the pricing and carbon emission reduction strategies of a supply chain wherein there is a retailer with corporate social responsibility and a manufacturer with altruistic preference.

2.2. The Influence of Altruistic Preference on Low-Carbon Supply Chain Decision-Making

Numerous psychological and behavioral economics studies have proven that policy-makers are not entirely rational in their self-interest but also consider the interests of other members [39,40]. In addition, the academic community has gradually acknowledged that it is insufficient to explain the behavior of enterprises from the perspective of external incentives. It is necessary to study behavior preference as the internal motivation of corporate decision-making [12]. Developing a low-carbon supply chain can help reduce total carbon emissions, excessive resource consumption, and environmental pollution [41]. In recent years, many scholars have been increasingly interested in studying the impact of altruistic preference on enterprises and society [42].

Considering consumers' low-carbon preferences, Fan et al. [11] incorporated retailers' altruistic behaviors into a low-carbon supply chain and explored the effects of retailers' altruistic preferences and consumers' low-carbon preferences on the optimal decision-making of a low-carbon supply chain. While Huang et al. [19] introduced consumers' green preferences and altruistic preferences into a cooperative supply chain with two cooperating manufacturers and one retailer, investigated the optimal greenness and pricing decision-making of a cooperative supply chain, and analyzed the impact of altruistic preference on the supply chain decision-making and profits. Considering carbon emission reduction and retailers' altruistic preferences, Wang et al. [20] studied the decision-making and coordination of a retailer-led low-carbon supply chain. In addition, Wan et al. [43] discussed the optimal pricing strategies and coordination contracts for providers of low-carbon tourism products and services and online travel agencies based on the altruistic preferences of decision-makers. Ma et al. [21] studied a low-carbon tourism online-to-offline (O_2O) supply chain and discussed the effects of big data empowerment, consumer preference effects, channel preferences, and corporate altruistic behaviors on optimal decision-making and performance. Wang et al. [44] and Liu et al. [45] studied altruistic preference behavior in the e-commerce supply chain including e-commerce platform. The government's low-carbon subsidy can increase enterprises' enthusiasm for low-carbon innovation [46]. Liu et al. [47] studied the impact of government subsidies and altruistic preferences on green supply chain innovation and analyzed enterprises' optimal decisions under different decision-making models. Xiao et al. [22] discussed the impact of altruistic preference and two types of government subsidies (eco-design subsidy and recycling subsidy) on the manufacturing–recycling system with eco-design. They explored rational altruism coefficients and subsidy strategies from the economy, environment, and social welfare perspectives.

In summary, considering altruistic preference in supply chain management decisions under the low carbon environment has become a hot topic in academic research. However, few studies have included carbon quota policy and altruistic preference in the decision-making process of low-carbon supply chains. No works have simultaneously considered the carbon quota policy and altruistic preference in a retailer-led low-carbon supply chain, and this study aims to fill this research gap. Fan et al. [11], Zhang et al. [16], Wang et al. [20], and Zhang et al. [23] are the most relevant papers to our study. Table 1 shows the differences between the existing research and our study.

Table 1. The differences between the existing literature and our study.

References	Cap-and-Trade	Retailer-Led	Low-Carbon Supply Chain	Altruistic Preference
[11]			✓	✓
[16]	✓	✓	✓	
[20]		✓	✓	✓
[23]	✓		✓	✓
This paper	✓	✓	✓	✓

3. Model and Analysis

We design a retailer-led low-carbon supply chain consisting of a manufacturer and a retailer, where the manufacturing process produces carbon emissions. At the beginning of each year, the government gives a free carbon quota to the manufacturer. If carbon emissions exceed the quota, the manufacturer must buy carbon credits from a carbon trading market, while if carbon emissions are lower than the quota, the manufacturer can sell the remaining carbon credits. To meet the low-carbon emission requirement and the growing low-carbon demand of consumers, the manufacturer has to accelerate the development of emission reduction technologies or update the equipment. This will increase the production costs of the manufacturer. In the low-carbon supply chain, the retailer buys the low-carbon products from the manufacturer at a wholesale price and sells them at a retail price.

According to the above low-carbon supply chain, three decision models, centralized, decentralized without altruistic preference, and decentralized with altruistic preference, are constructed to study the optimal pricing decision by considering the carbon quota policy. The main parameters and variables of the models are shown in Table 2.

Table 2. Main Parameters and Variables.

	Parameters
c	manufacturer's unit production cost
k	cost coefficient of carbon reduction investment
A	free carbon quotas provided by the government
e	unit initial carbon emissions of product
p_{ct}	unit carbon trading price
s	initial market demand for product
b	price sensitivity coefficient of consumer
λ	low-carbon preference coefficient of consumer
θ	altruistic preference coefficient of retailer
$(\ )_c^*$	centralized decision
$(\ )_d^*$	decentralized without altruistic preference decision
$(\ )_a^*$	decentralized with altruistic preference strategy
	Decision Variables
w	wholesale price of per unit product
p	sales price of per unit product
δ	per unit product profit of the retailer
β	carbon emission reduction rate per unit product
	Functions
q	market demand function of low-carbon product
π_r	the retailer's profit function
π_m	the manufacturer's profit function
π_s	profit function of the supply chain
U_r	the retailer's utility function

Among them, five functions are defined as follows:

(1) The market demand for low-carbon products is not only directly related to the retail or sales price of the products but also affected by consumers' low-carbon preference. Therefore, the market demand function (q) can be described by $q = s - bp + \lambda\beta$ $(b > 0, \lambda > 0)$ [48].

(2) The retailer's profit depends on the wholesale price, retail price, and market demand for the product and can be described by $\pi_r = (p - w)q$.

(3) The manufacturer's cost consists of three parts: production cost, carbon trading cost, and carbon emission reduction cost. Therefore, the manufacturer's profit can be described by $\pi_m = (w - c)q + [A - e(1 - \beta)q]p_{ct} - \frac{1}{2}k\beta^2$, $(0 < \beta < 1,\ k > 0)$, where $[A - e(1 - \beta)q]p_{ct}$ indicates carbon trading revenue, $\frac{1}{2}k\beta^2$ represents the cost of carbon emission reduction [49].

(4) The overall profit of the supply chain system is the sum of the retailer's profit and the manufacturer's profit, that is, $\pi_s = \pi_r + \pi_m$.

(5) In the retailer-led supply chain system, for the long-term development of the supply chain, retailers focus on their own benefits along with the benefits of the manufacture. Drawing on the literatures [20,50], the utility function under the retailer's altruistic preference is defined as $U_r = \pi_r - \theta(\pi_r - \pi_m)$, $(0 < \theta < 1)$.

3.1. Centralized Decision-Making Model

In the centralized decision-making model, the retailer and the manufacturer face the sales market together and make decisions on sales or retail price and carbon emission reduction rate to maximize the overall profit of the supply chain. The profit of the supply chain can be expressed as:

$$\pi_s = (p-c)(s-bp+\lambda\beta) + [A - e(1-\beta)(s-bp+\lambda\beta)]p_{ct} - \frac{1}{2}k\beta^2 \quad (1)$$

According to Equation (1), the Hesse matrix of $\pi_s\ (p,\beta)$ can be expressed as:

$$H_s(p,\beta) = \begin{bmatrix} -2b & \lambda - p_{ct}eb \\ \lambda - p_{ct}eb & 2p_{ct}e\lambda - k \end{bmatrix} \quad (2)$$

When $-2b < 0$ and $2bk - (\lambda + p_{ct}eb)^2 > 0$, $H_s(p,\beta)$ is a negative definite matrix and $\pi_s(p,\beta)$ has a maximum value. To ensure the practical significance of the model, we assume that the model satisfies $2bk - (\lambda + p_{ct}eb)^2 > 0$. Let $\frac{\partial \pi_s}{\partial p} = 0$ and $\frac{\partial \pi_s}{\partial \beta} = 0$, we can obtain the best decision in the centralized model:

$$p_c^* = \frac{k(s+bc+p_{ct}eb) - (\lambda + p_{ct}eb)(p_{ct}es + p_{ct}e\lambda + c\lambda)}{2bk - (\lambda + p_{ct}eb)^2} \quad (3)$$

$$\beta_c^* = \frac{(s-bc-p_{ct}eb)(\lambda + p_{ct}eb)}{2bk - (\lambda + p_{ct}eb)^2} \quad (4)$$

To ensure β_c^* is positive, it must be satisfied that $s - bc - p_{ct}eb > 0$. Then, the market demand and supply chain profit in a centralized decision model can be obtained:

$$q_c^* = s - bp_c^* + \lambda\beta_c^* = \frac{bk(s-bc-p_{ct}eb)}{2bk - (\lambda + p_{ct}eb)^2} \quad (5)$$

$$\begin{aligned} \pi_{sc}^* &= (p_c^* - c)(s - bp_c^* + \lambda\beta_c^*) + [A - e(1-\beta_c^*)(s - bp_c^* + \lambda\beta_c^*)]p_{ct} - \tfrac{1}{2}k\beta_c^{*2} \\ &= \frac{k(s-bc-p_{ct}eb)^2}{2\left[2bk - (\lambda + p_{ct}eb)^2\right]} + Ap_{ct} \end{aligned} \quad (6)$$

3.2. Decentralized Model without Altruistic Preference

In decentralized decision-making, retailer and manufacturer seek to maximize their profits through the Stackelberg game. The retailer can be regarded as a Stackelberg leader who determines the sales profit of the unit product (δ), and the manufacturer can be regarded as a follower who determines the wholesale price of the unit product (w) and the carbon emission reduction rate (β). The optimal decisions and profits of the retailer and the manufacturer are obtained by backward induction.

