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Supply-Chain Pricing and Coordination for New Energy Vehicles Considering Heterogeneity in Consumers' Low Carbon Preference

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Abstract: Given consumers' willingness to pay different prices for new energy vehicles (NEVs) and traditional vehicles, we construct a utility model of ordinary and green consumers. We establish pricing game models for centralized and decentralized decisions in an NEV's supply chain in order to study the impact of changes in consumers' low carbon preference heterogeneity on supply chain pricing and member profit. The results show that consumers' low carbon preferences and the ratio of green consumers increases with the ex-factory and selling prices of NEVs. An increase in the percentage of green consumers under centralized decision-making will reduce the total profit of the supply chain. Manufacturers' profits under decentralized decision-making are greater than the dealers' profits, and the sum of the two members' profits under decentralized decision-making is less than the total profit of the supply chain under centralized decision-making. We design a revenue-sharing contract to eliminate the double marginal effect.

Keywords: low carbon preference heterogeneity; new energy vehicle; price decision; coordination

1. Introduction

Due to increased resource and environmental pressures [1], the new energy vehicles (NEVs) industry has become the focus of many countries' policies. Compared to the production costs of traditional fuel vehicles, NEVs still have a competitive disadvantage in the vehicle market. Nevertheless, there are some green consumers in the market who show a greater willingness to buy green products such as NEVs, and are willing to pay more for those products [2]. The differences in the production costs and carbon footprints of NEVs and traditional vehicles lead to differences in the demand and market prices between the two types of auto products, which in turn affect the pricing decisions of the auto manufacturers. Therefore, in this study, we explore pricing decision-making for the two types of auto products when considering consumers' preference for low carbon vehicles.

A number of recent operations management studies examined decision-making for supply chain optimization when considering consumers' low carbon preferences. Some studies have examined the impact of low carbon preferences, as well as the methods and attitudes toward the fossil fuel used, on the production process [3–5]. Meanwhile, some research has constructed a demand function to systematically characterize the relationship between low carbon preferences, price, and product demand, and to investigate the impact of low carbon preferences on demand and price [6–8]. In addition, some studies have examined the influence of consumers' preferences for low carbon on supply chain coordination and optimization decisions from different perspectives. These studies have analyzed the interaction mechanism between consumers and supply chain operation decisions by portraying how consumers' preferences for low carbon lead to a market reaction for low carbon, and they have further

proposed a low-carbon supply-chain decision model and method [9–11]. In response to the rise of the NEV market, the relationship between consumers' preferences for low carbon and NEV market acceptance, government subsidies for NEVs, and the impact of low carbon preferences on NEV supply chain decisions, have attracted the interest of some scholars [8,12–15].

Some studies consider the impact of consumers' low carbon preferences on the total profit of the supply chain in the case of supply chain alliances, and study the optimal pricing strategies of products under different alliance models among supply chain enterprises. However, the heterogeneity of consumers is mainly reflected in the consumer purchase channel. No specific study of consumer preference differences has been conducted from a product perspective [16]. Relevant scholars have studied the impact of consumer environmental awareness on product prices in a supply chain consisting of a manufacturer and a retailer, and constructed models to obtain the optimal product prices when the manufacturer is the leader and the retailer is the follower. However, they did not discuss consumer types based on consumer environmental awareness [17]. Some experts established a low-carbon supply chain profit model by considering consumer preferences, considering the differences in consumer preferences, and quantifying them. At the same time, they studied single-channel and dual-channel supply chain pricing decisions and compared the two, but did not consider the coordination of supply chains under a decision mode. Their studies also do not take into account product characteristics in specific areas to describe consumer preference differences to build relevant models [18,19].

Many experts' research on consumer preferences shows that the heterogeneity of consumer preferences is crucial to product prices and sales, and affects the decision-making orientation of NEVs companies. With the increase of consumers' awareness of low-carbon environmental protection, the change in the proportion of green consumers has increasingly affected the development of NEVs. Therefore, the innovations of this study are mainly as follows: First, according to the characteristics of the NEV field, consumers are classified by consumer preferences, and the utility generated when purchasing traditional cars and NEVs is specifically divided. Using this model, we describe the value of green consumers buying NEVs based on the characteristics of the industry. Second, the centralized and decentralized decision-making models are established, and the model results are compared. Third, a coordination mechanism is established to achieve Pareto optimality. The manuscript analyzes the impact of changes on the proportion of green consumers, and the impact of consumer preferences on prices and profits.