The retailer sets the profit of per unit product δ; let the sales price $p = w + \delta$, market demand $q = s - b(w+\delta) + \lambda\beta$; at this time, the manufacturer's profit can be calculated:

$$\pi_m = (w-c)(s-b(w+\delta)+\lambda\beta) + [A - e(1-\beta)(s-b(w+\delta)+\lambda\beta)]p_{ct} - \frac{1}{2}k\beta^2 \quad (7)$$

According to Equation (7), the Hessian matrix of $\pi_m\ (w,\beta)$ can be expressed as:

$$H_m(w,\beta) = \begin{bmatrix} -2b & \lambda - p_{ct}eb \\ \lambda - p_{ct}eb & 2p_{ct}e\lambda - k \end{bmatrix} \quad (8)$$

When $-2b < 0$ and $2bk - (\lambda + p_{ct}eb)^2 > 0$, $\pi_m(w,\beta)$ has the maximum value. Through $\frac{\partial \pi_m}{\partial w} = 0$ and $\frac{\partial \pi_m}{\partial \beta} = 0$, we can get:

$$w = -\delta + \frac{k(s+bc+b\delta+p_{ct}eb) - (\lambda + p_{ct}eb)(p_{ct}es + p_{ct}e\lambda + c\lambda + c\delta)}{2bk - (\lambda + p_{ct}eb)^2} \quad (9)$$

$$\beta = \frac{(\lambda + p_{ct}eb)(s - bc - b\delta - p_{ct}eb)}{2bk - (\lambda + p_{ct}eb)^2} \tag{10}$$

Taking Equations (9) and (10) into the retailer's profit function, we can get:

$$\begin{aligned} &\pi_r \\ &= \delta\left[s - b\left(\frac{k(s+bc+b\delta+p_{ct}eb)-(\lambda+p_{ct}eb)(p_{ct}es+p_{ct}e\lambda+c\lambda+c\delta)}{2bk-(\lambda+p_{ct}eb)^2}\right)\right. \\ &\left.+\lambda\left(\frac{(\lambda+p_{ct}eb)(s-bc-b\delta-p_{ct}eb)}{2bk-(\lambda+p_{ct}eb)^2}\right)\right] \end{aligned} \tag{11}$$

Since $\frac{\partial^2 \pi_r}{\partial \delta^2} = \frac{-2b^2k}{2bk-(\lambda+p_{ct}eb)^2} < 0$, therefore, let $\frac{\partial \pi_r}{\partial \delta} = \frac{bk(s-bc-2b\delta-p_{ct}eb)}{2bk-(\lambda+p_{ct}eb)^2} = 0$, then we get:

$$\delta_d^* = \frac{s - bc - p_{ct}eb}{2b} \tag{12}$$

Substituting it into Equation (11), we can obtain the retailer's maximum profit under decentralized decision-making with altruistic preference:

$$\pi_{rd}^* = \frac{k(s - bc - p_{ct}eb)^2}{4\left[2bk - (\lambda + p_{ct}eb)^2\right]} \tag{13}$$

At the same time, substituting δ_d^* into Equations (9) and (10), we can obtain other decisions under a decentralized without altruistic preferences and the profits of the manufacturer and the supply chain system:

$$w_d^* = \frac{c + p_{ct}e}{2} + \frac{k(s + bc + p_{ct}eb) - (\lambda + p_{ct}eb)(p_{ct}es + p_{ct}e\lambda + c\lambda)}{2\left[2bk - (\lambda + p_{ct}eb)^2\right]} \tag{14}$$

$$\beta_d^* = \frac{(\lambda + p_{ct}eb)(s - bc - p_{ct}eb)}{2\left[2bk - (\lambda + p_{ct}eb)^2\right]} \tag{15}$$

$$p_d^* = w_d^* + \delta_d^* = \frac{s}{2b} + \frac{k(s + bc + p_{ct}eb) - (\lambda + p_{ct}eb)(p_{ct}es + p_{ct}e\lambda + c\lambda)}{2\left[2bk - (\lambda + p_{ct}eb)^2\right]} \tag{16}$$

$$q_d^* = s - bp_d^* + \lambda\beta_d^* = \frac{bk(s - bc - p_{ct}eb)}{2\left[2bk - (\lambda + p_{ct}eb)^2\right]} \tag{17}$$

$$\begin{aligned} \pi_{md}^* &= (w_d^* - c)q_d^* + \left[A - e\left(1 - \beta_d^*\right)q_d^*\right]p_{ct} - \tfrac{1}{2}k\beta_d^{*2} \\ &= \frac{k(s-bc-p_{ct}eb)^2}{8\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct} \end{aligned} \tag{18}$$

$$\pi_{sd}^* = \pi_{rd}^* + \pi_{md}^* = \frac{3k(s - bc - p_{ct}eb)^2}{8\left[2bk - (\lambda + p_{ct}eb)^2\right]} + Ap_{ct} \tag{19}$$

Proposition 1. $\pi_{md}^* = \pi_{rd}^*/2 + Ap_{ct}$.

Proof: See Appendix A. □

Unlike in [20], where the manufacturer's maximum profit is only half of the retailer's maximum profit, under the carbon quota policy in this paper, although the manufacturer bears the cost of carbon emission reduction, he can get extra gains by trading the remaining carbon quota, which can narrow the profit gap between the manufacturer and the retailer.

How much the gap narrowed depends on the carbon quota set by the government and the carbon trading price.

3.3. Decentralized Model with Altruistic Preference

As the leader in the supply chain, the retailer not only pays attention to his interests but also considers the profitability of the other members to form an altruistic preference for the stability and long-term development of the supply chain. By introducing the concept of utility in literature [20,50], the retailer's decision objective can be expressed as:

$$U_r = \pi_r - \theta(\pi_r - \pi_m) \tag{20}$$

Among them, $\theta(0 < \theta < 1)$ is the altruistic preference coefficient. The larger θ is, the stronger the retailer's altruistic preference is. For the supply chain leader, altruistic preference often occurs when the retailer's profitability is better than that of other members. Therefore, the constraint condition $\pi_r \geq \pi_m$ is added, and the optimal decision of the retailer's altruistic preference in the decentralized model can be defined as follows in this study:

$$\begin{cases} \max\limits_{\delta} & U_r = (1-\theta)\pi_r + \theta\pi_m \\ s.t. & \pi_r \geq \pi_m \end{cases} \tag{21}$$

Similarly to Section 3.2, the retailer and the manufacturer follow the Stackelberg game, where the retailer maximizes its utility through backward induction.

For the optimization problem shown in Equation (21), we calculate it by using the KKT condition. The Lagrangian function of Equation (21) is:

$$L = (1-\theta)\pi_r + \theta\pi_m + \eta(\pi_r - \pi_m) \tag{22}$$

The optimal solution of Equation (22) must satisfy the KKT condition as per the following:

$$\begin{cases} \frac{\partial L}{\partial \delta} = 0 \\ \pi_r \geq \pi_m \\ \eta(\pi_r - \pi_m) = 0 \\ \eta \geq 0 \end{cases} \tag{23}$$

Substituting Equations, take Equations (7) and (9)–(11) into the above equation, and we can get:

$$\delta = \frac{(1-2\theta+2\eta)(s-bc-p_{ct}eb)}{(2-3\theta+3\eta)b} \tag{24}$$

$$\pi_r - \pi_m = -\frac{k(s-bc-b\delta-p_{ct}eb)(s-bc-3b\delta-p_{ct}eb)}{2\left[2bk-(\lambda+p_{ct}eb)^2\right]} - Ap_{ct} \tag{25}$$

When $\frac{\partial^2 L}{\partial \delta^2} = \frac{b^2k(3\theta-3\eta-2)}{2bk-(\lambda+p_{ct}eb)^2} < 0$, $2bk-(\lambda+p_{ct}eb)^2 > 0$, so $3\theta-3\eta-2 < 0$, namely $0 < \theta < \frac{3\eta+2}{3}$, Equation (22) has an optimal solution.