The literature mentioned above illustrates that few studies have examined the impact of low carbon preference heterogeneity on low carbon supply chains, especially on NEV supply chain decision-making. Consumer choice caused by the heterogeneity of consumer preferences will lead to different market demands on these two kinds of products. What impact will this change in the market demand structure have on supply chain decisions? This study will examine this question. Specifically, when manufacturers produce both NEVs and traditional vehicles, it is especially important to characterize the impact of different consumers on the demand for the two types of vehicles. Therefore, this study constructs two kinds of consumer utility functions and two kinds of vehicle product demand functions, and establishes centralized and decentralized decision models of the vehicle supply chain. In addition, it designs a revenue-sharing contract and a coordination mechanism. Lastly, the study analyzes the impact of consumers' low-carbon preferences and the proportion of green consumers on supply chain profits, and provides references for NEV companies to make relevant decisions.

To answer these questions, we establish two stylized Stackelberg models. Our contribution includes the following four aspects. First, based on the characteristics of NEVs, this study divides the types of consumers into two types of consumer utility functions, and more fully considers the relevant market situation. Second, this study builds the game models of centralized and decentralized decision-making, the highlight of which is for the competitive market of NEVs and traditional vehicles. Third, through the coordination mechanism design, the profits under the decentralized decision-making are achieved under the centralized decision-making, the dealer has enough power to achieve Pareto improvement, and obtain the optimal price, demand, and profit under the coordination mechanism.

Finally, numerical analysis more intuitively shows the impact of consumer low carbon preferences and the proportion of green consumers on prices and supply chain profits.

Our analysis leads to some interesting results. First, the increase in consumers' low-carbon preferences and the proportion of green consumers will boost the ex-factory price and sales price of NEVs, and the increase in the proportion of green consumers under centralized decision-making will reduce the total profit of the supply chain. Second, by comparing the two decision-making results, the optimal market sales price of NEVs and traditional vehicles under decentralized decision-making is shown to be higher than centralized decision-making. Under centralized decision-making, consumers' demand for NEVs and traditional vehicles is greater than decentralized decision-making. Third, the profit of the manufacturer under the decentralized decision is greater than the profit of the dealer, but the sum of the two is less than the total profit of the supply chain under the centralized decision. Finally, under the revenue sharing contract, there is an interval to satisfy the profit of the automobile manufacturers and dealers after the coordination mechanism is greater than the profit before the coordination.

The remainder of this study is organized as follows: Section 1 reviews the literature. The problem description and parameter hypotheses are dealt with in Section 2. Section 3 established the two models including a centralized decision model and decentralized decision model for NEV supply chain, and compares the main decisions and profits under the two models. Section 4 designs coordination mechanism and Pareto improvement is realized to eliminate the "double marginal effect". Section 5 provides a numerical analysis of NEV supply chain decisions under centralized and decentralized decision making. Finally, Section 6 presents concluding remarks and future research directions.

2. Problem Description and Parameter Hypotheses

This study considered a two-tiered automotive supply chain consisting of a single supplier and a single dealer, the automaker as the leader in the supply chain, the dealer as the follower, with the automaker producing both traditional vehicles and NEVs. Assume that the unit production costs of traditional vehicles and NEVs are c_t and c_n , with $c_n > c_t$ [15]. The ex-factory prices of the two types of products are w_t and w_n . The corresponding market prices are p_t and p_n . Suppose the potential scale of the market is β . There are two types of consumer groups in the market: ordinary and green consumers. The difference in willingness to pay between ordinary and green consumers leads to differences in product valuations and consumption utilities. The ratio of ordinary consumers to green consumers is r , $0 < r < 1$, which means the ratio of green to ordinary consumers is $1 - r$.

Each consumer was assumed to buy at most one traditional vehicle or NEV. Both types of consumers are rational, since consumers have different estimates of the costs and benefits of NEVs and traditional vehicles. This study considers the difference in the environmental impact of the two types of vehicles, so it assumes that NEVs and traditional vehicles provide equal levels of utility to consumers in terms of basic needs (such as appearance, comfort, etc.). Assume the estimated value of consumers' basic needs from traditional and NEVs is λ , and follows a uniform distribution on $[0, 1]$. Consumer preference for low carbon is θ , with $0 < \theta < 1$. θ can be understood as the price that consumers are willing to pay to reduce one unit of carbon emissions; this means consumers are willing to pay a higher market price for environmentally friendly and low-carbon products. The estimated value of traditional vehicles for green consumers is λ . Green consumers who buy NEVs receive a higher utility from low carbon, so their valuation of NEVs is $(1 + \theta)\lambda$ [15]. Ordinary consumers do not consider the impact of low carbon, so their valuation of NEVs is equivalent to their valuation of traditional vehicles, thus they have no preference for NEVs.