According to Equations (23) and (24), when $\eta = 0$, $\delta = \delta_1 = \frac{(1-2\theta)(s-bc-p_{ct}eb)}{(2-3\theta)b}$, and $0 < \theta_1 < \frac{2}{3}$ can be obtained from $0 < \theta < \frac{3\eta+2}{3}$. From $\pi_r \geq \pi_m$ and $0 < \theta_1 < \frac{2}{3}$ we can get:

$$0 < \theta_1 \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2 - 6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3} \tag{26}$$

When $\eta > 0$, $\delta = \delta_2 = \frac{2(\mathrm{s}-bc-p_{ct}eb)}{3b} + \frac{\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}}{3bk}$ and $\delta = \delta_3 = \frac{2(\mathrm{s}-bc-p_{ct}eb)}{3b} - \frac{\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}}{3bk}$ can be obtained from $\pi_r - \pi_m = 0$. Substitute δ_2 and δ_3 into Equation (24) respectively, we can obtain:

$$\eta_2 = (\theta_2 - \frac{2}{3}) - \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} \tag{27}$$

$$\eta_3 = (\theta_3 - \frac{2}{3}) + \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} \tag{28}$$

$\eta > 0$, so:

$$\theta_2 > \frac{2}{3} + \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} \tag{29}$$

$$\theta_3 > \frac{2}{3} - \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} \tag{30}$$

Since $\frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} > \frac{1}{3}$, $\theta_2 > 1$ can be obtained, which is not consistent with $0 < \theta < 1$, but θ_3 meets $0 < \theta < 1$. Comparing $U_r(\delta_1)$ and $U_r(\delta_3)$ under the two situations of $\theta = \theta_1$ and $\theta = \theta_3$, $U_r(\delta_1) > U_r(\delta_3)$ can be obtained. Therefore, when $\delta_a^* = \delta_1$, the retailer obtains the maximum utility. Here:

$$\delta_a^* = \frac{(1-2\theta)(\mathrm{s}-bc-p_{ct}eb)}{(2-3\theta)b} \tag{31}$$

$$U_{ra}^* = \frac{(1-\theta)^2 k(\mathrm{s}-bc-p_{ct}eb)^2}{2(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct}\theta \tag{32}$$

Through the above analysis, the following proposition can be obtained:

Proposition 2: *In order for the retailer to realize higher profits than the manufacturer, the coefficient of altruistic preference must satisfy* $0 < \theta \le \frac{2}{3} - \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}}$. *Within this value range, the retailer can obtain maximum utility.*

When $\theta = \frac{2}{3} - \frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}}$, the retailer profit is equal to the manufacturer's profit. Since $\frac{k(\mathrm{s}-bc-p_{ct}eb)}{3\sqrt{k^2(\mathrm{s}-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} > \frac{1}{3}$, there is $0 < \theta < \frac{1}{3}$, where the range of the altruistic preference coefficient is less than the range of $\theta(0 < \theta \le 1/2)$ in [45] and that of $\theta(0 < \theta \le 1/3)$ in [20]. The government's carbon cap policy allows the manufacturer to earn profit through carbon trading, which will reduce the profit gap between the retailer and the manufacturer. The smaller profit gap between the retailer and the manufacturer will lead to a smaller value range for the retailer's altruistic preference coefficient.

Substitute δ_a^* into Equations (9) and (10); the following can be obtained:

$$w_a^* = \frac{(1-2\theta)(c+p_{ct}e)}{2-3\theta} + \frac{(1-\theta)[k(s+bc+p_{ct}eb)-(\lambda+p_{ct}eb)(p_{ct}es+p_{ct}e\lambda+c\lambda)]}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]} \tag{33}$$

$$\beta_a^* = \frac{(1-\theta)(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]} \tag{34}$$

The other optimal decisions in a decentralized model with altruistic preference are as follows:

$$p_a^* = w_a^* + \delta_a^* = \frac{(1-2\theta)s}{(2-3\theta)b} + \frac{(1-\theta)[k(s+bc+p_{ct}eb)-(\lambda+p_{ct}eb)(p_{ct}es+p_{ct}e\lambda+c\lambda)]}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]} \tag{35}$$

$$q_a^* = s - bp_a^* + \lambda\beta_a^* = \frac{(1-\theta)bk(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]} \tag{36}$$

$$\pi_{ra}^* = \delta_a^* q_a^* = \frac{(1-\theta)(1-2\theta)k(s-bc-p_{ct}eb)^2}{(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} \tag{37}$$

$$\pi_{ma}^* = (w_a^*-c)q_a^* + [A-e(1-\beta_a^*)q_a^*]p_{ct} - \frac{1}{2}k\beta_a^{*2} = \frac{(1-\theta)^2k(s-bc-p_{ct}eb)^2}{2(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct} \tag{38}$$

$$\pi_{sa}^* = \pi_{ra}^* + \pi_{ma}^* = \frac{(1-\theta)(3-5\theta)k(s-bc-p_{ct}eb)^2}{2(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct} \tag{39}$$

Proposition 3. *(1) β_a^*, q_a^*, π_{ma}^*, π_{sa}^*, U_{ra}^* have positive correlations with θ, while δ_a^*, π_{ra}^* have negative correlations with θ. (2) When $bk > p_{ct}eb(\lambda + p_{ct}eb)$, w_a^* is positively correlated with θ, and when $bk < p_{ct}eb(\lambda + p_{ct}eb)$, w_a^* is negatively correlated with θ. (3) When $bk < \lambda(\lambda + p_{ct}eb)$, p_a^* is positively correlated with θ, and when $bk > \lambda(\lambda + p_{ct}eb)$, p_a^* is negatively correlated with θ.*

Proof: See Appendix B. □

Proposition 3 shows that all optimal decisions are affected by the altruistic preference coefficient under the retailer's altruistic preference. Carbon emission reduction rate β_a^*, market demand for the product q_a^*, manufacturer's profit π_{ma}^*, and supply chain system profit π_{sa}^* are positively correlated with the altruistic preference coefficient θ. Although the retailer's unit product profit δ_a^* and total profit π_{ra}^* are negatively correlated with θ, the retailer's utility U_{ra}^* increases with the increase of θ, which is contrary to previous studies [38] where carbon reduction levels and manufacturer profits were negatively related to the equity concern coefficient while retailer profits were positively related to the equity concern coefficient. Moreover, different from the conclusion in the previous study that the wholesale price of the product w_a^* increases with the altruistic preference coefficient θ [20], under the carbon quota policy, the correlation between w_a^* and θ depends on b, k, λ, p_{ct}, e. When k is high, w_a^* is positively correlated with θ; when $p_{ct}e$ is high, w_a^* is negatively correlated with θ. The correlation between p_a^* and θ also depends on b, k, λ, p_{ct}, and e. When k is high, p_a^* is negatively correlated with θ; when λ is high, p_a^* is positively correlated with θ. Therefore, under the carbon quota policy, in addition to carbon emission reduction cost and consumer's low-carbon preference, the price of carbon trading is also an important factor to affect the product cost.

Propositions 4–7 are obtained by comparing the models of centralized decision, decentralized decision without altruistic preference, and decentralized decision with altruistic preference (altruistic preference coefficient satisfies

$$0 < \theta \leq \frac{2}{3} - \frac{k(\mathrm{s} - bc - p_{ct}eb)}{3\sqrt{k^2(\mathrm{s} - bc - p_{ct}eb)^2 - 6Ap_{ct}k\left[2bk - (\lambda + p_{ct}eb)^2\right]}}.$$

Proposition 4. *The relationship between retail prices of the three models satisfies: (1) When $bk > \lambda(\lambda + p_{ct}eb)$, $p_c^* < p_a^* < p_d^*$, $(p_d^* - p_a^*) < (p_a^* - p_c^*)$; (2) When $bk < \lambda(\lambda + p_{ct}eb)$, $p_d^* < p_a^* < p_c^*$, $(p_a^* - p_d^*) < (p_c^* - p_a^*)$.*

Proof: See Appendix C. □

Proposition 4 shows that, (1) when $bk > \lambda(\lambda + p_{ct}eb)$, the retail price in the centralized decision model is the lowest, and the retail price in the decentralized model without altruistic preference is the highest. Under decentralized decision-making, the manufacturer bears the cost of carbon emission reduction alone, so his profit is guaranteed by raising the wholesale price, which ultimately leads to a higher retail price. (2) When $bk < \lambda(\lambda + p_{ct}eb)$, the retail price under the centralized decision is the highest, and the retail price under the decentralized model without altruistic preference is the lowest. Under the decentralized model, the consumer's low-carbon preference expands market demand for green products, where the manufacturer can maintain a lower carbon emission cost at a lower level of carbon emission reduction. In this case, the manufacturer can obtain better profits without raising the product price. On the contrary, under the centralized decision, the manufacturer obtains profits by increasing the level of carbon emission reduction and the retail price of the product. (3) Under the decentralized model with the retailer's altruistic preference, the difference in retail prices between the centralized decision and the decentralized decision will be narrowed, but the reduction is limited.

Proposition 5. *When $k > p_{ct}e(\lambda + p_{ct}eb)$, $w_a^* > w_d^*$; when $k < p_{ct}e(\lambda + p_{ct}eb)$, $w_a^* < w_d^*$.*

Proof: See Appendix D. □

Proposition 5 shows that when $k > p_{ct}e(\lambda + p_{ct}eb)$, the wholesale price of products is higher in decentralized model with altruistic preference than in the decentralized model without altruistic preference. In this case, the cost of carbon reduction is higher. Under the decentralized model without altruistic preference, the manufacturer prefers a low level of carbon emission reduction to ensure profits. Under the decentralized model with altruistic preference, the retailer's altruistic preference motivates the manufacturer to improve the level of carbon emission reduction and increase the wholesale price to cover the increased cost of carbon emission reduction. When $k < p_{ct}e(\lambda + p_{ct}eb)$, the wholesale price of products is lower in the decentralized model with an altruistic preference than in the decentralized model without an altruistic preference. In this case, the carbon trading volume greatly impacts the manufacturer's profits. Under decentralized decision-making without altruistic preference, it is difficult for the manufacturer to profit from the carbon trading market, and he has to make a profit by raising the wholesale price. However, under decentralized decision-making with an altruistic preference, the manufacturer can obtain ideal profits at a lower wholesale price due to the increment of carbon trading revenue and product demand.

Proposition 6. *The relationship between emission reduction rates and market demands for the three models satisfies: (1) $\beta_d^* = \frac{1}{2}\beta_c^*$, $\beta_a^* = \frac{1-\theta}{2-3\theta}\beta_c^*$, $\beta_d^* < \beta_a^* < \beta_c^*$, $\left(\beta_a^* - \beta_d^*\right) < \left(\beta_c^* - \beta_a^*\right)$; (2) $q_d^* = \frac{1}{2}q_c^*$, $q_a^* = \frac{1-\theta}{2-3\theta}q_c^*$, $q_d^* < q_a^* < q_c^*$, $\left(q_a^* - q_d^*\right) < \left(q_c^* - q_a^*\right)$.*

Proof: See Appendix E. □

Proposition 6 shows that, among the three models, the carbon emission reduction rate under centralized decision-making is the highest, twice that of the decentralized decision-making without an altruistic preference model. So, there is the highest product demand under centralized decision-making, while the demand under decentralized decision-making without an altruistic preference is only half.

Retailers' altruistic preference can increase the carbon emission reduction rate, which in turn increases the demand for the products. However, because the retailer's altruistic preference is based on its profit being higher than the manufacturer's, it cannot greatly improve the carbon emission reduction rate and the market demand for the product. There is still a large gap between the optimal solutions in the centralized model and the decentralized model without an altruistic preference, which indicates that the decentralized model with an altruistic preference still cannot achieve the system profit of the centralized model.

Proposition 7. *In the three models, the relationships among manufacturer's profit, retailer's profit and the system profit satisfy: (1)* $\pi^*_{md} < \pi^*_{ma}$, $\pi^*_{rd} > \pi^*_{ra}$, $\pi^*_{sd} < \pi^*_{sa} < \pi^*_{sc}$; *(2)* $(\pi^*_{ra} - \pi^*_{ma}) < (\pi^*_{rd} - \pi^*_{md})$.

Proof: See Appendix F. □

Proposition 7 shows that centralized decision-making has the highest system profit, while decentralized decision-making without altruistic preference has the lowest system profit. The retailer's altruistic preference will reduce its profit while increasing the profits of the manufacturer and the system, which will maintain the supply chain's stability by reducing the profit difference between the retailer and manufacturer. Altruistic preference helps to improve system efficiency, and this provides ideas for designing coordination contracts through altruistic preference. The findings of Propositions 6 and 7 are the same as those of the decentralized decision with altruistic preference in a low-carbon supply chain without carbon quota restrictions [20], which implies that the impacts of carbon quotas on the three models are consistent.

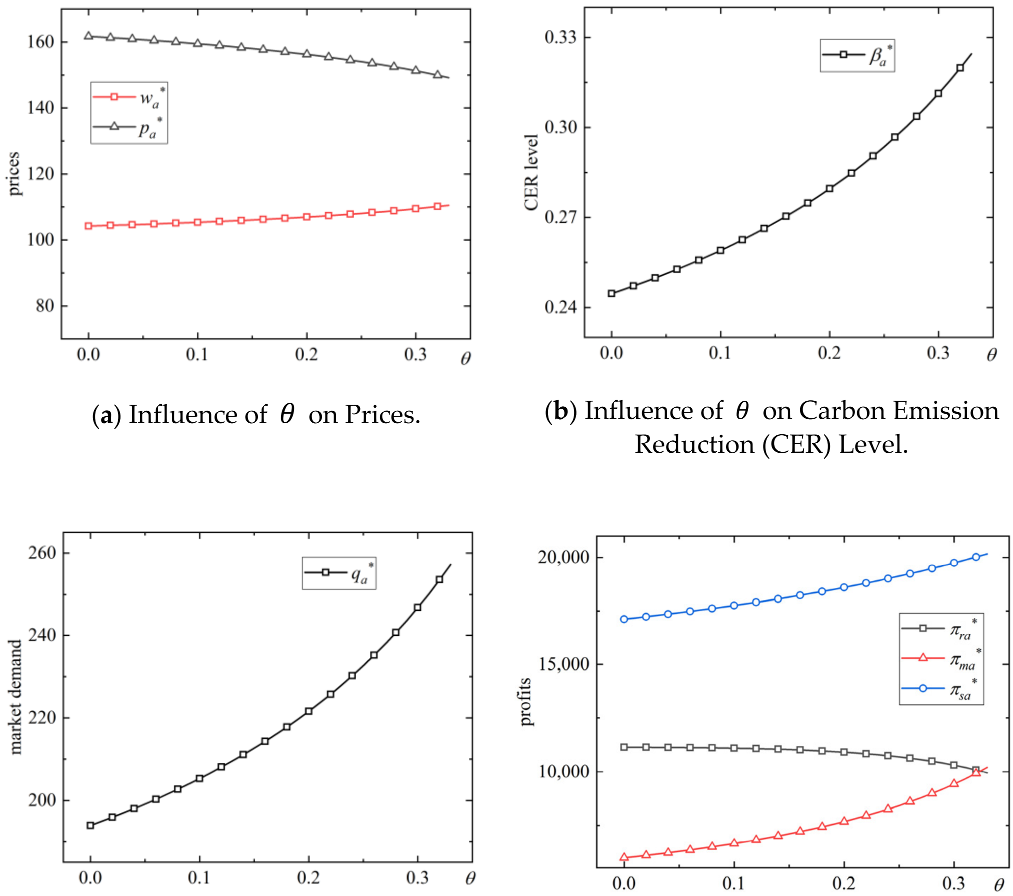
4. Numerical Simulation

To illustrate the above conclusions intuitively and further discover other unknown conclusions, this part will use numerical examples for simulation analysis. Referring to the relevant research [20], the parameter values of the examples all satisfy the requirements of the model descriptions and ensure that the optimal decision is positive.

4.1. Effects of Main Parameters on Optimal Decisions

Using the numerical analysis method, we discuss the influence of the retailer's altruistic preference coefficient, the manufacturer's carbon emission reduction cost, the consumer's low-carbon preference, and the carbon trading price on the optimal decision of the supply chain (including price, carbon emission reduction level, market demand, and profit). We give some estimated parameters as follows: $s = 1000$, $b = 5$, $c = 5$, $k = 65,000$, $A = 500$, $e = 100$, $p_{ct} = 1$, $\lambda = 10$, $\theta = 0.2$.

Figure 1 shows that the carbon emission reduction level β, market demand q, manufacturer's profit π_m, and the supply chain system profit π_s are positively correlated with the retailer's altruistic preference coefficient θ, while the retailer's profit π_r is negatively correlated with θ. Although the altruistic behavior sacrifices the retailer's interests, it is beneficial to the climate environment, consumers, manufacturer, and the whole supply chain. According to proposition 3, the influence of θ on wholesale price w and retail price p is closely related to b, k, p_{ct}, e, λ. According to the parameter values set, when $bk > p_{ct}eb(\lambda + p_{ct}eb)$ and $bk > \lambda(\lambda + p_{ct}eb)$, the wholesale price w is positively correlated with θ, and the sales price p is negatively correlated with θ. When the cost of carbon reduction is high, the manufacturer's cost pressure increases significantly. In this case, with the retailer's altruistic preference increases, the wholesale price rises, the retail price falls, and the market demand increases, which in turn ensures profits. On the contrary, when $bk < p_{ct}eb(\lambda + p_{ct}eb)$, w is negatively correlated with θ; when $bk < \lambda(\lambda + p_{ct}eb)$, p is positively correlated with θ. These will be discussed in detail in the next subsection



(**a**) Influence of θ on Prices.

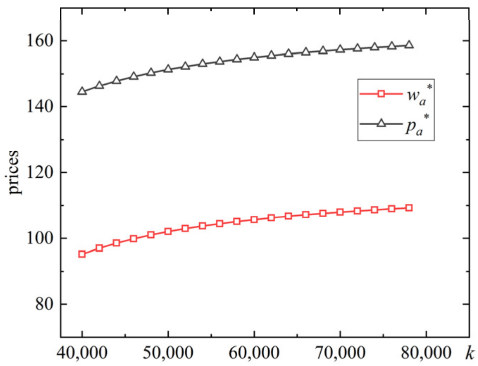
(**b**) Influence of θ on Carbon Emission Reduction (CER) Level.

(**c**) Influence of θ on Market Demand.

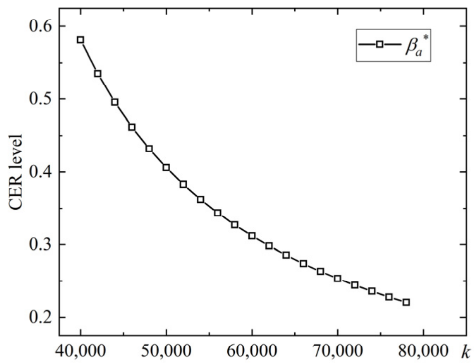
(**d**) Influence of θ on Profits.