Following Zhu [20], if the estimated value of the product to the consumer is γ , and the product's selling price is p , then the net utility to the consumer of purchasing the product is $U = \gamma - p$. Therefore, the utility to green consumers of buying traditional vehicles is $U_t^a = \lambda - p_t$ and for NEVs it is $U_n^a = (1 + \theta)\lambda - p_n$. The utility to ordinary consumers of buying traditional vehicles is $U_t^b = \lambda - p_t$ and for NEVs it is $U_n^b = \lambda - p_n$.

Green consumers are more inclined to buy traditional vehicles when the following conditions are met: $U_t^a > U_n^a$ and $U_t^a > 0$; simplified, this means that $\lambda < \frac{p_n - p_t}{\theta}$ and $\lambda > p_t$. Therefore, if green consumers' willingness to pay meets $p_t < \lambda < \frac{p_n - p_t}{\theta}$, $p_n > (1 + \theta)p_t$, then green consumers' demand for traditional vehicles is $D_t^a = \beta r \int_{p_t}^{\frac{p_n - p_t}{\theta}} f(\lambda) d\lambda = \beta r \left(\frac{p_n - p_t}{\theta} - p_t \right)$. The condition under which green consumers tend to buy NEVs is when $U_n^a > U_t^a$ and $U_n^a > 0$; when this is simplified, we get $\lambda > \frac{p_n - p_t}{\theta}$ and $\lambda > \frac{p_n}{1 + \theta}$. From to $p_n > (1 + \theta)p_t$ we get $\frac{p_n - p_t}{\theta} > \frac{p_n}{1 + \theta}$. So when green consumers' willingness to pay meets $\frac{p_n - p_t}{\theta} < \lambda < 1$, green consumers' demand for NEVs is $D_n^a = \beta r \int_{\frac{p_n - p_t}{\theta}}^1 f(\lambda) d\lambda = \beta r \left(1 - \frac{p_n - p_t}{\theta} \right)$.

Similarly, the conditions under which ordinary consumers purchase NEVs are when $U_n^b > U_t^b$ and $U_n^b > 0$. When their willingness to pay meets $p_n < \lambda < 1$, their demand for NEVs is $D_n^b = \beta(1 - r) \int_{p_n}^1 f(\lambda) d\lambda = \beta(1 - r)(1 - p_n)$. Ordinary consumers' willingness to pay for traditional vehicles meets $p_t < \lambda < 1$, and their demand for traditional vehicles is $D_t^b = \beta(1 - r) \int_{p_t}^1 f(\lambda) d\lambda = \beta(1 - r)(1 - p_t)$.

Therefore, the total demand for NEVs and traditional vehicles is:

$$D_n = D_n^a + D_n^b = \beta r \left(1 - \frac{p_n - p_t}{\theta} \right) + \beta(1 - r)(1 - p_n) \tag{1}$$

$$D_t = D_t^a + D_t^b = \beta r \left(\frac{p_n - p_t}{\theta} - p_t \right) + \beta(1 - r)(1 - p_t). \tag{2}$$

The profit function expressions for vehicle manufacturers and dealers are:

$$\prod_m = (w_t - c_t)D_t + (w_n - c_n)D_n$$

$$\prod_l = (p_t - w_t)D_t + (p_n - w_n)D_n.$$

Finally, the symbols used in this paper are summarized in Table 1.

Table 1. Parameter descriptions.

Parameter Symbol	Description	Parameter Hypotheses
c_t, c_n	Unit production cost of traditional vehicles, NEVs	
p_t, p_n	Market selling price of traditional vehicles, NEVs	
w_t, w_n	Ex-factory price of unit traditional vehicles, NEVs	
β	Potential market scale	
r	The proportion of green consumers	$0 < r < 1$
λ	Consumer basic needs valuations of traditional vehicle and NEV	$0 < \lambda < 1$
θ	Consumer preference for low carbon	$0 < \theta < 1$
U_t^a	The utility function of green consumers for buying traditional vehicles	
U_n^a	The utility function of green consumers for buying NEVs	
U_t^b	The utility function of ordinary consumers for buying traditional vehicles	
U_n^b	Utility function of ordinary consumers for buying NEVs	
D_n^a, D_n^b	Market demand for buying NEVs for ordinary consumers, green consumers	
D_t^a, D_t^b	Market demand for buying traditional vehicles for ordinary consumers, green consumers	
D_t, D_n	Total demand for traditional vehicles, NEVs	
Π_s	Total profit of supply chain under centralized decision-making	
Π_m^j, Π_l^j	Total profit of automakers and dealers under decentralized decision-making	
p_t^j, p_n^j	Selling price of traditional vehicles and NEVs under decentralized decision-making	
w_t^j, w_n^j	Ex-factory price of traditional vehicles and NEVs under decentralized decision-making	

3. Model Establishment and Solutions

3.1. Centralized Decision Model of the NEV Supply Chain

This section assumes that NEV supply chain companies maximize their overall profits through centralized decision-making. Thus, the total profit function for the NEV supply chain is:

$$\prod_S = (p_t - c_t)D_t + (p_n - c_n)D_n. \quad (3)$$

According to the above formula, the Hessian matrix of \prod_S is:

$$H = \begin{bmatrix} -2\beta(1-r) - \frac{2\beta r}{\theta} & \frac{2\beta r}{\theta} \\ \frac{2\beta r}{\theta} & -2\beta(1-r) - 3\beta r(1 + \frac{1}{\theta}) \end{bmatrix}.$$

The Hessian matrix is negative for $-2\beta(1-r) - \frac{2\beta r}{\theta} < 0$ and $|H| > 0$. Therefore, with respect to p_n and p_t , \prod_S is strictly a convex function, and a unique optimal solution exists. Proposition 1 can be obtained by combining Equations (1) and (2) to solve Equation (3).

Proposition 1. Under centralized decision-making, the optimal selling prices for NEVs and traditional vehicles are:

$$p_n = \frac{r(\theta c_n + r c_n + r) - (c_n + 1)(2r + \theta)}{2[r(r + \theta) - (2r + \theta)]} \quad (4)$$

$$p_t = \frac{r[\theta(2 + c_t) - 2(1 + c_t) + r^2(1 - \theta + c_t) - \theta(1 + c_t)]}{2(r^2 + r\theta - \theta)}. \quad (5)$$

Take the first partial derivative with respect to p_n, p_t and assume $\frac{\partial \prod_S}{\partial p_n} = 0$ and $\frac{\partial \prod_S}{\partial p_t} = 0$. Solving the simultaneous equations yields, the optimal selling price for NEVs and traditional vehicles.

Proposition 2. Under centralized decision-making, the optimal selling price of NEVs is a concave function about θ and r .

Taking the first partial derivative with respect to p_n, p_t , we get

$$\frac{\partial p_n}{\partial \theta} = \frac{(2-r)r^2}{2[r^2 + (\theta-2) - \theta]^2} > 0,$$

$$\frac{\partial p_n}{\partial r} = \frac{\theta(r^2 + \theta)}{2[r^2 + r(\theta-2) - \theta]^2} > 0.$$

That is, as θ increases, the selling price of NEVs increases; also, as the proportion of green consumers increases, the selling price of NEVs increases.

Substituting p_n, p_t into Equations (1)–(3) yields the market demand and total supply chain profit for NEVs and traditional vehicles. The functional expressions are as follows:

$$D_n = \frac{\beta[\theta[1 + c_t(r-1)] + r(c_n - c_t)]}{2\theta} \quad (6)$$

$$D_t = \frac{\beta r(c_n - c_t) - \beta\theta(c_t + r - 1)}{2\theta} \quad (7)$$

$$\begin{aligned} \Pi_S = & \frac{[(c_t-1)(\theta-r^2)-rc_t(\theta-2)-2r][\theta+\theta c_t(r-1)+r(c_n-c_t)]}{4\beta\theta[r^2-\theta+(\theta-2)]} \\ & + \frac{[(\theta+2r+r\theta(c_t-2)-2rc_t)-\theta c_t+r^2(\theta+c_t-1)][\theta(r+c_t-1)+r(c_t)]}{4\beta\theta[r^2-\theta+(\theta-2)]} \end{aligned} \tag{8}$$

Proposition 3. Under centralized decision-making, the demand for NEVs is a concave function about θ , and the demand for traditional vehicles is a convex function about θ .

Under centralized decision-making, take the first partial derivative with respect to θ in NEV market demand D_n , then $\frac{\partial D_n}{\partial \theta} = \frac{\beta r(c_n - c_t)}{2\theta^2} > 0$. As consumers' preferences for low carbon quality increase, so too does the demand for NEVs. Similarly, $\frac{\partial D_t}{\partial \theta} = -\frac{r^2(r+3)(r-1)}{2[r^2+r(\theta-2)-\theta]^2} < 0$, and the demand in the traditional vehicle market decreases as θ increases.

3.2. Decentralized Decision Model of the NEV Supply Chain

Under decentralized decision-making, automakers are leaders in the supply chain for NEVs, and dealers are followers. Both parties maximize their profits. The manufacturer determines the ex-factory price of the product based on the demand for the two products. The dealer decides the final market prices of the traditional vehicle and the NEV. Thus, we can obtain the Stackelberg game model of the two-level supply chain of NEVs that consists of a vehicle manufacturer and a dealer. The details are as follows:

$$\text{Max} \prod_m^j = (w_t - c_t)D_t + (w_n - c_n)D_n \tag{9}$$

$$\text{s.t. Max} \prod_l^j = (p_t - w_t)D_t + (p_n - w_n)D_n. \tag{10}$$

Here, j represents the optimal solution under decentralized decision-making. Combining Equations (1), (2), (4), and (5) to calculate and solve the model above, we obtain Proposition 4.