Figure 1. The Influence of Altruistic Preference θ on Supply Chain Decision.

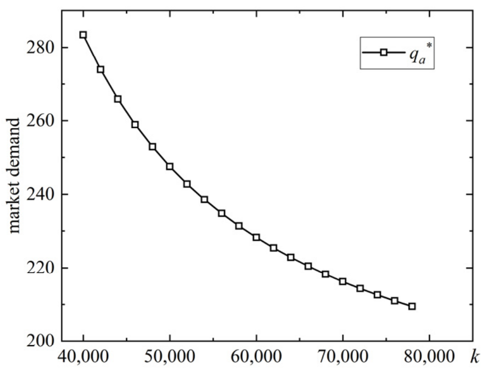
Figures 2 and 3 shows that the impacts of carbon reduction cost k and consumers' low-carbon preference λ on each optimal decisions are completely contrary to Figure 1. Among them, the retail and wholesale prices are positively correlated with the carbon emission reduction cost, and negatively correlated with the consumers' low-carbon preference level. In contrast, the carbon emission reduction level and the market demand are negatively correlated with the carbon emission reduction cost and positively correlated with the consumers' low-carbon preference level. Meanwhile, the profit of the retailer, the manufacturer and the supply chain are negatively correlated with the carbon emission reduction cost and positively correlated with the consumers' low-carbon preference level.



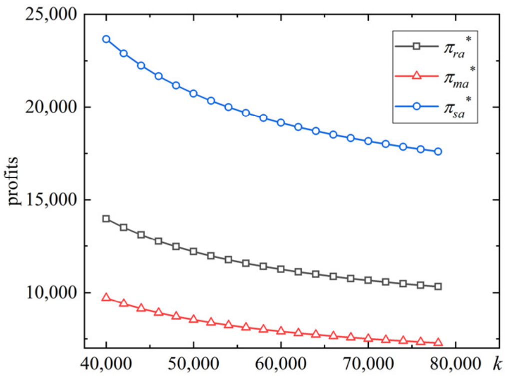
(**a**) Influence of k on Prices.



(**b**) Influence of k on Carbon Emission Reduction (CER) Level.



(**c**) Influence of k on Market Demand.

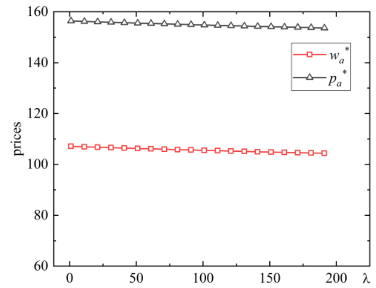


(**d**) Influence of k on Profits.

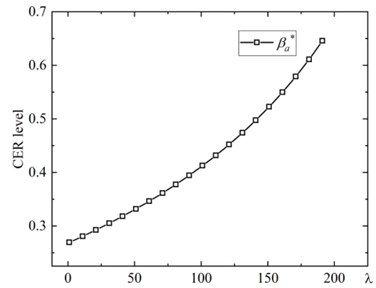
Figure 2. The Influence of Carbon Emission Reduction Cost k on Supply Chain Decision.

The cost of carbon emission reduction is the main factor to hinder the carbon emission reduction level. Usually, the players tend to ensure their profits by raising the price due to the increased production cost for carbon emission reduction. With the increase in the retail price, though, the market demand will decrease, ultimately affecting the profits of the retailer, the manufacturer, and the supply chain. Consumers' preference for low-carbon products expands the market size and motivates the manufacturer to reduce carbon emissions. With the growth of carbon trading and product demand, the players can earn good returns without raising or lowering prices.

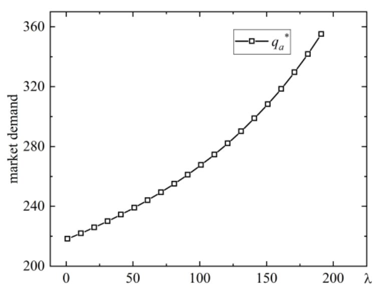
In Figure 4, the sales price, the wholesale price, and the carbon emission reduction level are positively correlated with the carbon trading price, while the market demand and the profit of the retailer, the manufacturer, and the system are negatively correlated with the carbon trading price. As the carbon trading price rises, the manufacturer earns more profits in the carbon trading market, which promotes the level of carbon emission reduction. When the parameters satisfy $bk > p_{ct}eb(\lambda + p_{ct}eb)$, the wholesale price and retail price will rise inexorably due to the high carbon emission reduction cost borne by the manufacturer, which will affect the consumer's willingness to buy and ultimately reduce the profits of the manufacturer, retailer, and supply chain.



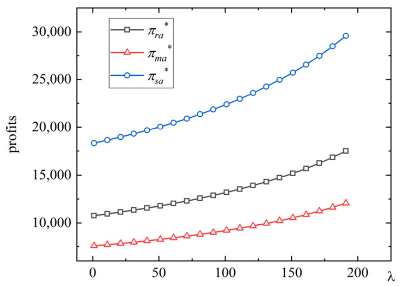
(**a**) Influence of λ on Prices.



(**b**) Influence of λ on Carbon Emission Reduction (CER) Level.

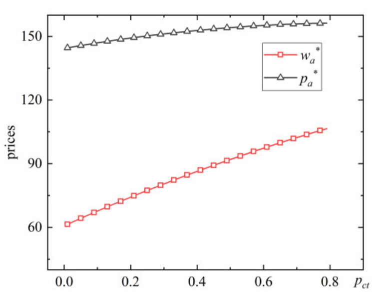


(**c**) Influence of λ on Market Demand.

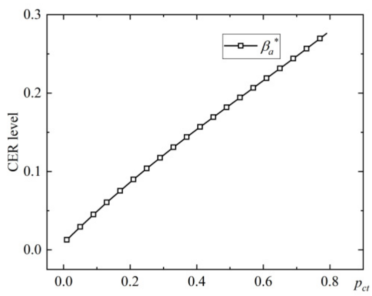


(**d**) Influence of λ on Profits.

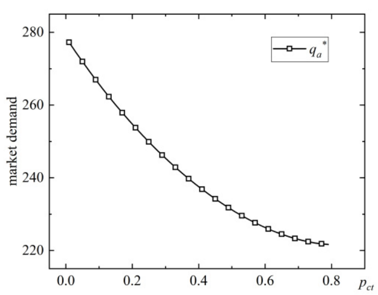
Figure 3. The Influence of Consumers' Low Carbon Preference λ on Supply Chain Decision.



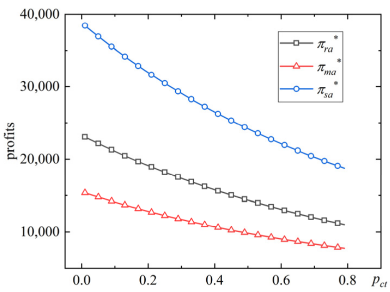
(**a**) Influence of p_{ct} on Prices.



(**b**) Influence of p_{ct} on Carbon Emission Reduction (CER) Level.



(**c**) Influence of p_{ct} on Market Demand.



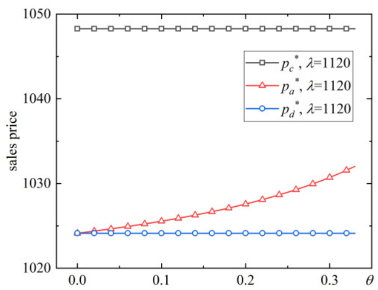
(**d**) Influence of p_{ct} on Profits.

Figure 4. The Influence of Carbon Trading Price p_{ct} on Supply Chain Decision.

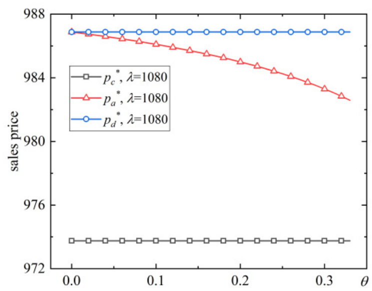
4.2. Comparison of The Optimal Decisions under The Three Models

The optimal decisions of the three models of the centralized decision, decentralized decision without altruistic preference, and decentralized decision with altruistic preference are compared and analyzed. We give some estimated parameters as follows: $s = 1000$, $b = 1$, $c = 5$, $k = 1,200,000$, $A = 500$, $e = 1$, $p_{ct} = 1$, $\lambda = 1080$, $\theta \in [0,\ 0.33]$.