Proposition 4. Under decentralized decision-making, the optimal ex-factory price of NEVs and traditional vehicles, and the optimal selling price for dealers, are:

$$w_n^j = \frac{(1 + c_n)(r^2 - \theta) + r[-2 + (\theta - 2)c_n]}{2[r^2 + r(\theta - 2) - \theta]} \tag{11}$$

$$w_t^j = \frac{r^2(1 - r + c_t) + r[-2(1 + c_t) + \theta(2 + c_t)] - \theta(1 + c_t)}{2[r^2 + r(\theta - 2) - \theta]} \tag{12}$$

$$p_n^j = \frac{(3 + c_n)(r^2 - \theta) + r[c_n(\theta - 2) - 6]}{4[r^2 + r(\theta - 2) - \theta]} \tag{13}$$

$$p_t^j = \frac{r^2(3 - 3\theta + c_t) + r[-2(3 + c_t) + \theta(6 + c_t)] - \theta(3 + c_t)}{4[r^2 + r(\theta - 2) - \theta]} \tag{14}$$

Substituting the above optimal decision results into Equations (1), (2), (9), and (10), we obtain optimal demand D_n^j for NEVs and D_t^j for traditional vehicles.

Taking the first partial derivative of \prod_l^j with respect to p_n, p_t , we reveal that it is strictly a convex function about \prod_l^j , and that a unique optimal solution exists. Substituting it into \prod_m^j , \prod_m^j is a strictly convex function about w_n, w_t . There is a unique ex-factory price for NEVs and traditional vehicles, and the market price for NEVs and traditional vehicles is p_n^j, p_t^j . Solving by inverse induction and

assuming $\frac{\partial \Pi_m^j}{\partial w_n} = 0$, then $w_n = \frac{r\theta c_n + rc_t - 2rw_t - \theta - c_n(1+c_n)}{2(r\theta - r - \theta)}$. Substituting that into $\frac{\partial \Pi_m^j}{\partial w_t} = 0$, we can obtain the optimal ex-factory price and market selling price for the two types of products.

Proposition 4 indicates that, under decentralized decision-making, the profit of automakers increases as the ex-factory prices of NEVs and traditional vehicles increase, signifying that the increase in ex-factory prices has no obvious impact on consumer demand. Thus, automobile manufacturers should increase their ex-factory prices under conditions that guarantee a certain sales volume, and thus increase their profits.

Proposition 5. Under the decentralized decision-making model, the optimal ex-factory and market selling prices of NEVs are concave functions about the preference for low carbon, θ , and the proportion of green consumers, r . Conversely, w_t^j and p_t^j of traditional vehicles are convex functions with respect to θ and r .

Taking the first partial derivative of w_n^j and p_n^j with respect to θ and r :

$$\frac{\partial w_n^j}{\partial \theta} = \frac{(2-r)r^2}{2[r^2 + r(\theta - 2) - \theta]^2} > 0,$$

$$\frac{\partial p_n^j}{\partial r} = \frac{\theta(r^2 + \theta)}{2[r^2 + r(\theta - 2) - \theta]} > 0.$$

w_n^j, p_n^j increase as θ increases, and w_t^j, p_t^j decrease as θ increases. w_n^j, p_n^j increase as r increases, w_t^j, p_t^j decrease as r increases. The increase in consumers' preferences for low carbon and the proportion of green consumers will help automakers and dealers sell NEVs, and will increase consumer demand for NEVs. Therefore, automakers and dealers should actively take measures to raise consumer awareness of environmental protection, increase the proportion of green consumers, and increase the market price of NEVs, which will contribute to the profit growth of NEV supply chain enterprises.

3.3. Comparison of Results

We obtained Propositions 6 and 7 by comparing the selling price and market demand for NEVs and traditional vehicles under centralized and decentralized decision-making.

Proposition 6. Comparing the selling price and market demand for NEVs and traditional vehicles under centralized and decentralized decision-making, we get: $p_n < p_n^j, p_t < p_t^j$.

We observe that $p_n < p_n^j$ for $p_n - p_n^j < 0$. Similarly, $p_t < p_t^j$. This result indicates that the optimal market selling price of NEVs and traditional vehicles is higher under decentralized decision-making than centralized decision-making. Under decentralized decision-making, automakers and dealers make decisions to increase their own profits and increase the selling prices of the two types of vehicles, thereby reducing market demand.

Proposition 7. Under both centralized and decentralized decision-making, the demand for NEVs and traditional vehicles follows the following relationship: $D_n > D_n^j, D_t > D_t^j$.

From Equation (6), $D_n = \frac{\beta[\theta [1 + c_t(r-1)] + r(c_n - c_t)]}{2\theta}$. Substituting Equations (11)–(14) into (1), we get $D_n^j = \frac{\beta[\theta [1 + c_t(r-1)] + r(c_n - c_t)]}{4\theta}$. Therefore, $D_n > D_n^j$. Similarly, $D_t = \frac{\beta r(c_n - c_t) - \beta\theta(c_t + r - 1)}{2\theta}$, $D_t^j = \frac{\beta r(c_n - c_t) - \beta\theta(c_t + r - 1)}{4\theta}$, meaning $D_t > D_t^j$. This signifies that the demand for NEVs and traditional vehicles by consumers under centralized decision-making is greater than the demand under decentralized decision-making. In the case of decentralized decision-making, automakers should stimulate demand

and promote profit growth by considering other factors that may affect consumer demand, such as price expectations.

4. Coordination Mechanism Design

Centralized decision-making is the ideal decision-making method for the NEV supply chain, but in practice, most members of the supply chain make decentralized decisions. Under decentralized decision-making, the members of the supply chain are independent participants who try their best to maximize their own interests, which leads to a “double marginal effect” that damages the interests of other supply chain enterprises and a loss of supply chain profits. Currently, a coordination mechanism design is necessary to make profits under decentralized decision-making that are equal to those under centralized decision-making. Dealers have sufficient motivation to achieve Pareto improvement, which coordinates the relationship between manufacturers and dealers through revenue sharing contracts. Dealers transfer part of their sales revenue to manufacturers to expand their revenues and maximize supply chain profits under decentralized decision-making. Dealers not only pay the manufacturer’s ex-factory price w , but also pay the manufacturer a portion of the sales revenue. The manufacturer’s sales share is φ , making the dealer’s sales share $1-\varphi$ ($0 \leq \varphi \leq 1$). Following these assumptions, we obtained profit functions for the manufacturer and the distributor.

$$\prod_m^{j^*} = (w_t - c_t)D_t + (w_n - c_n)D_n + \varphi(w_t D_t + w_n D_n) \quad (15)$$

$$\prod_l^{j^*} = ((1 - \varphi)p_t - w_t)D_t + ((1 - \varphi)p_n - w_n)D_n \quad (16)$$

$$\prod_m^s \geq \prod_m^j, \prod_l^s \geq \prod_l^j \quad (17)$$

Equations (15) and (16) are incentive compatibility conditions. To ensure maximum profits for dealers, the constraint of Formula (17) is that the dealer and the manufacturer are willing to cooperate if their profits are greater under coordination; in that case, the supply chain enterprise accepts the contract coordination mechanism. According to Gérard et al. [21], the revenue sharing contract needs to meet $p_n^{j^*} = p_n, p_t^{j^*} = p_t$; assuming $p_n^{j^*} = p_n, p_t^{j^*} = p_t$, we get Proposition 8.

Proposition 8. Under the coordination mechanism:

C1. The optimal ex-factory price for NEVs and traditional vehicles is:

$$w_n^{j^*} = \frac{(r^2 - \theta)(1 + c_n + \varphi) + r((\theta - 2)c_n - 2(1 + \varphi))}{2((r(\theta - 2) + r^2 - \theta)(1 + \varphi))} \quad (18)$$

$$w_t^{j^*} = \frac{r^2(1 + c_t + \varphi - r - r\varphi) + r(-2(1 + c_t + \varphi) + \theta(2 + c_t + 2\varphi)) - \theta(1 + c_t + \varphi)}{2(r^2 - \theta + r(\theta - 2))(1 + \varphi)} \quad (19)$$

C2. The optimal demand for NEVs and traditional vehicles is:

$$D_n^{j^*} = \frac{\beta[\theta [1 + c_t(r - 1)] + r(c_n - c_t)]}{2\theta} \quad (20)$$

$$D_t^{j^*} = \frac{\beta r(c_n - c_t) - \beta\theta(c_t + r - 1)}{2\theta} \quad (21)$$