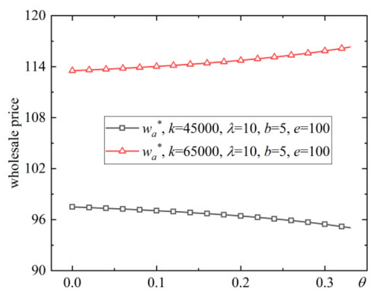
The results show that among the three models, the centralized model has the highest carbon emission reduction level β, market demand q, and supply chain profit π_s, while the decentralized model without altruistic preference has the lowest β, q, and π_s. With the altruistic preference, the coefficient θ increases, the differences of β, q, and π_s between the two decentralized models gradually increase, and the three optimal values in the altruistic preference model are constantly approaching the ideal value of the centralized model (Figure 5d,e,h). Although the retailer's profit in the decentralized model with altruistic preference decreases as the altruistic preference coefficient θ increases (Figure 5f), the decrease is less than the increase in the manufacturer's profit (Figure 5g), which improves the overall benefit of the supply chain system. When $bk < \lambda(\lambda + p_{ct}eb)$, consumers have a higher low-carbon preference, the centralized model has the highest sales price, and the decentralized model without altruistic preference has the lowest sales price. When $bk > \lambda(\lambda + p_{ct}eb)$, the carbon emission reduction cost is higher, the decentralized model without altruistic preference has the highest sales price, while the centralized model has the lowest sales price (Figure 5a,b). When $k > p_{ct}e(\lambda + p_{ct}eb)$, compared to the case where there is no altruistic preference, the retailer's altruistic preference is conducive to the manufacturer earning more profits by increasing the wholesale price to compensate for carbon emission reduction costs. When $k < p_{ct}e(\lambda + p_{ct}eb)$, the high profits earned from the carbon trading market enables the manufacturer to ensure profits at a lower wholesale price. The retailer's altruistic preference can further encourage the manufacturer to set a lower wholesale price (Figure 5c).



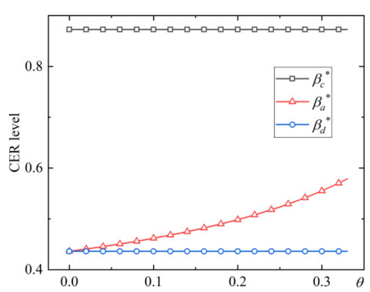
(**a**) Comparison of Sales Prices ($bk < \lambda(\lambda{+}p_{ct}eb)$)



(**b**) Comparison of Sales Prices $bk > \lambda(\lambda{+}p_{ct}eb)$

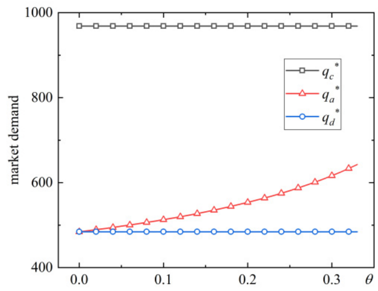


(**c**) Comparison of Wholesale Prices

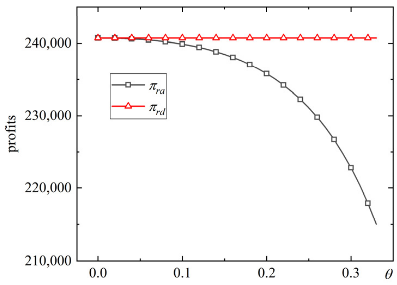


(**d**) Comparison of Carbon Emission Reduction Levels

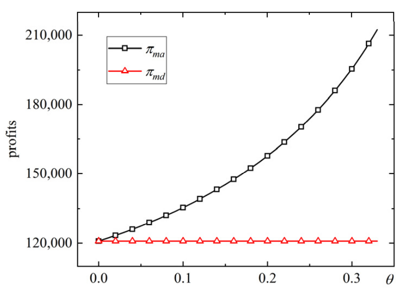
Figure 5. *Cont.*



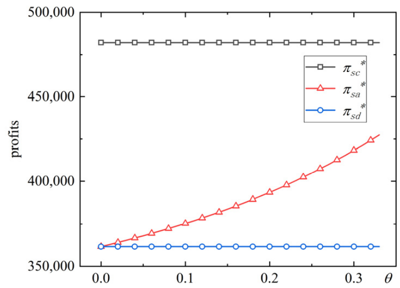
(**e**) Comparison of Market Demands



(**f**) Comparison of Retailers' Profits



(**g**) Comparison of Manufacturer Profits



(**h**) Comparison of Supply Chain Profits

Figure 5. Comparison of Optimal Decisions among the Three Models.

5. Conclusions

5.1. Conclusions

The increased awareness of low carbon has promoted the production of green products, while the increased cost of carbon emission reduction puts manufacturers at a disadvantage in the retailer-led supply chain. An important issue worth thoroughly inquiring about is how to incentivize manufacturers to reduce carbon emissions and maintain the sustainability of the low-carbon supply chain. This study investigates a retailer-led low-carbon supply chain problem by considering the government's carbon quota policy and the retailer's altruistic preference. Three models of centralized decision, decentralized decision without altruistic preference, and decentralized decision with altruistic preference are constructed. The main findings are as follows:

(1) Carbon trading under the carbon quota policy is important in improving the carbon emission reduction level. When the carbon price is high, the carbon trading revenue will effectively cover the cost of carbon emission reduction while the manufacturer's cost pressure decreases significantly. When the wholesale price remains low while improving the carbon emission reduction level, it is beneficial to expand market demand and increase the profit of the system.

(2) Retailers' altruistic preferences contribute to the sustainability of the low-carbon supply chain. The level of carbon emission reduction, the demand for low-carbon products, and the profits of manufacturers and systems are all positively related to the intensity of retailers' altruistic preferences. However, retailers' altruistic preferences will harm their interests. The improvement of retailers' altruistic preferences on decentralization decisions is limited due to the profit constraint.

(3) The effects of retailers' altruistic preferences on wholesale and retail prices are closely related to carbon reduction costs, carbon transaction prices, and consumers' low-carbon preferences. When carbon reduction costs are high, the wholesale price is positively related to the intensity of altruistic preference, while the retail price is negatively related to the intensity of altruistic preference; when carbon transaction prices and consumers'

low-carbon preferences are high, the wholesale price is negatively related to the intensity of altruistic preferences, and the retail price is positively related to the intensity of altruistic preferences.

5.2. Insights

Through the research of this paper, we can obtain the following theoretical and practical significance:

Theoretical significance: First, we consider the government's carbon quota policy and retailers' altruistic preferences in exploring retailer-led low-carbon supply chain decision-making and analyze the effects of retailers' altruistic preferences, manufacturers' carbon reduction costs, consumers' low-carbon preferences, and carbon trading prices on low-carbon supply chain decision-making, providing ideas for the study of irrational behaviors in low-carbon supply chain decision-making under carbon policies. Second, the research in this paper analyzes the impact of the carbon quota policy on the altruistic preference coefficient of the dominant supply chain player (retailers), which enriches the theoretical basis for studying the low-carbon supply chain and altruistic preferences. Subsequent scholars can conduct empirical studies based on this study to further verify the scope of altruistic preferences.

Practical significance: (1) The carbon quota policy positively relieves the cost pressure on manufacturers and improves the carbon emission reduction level. Therefore, while facing environmental problems and promoting carbon emission policies, the government should pay attention to the carbon emission reduction costs borne by manufacturers, improve the carbon trading market mechanism, and promote an increase in the carbon emission reduction rate of the whole society. (2) Retailers' altruistic preferences are conducive to improving profits in the retailer-led low-carbon supply chain. Therefore, retailers can provide service and support in finance, logistics, personnel training, and low-carbon product promotion to benefit manufacturers, enhance their willingness to cooperate, and promote the sustainable development of the supply chain system. (3) Consumers' low-carbon preferences contribute to improving carbon emission reduction levels and increasing profits in the low-carbon supply chain. Therefore, the government should strengthen environmental publicity and education and vigorously advocate green and low-carbon consumption. Enterprises should actively promote low-carbon products and cultivate a low-carbon consumption market. Although the input of carbon emission reduction costs will increase the price of products, popularizing the low-carbon consumption concept will bring great economic benefits and environmental improvement in the long run.

5.3. Directions for Future Research

Our study still has some limitations, which we will explore in the future.

(1) This study only considers the impact of the government's carbon quota policy and retailers' altruistic preferences on retailer-led low-carbon supply chain decisions. Other carbon policies (e.g., carbon tax policies) and social preferences (e.g., equity preferences, reciprocity preferences) can also have far-reaching effects on the decision-making and operation of the low-carbon supply chain, which will be our next research direction.

(2) This study is limited to the low-carbon supply chain with one dominant retailer and one manufacturer. Therefore, a future research direction is to extend this model and apply it to a more realistic supply chain system with one dominant retailer and multiple manufacturers. In this network configuration, the impact of the government's environmental policies and the social preferences of supply chain members on low-carbon supply chain decision-making is further explored.

(3) The low-carbon supply chain model in this study only considers the carbon reduction cost of manufacturers. However, as the dominant player in the supply chain, retailers should bear the responsibility of carbon reduction, which we will further explore based on this study.

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Appendix A

Proof of Proposition 1. $\pi_{md}^* = \frac{k(s-bc-p_{ct}eb)^2}{8\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct} = \frac{1}{2}\cdot\frac{k(s-bc-p_{ct}eb)^2}{4\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct}$, $\pi_{rd}^* = \frac{k(s-bc-p_{ct}eb)^2}{4\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, so $\pi_{md}^* = \frac{1}{2}\cdot\pi_{rd}^* + Ap_{ct}$. □

Proposition 1 is demonstrated.