C3. The profits of automakers and dealers are:

$$\Pi_m^{j*} = \frac{\left\{ \begin{array}{l} \theta^2 \beta (c_n^2 + c_t^2 + 2(1 + \varphi) - (2 + \varphi)(c_n + c_t)) + r\theta\beta(3c_n^2 + 4c_t - 3c_t^2 - 4\varphi + 2c_t\varphi + 2c_n(2 + c_t + c_n)) \\ + \theta\beta(2c_n^2 + c_t^2 + 3 + 3\varphi - (2 + \varphi)(c_n + 2c_t)) + r^3\beta(\theta^2(1 + \varphi) - \theta(1 + c_n^2 + \varphi - 2c_t - \varphi c_t)) - \\ \beta(r^2\theta^2(c_n^2 + 3 + 3\varphi - 2c_t - \varphi c_t) + \theta(-4c_n^2 - 2c_t^2 - 4(1 + \varphi) + 3c_t(2 + \varphi) + c_n(2 + 2c_t + \varphi))) \end{array} \right\}}{4\theta(r^2 + \theta + r(\theta - 2))} \quad (22)$$

$$\Pi_l^{j*} = \frac{\left\{ \begin{array}{l} \theta^2 \beta \varphi (c_n + c_t + \varphi c_n^2 + \varphi c_t^2 - 2(1 + \varphi)) + r^3 \beta \varphi ((c_n - c_t)^2 \varphi + \theta^2(1 + \varphi) + \theta(c_t - 1 + \varphi c_n^2 - \varphi)) \\ - r\beta\varphi\theta(4 - 2c_t + 4\varphi - 3\varphi c_n^2 - 3\varphi c_t^2 + 2c_t(\varphi c_t - 1) + \theta(c_n + 2c_t - 3\varphi + 2\varphi c_n^2 + \varphi c_t^2)) + \\ r^2 \beta \varphi (2\varphi(c_n - c_t)^2 + \theta^2(\varphi + \varphi(c_n^2 - 3) - 3) - \theta\beta\varphi(c_n + 3c_t + 4\varphi c_n^2 - 2\varphi c_n c_t + 2\varphi c_t^2 - 4(1 + \varphi))) \end{array} \right\}}{4\theta(1 + \varphi)(r^2 + r(\theta - 2) - \theta)} \quad (23)$$

The method of proof here is identical to the proof for Proposition 4. p_n^{j*} and p_t^{j*} are available in revenue sharing contracts. According to the theory of revenue sharing contracts, assume $p_n^{j*} = p_n$, $p_t^{j*} = p_t$, then we can obtain the ex-factory prices w_n^{j*} and w_t^{j*} for NEVs and traditional vehicles about D_n^{j*} and D_t^{j*} . Substituting these results into Equations (15) and (16) results in the profits for automobile manufacturers and dealers, Π_m^{j*} and Π_l^{j*} .

If the supply chain enterprise agrees to a revenue sharing contract, it will accept the contract coordination mechanism when the manufacturer's and the coordinated dealer's profits are greater with coordination than without coordination.

$$\prod_m^s \geq \prod_m^j, \prod_l^s \geq \prod_l^j \quad (24)$$

Following the above conditions, we obtain Proposition 9.

Proposition 9. Under a revenue sharing contract, there is an interval $[\underline{\varphi}, \overline{\varphi}]$, $\varphi \in [\underline{\varphi}, \overline{\varphi}]$, that meets the condition that the profits of automakers and dealers are greater than their profits without coordination. There are a number of different values for φ that result in the profit of the automobile supply chain enterprise under the coordination mechanism matching its profit under centralized decision-making.

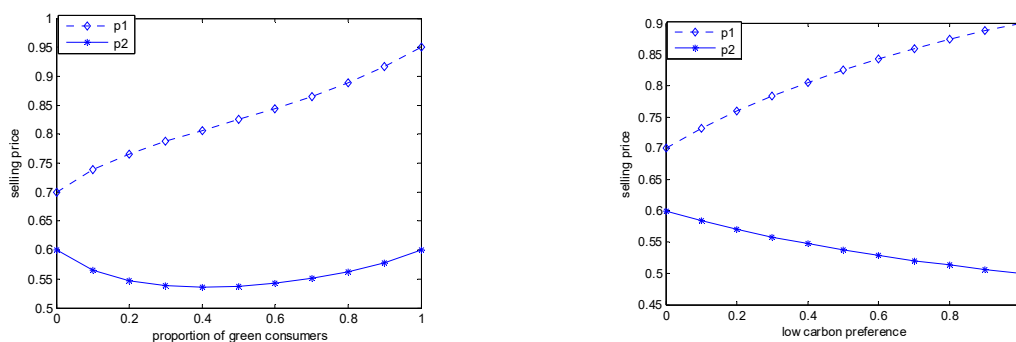
We apply Equation (24) to calculate the interval $[\underline{\varphi}, \overline{\varphi}]$, $0 < \varphi \leq 1$, which assures the profit of the coordinated supply chain enterprise is higher than its profit before coordination.