Appendix B

Proof of Proposition 3. When $0 < \theta \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3}$, $\frac{\partial\delta_a^*}{\partial\theta} = \frac{-(s-bc-p_{ct}eb)}{(2-3\theta)^2 b} < 0$, $\frac{\partial\beta_a^*}{\partial\theta} = \frac{(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} > 0$, $\frac{\partial q_a^*}{\partial\theta} = \frac{bk(s-bc-p_{ct}eb)}{(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} > 0$, $\frac{\partial\pi_{ma}^*}{\partial\theta} = \frac{2(1-\theta)k(s-bc-p_{ct}eb)^2}{2(2-3\theta)^3\left[2bk-(\lambda+p_{ct}eb)^2\right]} > 0$, $\frac{\partial\pi_{ra}^*}{\partial\theta} = \frac{-\theta k(s-bc-p_{ct}eb)^2}{(2-3\theta)^3\left[2bk-(\lambda+p_{ct}eb)^2\right]} < 0$, $\frac{\partial\pi_{sa}^*}{\partial\theta} = \frac{(1-2\theta)k(s-bc-p_{ct}eb)^2}{(2-3\theta)^3\left[2bk-(\lambda+p_{ct}eb)^2\right]} > 0$, $\frac{\partial U_{ra}^*}{\partial\theta} = \frac{(3+\theta)(1-\theta)k(s-bc-p_{ct}eb)^2}{2(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]} + Ap_{ct} > 0$. $\frac{\partial w_a^*}{\partial\theta} = \frac{(s-bc-p_{ct}eb)[bk-p_{ct}eb(\lambda+p_{ct}eb)]}{(2-3\theta)^2 b\left[2bk-(\lambda+p_{ct}eb)^2\right]}$; When $bk > p_{ct}eb(\lambda+p_{ct}eb)$, $\frac{\partial w_a^*}{\partial\theta} > 0$; when $bk < p_{ct}eb(\lambda+p_{ct}eb)$, $\frac{\partial w_a^*}{\partial\theta} < 0$. $\frac{\partial p_a^*}{\partial\theta} = \frac{(s-bc-p_{ct}eb)[-bk+\lambda(\lambda+p_{ct}eb)]}{(2-3\theta)^2 b\left[2bk-(\lambda+p_{ct}eb)^2\right]}$; when $bk < \lambda(\lambda+p_{ct}eb)$, $\frac{\partial p_a^*}{\partial\theta} > 0$; when $bk > \lambda(\lambda+p_{ct}eb)$, $\frac{\partial p_a^*}{\partial\theta} < 0$. □

Proposition 3 is demonstrated.

Appendix C

Proof of Proposition 4. $p_d^* - p_a^* = \frac{\theta(s-bc-p_{ct}eb)[bk-\lambda(\lambda+p_{ct}eb)]}{2(2-3\theta)b\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $p_a^* - p_c^* = \frac{(1-2\theta)(s-bc-p_{ct}eb)[bk-\lambda(\lambda+p_{ct}eb)]}{(2-3\theta)b\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, Since $0 < \theta \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3}$, therefore, when $bk > \lambda(\lambda+p_{ct}eb)$, $p_c^* < p_a^* < p_d^*$, $(p_d^* - p_a^*) < (p_a^* - p_c^*)$; when $bk < \lambda(\lambda+p_{ct}eb)$, $p_d^* < p_a^* < p_c^*$, $(p_a^* - p_d^*) < (p_c^* - p_a^*)$. □

Proposition 4 is demonstrated.

Appendix D

Proof of Proposition 5. $w_d^* - w_a^* = \frac{\theta(s-bc-p_{ct}eb)[bk-p_{ct}eb(\lambda+p_{ct}eb)]}{2(2-3\theta)b\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, since $0 < \theta \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3}$, therefore, when $k > p_{ct}e(\lambda + p_{ct}eb)$, $w_a^* > w_d^*$; when $k < p_{ct}e(\lambda + p_{ct}eb)$, $w_a^* < w_d^*$. □

Proposition 5 is demonstrated.

Appendix E

Proof of Proposition 6. $\beta_c^* = \frac{(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{2bk-(\lambda+p_{ct}eb)^2}$, $\beta_d^* = \frac{(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\beta_a^* = \frac{(1-\theta)(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\beta_a^* - \beta_d^* = \frac{\theta(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{2(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\beta_c^* - \beta_a^* = \frac{(1-2\theta)(\lambda+p_{ct}eb)(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $q_c^* = \frac{bk(s-bc-p_{ct}eb)}{2bk-(\lambda+p_{ct}eb)^2}$, $q_d^* = \frac{bk(s-bc-p_{ct}eb)}{2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $q_a^* = \frac{(1-\theta)bk(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $q_a^* - q_d^* = \frac{\theta bk(s-bc-p_{ct}eb)}{2(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $q_c^* - q_a^* = \frac{(1-2\theta)bk(s-bc-p_{ct}eb)}{(2-3\theta)\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, since $0 < \theta \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3}$, therefore, $\beta_d^* < \beta_a^* < \beta_c^*$, $(\beta_a^* - \beta_d^*) < (\beta_c^* - \beta_a^*)$; $q_d^* < q_a^* < q_c^*$, $(q_a^* - q_d^*) < (q_c^* - q_a^*)$. □

Proposition 6 is demonstrated.

Appendix F

Proof of Proposition 7. $\pi_{ma}^* - \pi_{md}^* = \frac{(4-5\theta)\theta k(s-bc-p_{ct}eb)^2}{8(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\pi_{ra}^* - \pi_{rd}^* = \frac{-\theta k(s-bc-p_{ct}eb)^2}{4(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\pi_{sa}^* - \pi_{sd}^* = \frac{(4-7\theta)\theta k(s-bc-p_{ct}eb)^2}{8(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, $\pi_{sc}^* - \pi_{sa}^* = \frac{(1-2\theta)^2 k(s-bc-p_{ct}eb)^2}{2(2-3\theta)^2\left[2bk-(\lambda+p_{ct}eb)^2\right]}$, since $0 < \theta \leq \frac{2}{3} - \frac{k(s-bc-p_{ct}eb)}{3\sqrt{k^2(s-bc-p_{ct}eb)^2-6Ap_{ct}k\left[2bk-(\lambda+p_{ct}eb)^2\right]}} < \frac{1}{3}$, therefore, $\pi_{md}^* < \pi_{ma}^*$, $\pi_{rd}^* > \pi_{ra}^*$, $\pi_{sd}^* < \pi_{sa}^* < \pi_{sc}^*$; $(\pi_{ra}^* - \pi_{ma}^*) < (\pi_{rd}^* - \pi_{ma}^*) < (\pi_{rd}^* - \pi_{md}^*)$. □

Proposition 7 is demonstrated.

References

1. Chan, H.S.; Li, S.J.; Zhang, F. Firm competitiveness and the European Union emissions trading scheme. *Energy Policy* **2013**, *63*, 1056–1064. [CrossRef]
2. Wang, Z.; Wang, C. How carbon offsetting scheme impacts the duopoly output in production and abatement: Analysis in the context of carbon cap-and-trade. *J. Clean. Prod.* **2015**, *103*, 715–723. [CrossRef]
3. Adaman, F.; Karalı, N.; Kumbaroğlu, G.; Or, I.; Özkaynak, B.; Zenginobuz, Ü. What determines urban households' willingness to pay for CO_2 emission reductions in Turkey: A contingent valuation survey. *Energy Policy* **2011**, *39*, 689–698. [CrossRef]
4. Xia, L.; Liu, H.; Zhang, M.; Yuan, B.; Li, Y. Supply Chain Coordination Based on Incremental Profit-Sharing Contract of Carbon Emission Reduction under Mandatory Carbon Emissions Capacity Scheme. *J. Oper. Res. Manag. Sci.* **2019**, *28*, 92.
5. Benjaafar, S.; Li, Y.Z.; Daskin, M. Carbon Footprint and the Management of Supply Chains: Insights from Simple Models. *IEEE Trans. Autom. Sci. Eng.* **2013**, *10*, 99–116. [CrossRef]
6. Liu, Z.; Anderson, T.D.; Cruz, J.M. Consumer environmental awareness and competition in two-stage supply chains. *Eur. J. Oper. Res.* **2012**, *218*, 602–613. [CrossRef]
7. Shuai, C.; Ding, L.; Zhang, Y.; Guo, Q.; Shuai, J. How consumers are willing to pay for low-carbon products?—Results from a carbon-labeling scenario experiment in China. *J. Clean. Prod.* **2014**, *83*, 366–373. [CrossRef]
8. Wu, P.; Jin, Y.; Shi, Y.; Shyu, H. The impact of carbon emission costs on manufacturers' production and location decision. *Int. J. Prod. Econ.* **2017**, *193*, 193–206. [CrossRef]
9. Sun, Y.; Yuan, X.; Shi, K. Research on decision of supply chain of fresh agricultural product based on altruism preference. *J. Syst. Eng. Theory Pract.* **2017**, *37*, 1243–1253.

10. Shen, L.; FAN, R.; Wang, Y. Pricing Service Decision and Coordination Mechanism of Low-Carbon ECSC Based on Altruistic Preference. *J. Syst. Sci. Math. Sci.* **2022**, *42*, 1788–1804.
11. Fan, R.; Lin, J.; Zhu, K. Study of game models and the complex dynamics of a low-carbon supply chain with an altruistic retailer under consumers' low-carbon preference. *Phys. A Stat. Mech. Appl.* **2019**, *528*, 121460. [CrossRef]
12. Loch, C.; Wu, Y. Social preferences and supply chain performance: An experimental study. *Manag. Sci.* **2008**, *54*, 1835–1849. [CrossRef]
13. Guo, W.H.; Cheng, T.C.E.; Wang, S.Y. Managing Carbon Footprints in Inventory Control. *Int. J. Prod. Econ.* **2011**, *132*, 178–185.
14. Du, S.F.; Zhu, L.L.; Liang, L.; Ma, F. Emission-dependent supply chain and environment-policy-making in the 'cap-and-trade' system. *Energy Policy* **2013**, *57*, 61–67. [CrossRef]
15. Ji, J.N.; Zhang, Z.Y.; Yang, L. Comparisons of initial carbon allowance allocation rules in an O_2O retail supply chain with the cap-and-trade regulation. *Int. J. Prod. Econ.* **2017**, *187*, 68–84. [CrossRef]
16. Zhang, S.; Wang, C.; Yu, C.; Ren, Y. Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures. *Comput. Ind. Eng.* **2019**, *134*, 27–36. [CrossRef]
17. Mondal, C.; Giri, B.C. Analyzing a manufacturer-retailer sustainable supply chain under cap-and-trade policy and revenue sharing contract. *Oper. Res.* **2022**, *22*, 4057–4092. [CrossRef]
18. Li, Z.; Pan, Y.; Yang, W.; Ma, J.; Zhou, M. Effects of government subsidies on green technology investment and green marketing coordination of supply chain under the cap-and-trade mechanism. *Energy Econ.* **2021**, *101*, 105426. [CrossRef]
19. Huang, H.; Zhang, J.; Ren, X.; Zhou, X. Greenness and Pricing Decisions of Cooperative Supply Chains Considering Altruistic Preferences. *Int. J. Environ. Res. Public Health* **2019**, *16*, 51. [CrossRef]
20. Wang, Y.; Yu, Z.; Jin, M.; Mao, J. Decisions and Coordination of Retailer-Led Low-Carbon Supply Chain under Altruistic Preference. *Eur. J. Oper. Res.* **2021**, *293*, 910–925. [CrossRef]
21. Ma, D.; Hu, J.; Yao, F. Big data empowering low-carbon smart tourism study on low-carbon tourism O_2O supply chain considering consumer behaviors and corporate altruistic preferences. *Comput. Ind. Eng.* **2021**, *153*, 107061. [CrossRef]
22. Xiao, S.; Chang, X.; Chen, M. Altruistic preference and government subsidies in a manufacturing-recycling system with eco-design. *J. Clean. Prod.* **2022**, *359*, 132095. [CrossRef]
23. Zhang, G.; Zhao, L.; Zhang, Q.; Zhang, Z. Effects of socially responsible behaviors in a supply chain under carbon cap-and-trade regulation. *Discret. Dyn. Nat. Soc.* **2021**, *2021*, 6218978. [CrossRef]
24. Asgari, N.; Nikbakhsh, E.; Hill, A.; Farahani, R.Z. Supply chain management 1982–2015: A review. *IMA J. Manag. Math.* **2016**, *27*, 353–379. [CrossRef]
25. Das, C.; Jharkharia, S. Low carbon supply chain: A state-of-the-art literature review. *J. Manuf. Technol. Manag.* **2018**, *29*, 398–428. [CrossRef]
26. Barragán-Beaud, C.; Pizarro-Alonso, A.; Xylia, M.; Syri, S.; Silveira, S. Carbon tax or emissions trading? An analysis of economic and political feasibility of policy mechanisms for greenhouse gas emissions reduction in the Mexican power sector. *Energy Policy* **2018**, *122*, 287–299. [CrossRef]
27. Song, J.; Leng, M. Analysis of the single-period problem under carbon emissions policies. In *Handbook of Newsvendor Problems*; Choi, T.-M., Ed.; Springer: New York, NY, USA, 2012; Volume 176, pp. 297–313. ISBN 9781461435990.
28. He, P.; Zhang, W.; Xu, X.Y.; Bian, Y.W. Production lot-sizing and carbon emissions under cap-and-trade and carbon tax regulations. *J. Clean. Prod.* **2015**, *103*, 241–248. [CrossRef]
29. Swami, S.; Shah, J. Channel coordination in green supply chain management. *J. Oper. Res. Soc.* **2013**, *64*, 336–351. [CrossRef]
30. Lee, J.Y.; Choi, S. Supply chain investment and contracting for carbon emissions reduction: A social planner's perspective. *Int. J. Prod. Econ.* **2021**, *231*, 107873. [CrossRef]
31. Xu, X.; Ping, H.; Hao, X.; Zhang, Q. Supply chain coordination with green technology under cap-and-trade regulation. *Int. J. Prod. Econ.* **2017**, *183*, 433–442. [CrossRef]
32. Bai, Q.G.; Xu, J.T.; Zhang, Y.Y. Emission reduction decision and coordination of a make-to-order supply chain with two products under cap-and-trade regulation. *Comput. Ind. Eng.* **2018**, *119*, 131–145.
33. Li, B.; Zhu, M.; Jiang, Y.; Li, Z. Pricing policies of a competitive dual-channel green supply chain. *J. Clean. Prod.* **2015**, *112*, 2029–2042.
34. Xu, L.; Wang, C.X.; Zhao, J.J. Decision and coordination in the dual-channel supply chain considering cap-and-trade regulation. *J. Clean. Prod.* **2018**, *197*, 551–561. [CrossRef]
35. Jiang, W.; Liu, M.; Gan, L.; Wang, C. Optimal Pricing, Ordering, and Coordination for Prefabricated Building Supply Chain with Power Structure and Flexible Cap-and-Trade. *Mathematics* **2021**, *9*, 2426. [CrossRef]
36. Gino, F.; Pisano, G. Toward a theory of behavioral operations. *Manuf. Serv. Oper. Manag.* **2008**, *10*, 676–691. [CrossRef]
37. Xia, L.; Hao, W.; Qin, J.; Ji, F.; Yue, X. Carbon emission reduction and promotion policies considering social preferences and consumers' low-carbon awareness in the cap-and-trade system. *J. Clean. Prod.* **2018**, *195*, 1105–1124. [CrossRef]
38. Zou, H.; Qin, J.; Dai, B. Optimal Pricing Decisions for a Low-Carbon Supply Chain Considering Fairness Concern under Carbon Quota Policy. *Int. J. Environ. Res. Public Health* **2021**, *18*, 556. [CrossRef]
39. Fehr, E.; Schmidt, K.M. A theory of fairness, competition, and cooperation. *Q. J. Econ.* **1999**, *114*, 817–868. [CrossRef]
40. Charness, G.; Rabin, M. Understanding Social Preferences with Simple Tests. *Q. J. Econ.* **2002**, *117*, 817–869. [CrossRef]

41. Nie, D.; Li, H.; Qu, T.; Liu, Y.; Li, C. Optimizing supply chain configuration with low carbon emission. *J. Clean. Prod.* **2020**, *271*, 122539. [CrossRef]
42. Fehr, E.; Schmidt, K.M. The economics of fairness, reciprocity and altruism—Experimental evidence and new theories. In *Handbook of the Economics of Giving, Altruism and Reciprocity*; Elsevier Science: New York, NY, USA, 2006; Volume 1, pp. 615–691.
43. Wan, X.; Jiang, B.; Qin, M.; Du, Y. Pricing decision and coordination contract in low-carbon tourism supply chains based on altruism preference. *Environ. Eng. Manag. J.* **2019**, *18*, 2501–2518.
44. Wang, Y.; Yu, Z.; Shen, L.; Dong, W. E-Commerce Supply Chain Models under Altruistic Preference. *Mathematics* **2021**, *9*, 632. [CrossRef]
45. Liu, J.; Zhou, L.; Wang, Y. Altruistic Preference Models of Low-Carbon E-Commerce Supply Chain. *Mathematics* **2021**, *9*, 1682. [CrossRef]
46. Wang, M.Y.; Li, Y.M.; Li, M.M.; Shi, W.Q.; Quan, S.P. Will carbon tax affect the strategy and performance of low-carbon technology sharing between enterprises? *J. Clean. Prod.* **2019**, *210*, 724–737. [CrossRef]
47. Liu, G.D.; Chen, J.G.; Li, Z.Y.; Zhu, H.G. Green supply chain innovation strategies considering government subsidy and altruistic preference. *Math. Probl. Eng.* **2022**, *2022*, 5495374. [CrossRef]
48. Bakal, I.S.; Akcali, E. Effects of random yield in remanufacturing with price-sensitive supply and demand. *Prod. Oper. Manag.* **2006**, *15*, 407–420. [CrossRef]
49. Nair, A.; Narasimhan, R. Dynamics of competing with quality-and advertising-based goodwill. *Eur. J. Oper. Res.* **2006**, *175*, 462–474. [CrossRef]
50. Nie, T.; Du, S. Dual-fairness supply chain with quantity discount contracts. *Eur. J. Oper. Res.* **2016**, *258*, 491–500. [CrossRef]