5. Numerical Analysis

This section provides a numerical analysis of NEV supply chain decisions under centralized and decentralized decision-making. The influence of the proportions of green consumers and those with low carbon preferences on the price of NEVs and the profit of the supply chain under centralized and decentralized decision-making is presented through numerical analysis, in order to more accurately judge how the changes are trending. The numerical analysis chart can also compare the changes brought by the parameters more directly, meaning the changing trend of the influence of parameters on profit can be clearly seen and analyzed. As such, we can get the relevant research results more clearly. Since $c_n > c_t$, this section assumes that the production costs of NEVs and traditional vehicles are $c_n = 0.4$ and $c_t = 0.2$, respectively, and that the market scale is $\beta = 1$.

5.1. The Impact of r and θ on Prices and Supply Chain Profit under Centralized Decision-Making

Figure 1a,b show the effect the proportion of green consumers and those with low carbon preferences has on the selling prices of NEVs and traditional vehicles under centralized decision-making, and verify the conclusion from Proposition 2. Figure 1a,b illustrate that increases in the proportion of green consumers or low carbon preferences lead to an increase in the selling price of NEVs. An expansion in the proportion of green consumers or low carbon preferences increases consumer demand for NEVs, which increases the price of NEVs. For traditional vehicles, Figure 1a reveals that an increase in the proportion of green consumers causes the selling price of traditional vehicles to decrease to a certain point before it starts to rise. Therefore, when the proportion of green consumers begins to increase, it has a major impact on traditional vehicles; consumer demand for traditional vehicles decreases, which lowers their market prices. The price starts to increase gradually as the proportion of green customers passes 60%. Therefore, traditional automakers should actively adjust their sales strategies and expand market share during this period, as it is beneficial for price growth and profit. Figure 1b shows that an increase in low carbon preference reduces the demand for traditional vehicles and lowers their selling prices.

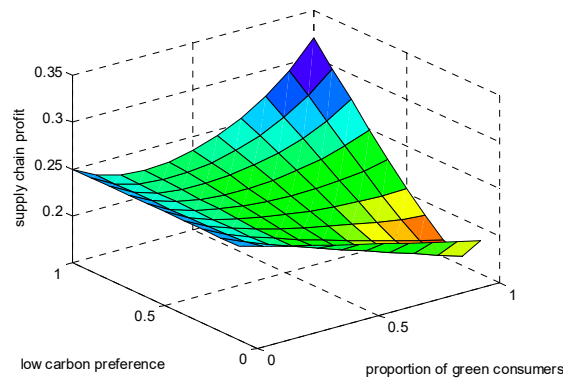


(a) The impact of r on the selling price of NEVs and traditional vehicles under centralized decision-making.

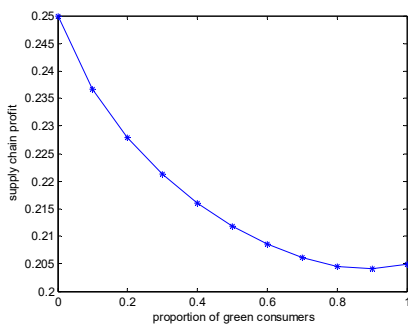
(b) The impact of θ on the selling price of NEVs and traditional vehicles under centralized decision-making.

Figure 1. The impacts of r and θ on the selling price of NEVs and traditional vehicles under centralized decision-making.

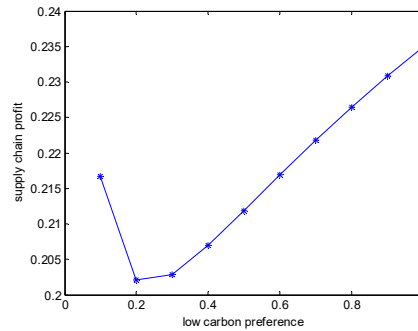
Figure 2a shows the effect the proportion of green consumers and those with low carbon preferences has on the total profit of the supply chain under centralized decision-making. Figure 2b,c display that information in two-dimensional charts. Figure 2a shows that, although the proportion of green consumers increases the selling price in the NEV market, overall, it is detrimental to the total profit of the supply chain under centralized decision-making. This relates to the decline in the price of traditional vehicles, as that decline reduces profits and the increase in the price of NEVs decreases consumer demand. Therefore, NEV manufacturers should increase the selling price of NEVs based on changes in the market environment. Figure 2c clearly illustrates that an increase in low carbon preference leads to a decline in the total profit of the supply chain under centralized decision-making until it drops to a certain level, after which it increases rapidly. The low carbon preference of consumers is directly proportional to market demand. The trend in supply chain profit is inextricably linked to changes in consumers' low carbon preferences.



(a) The impact of r and θ on supply chain profit under centralized decision-making.



(b) The impact of r on supply chain profit under centralized decision-making.



(c) The impact of θ on supply chain profit under centralized decision-making.

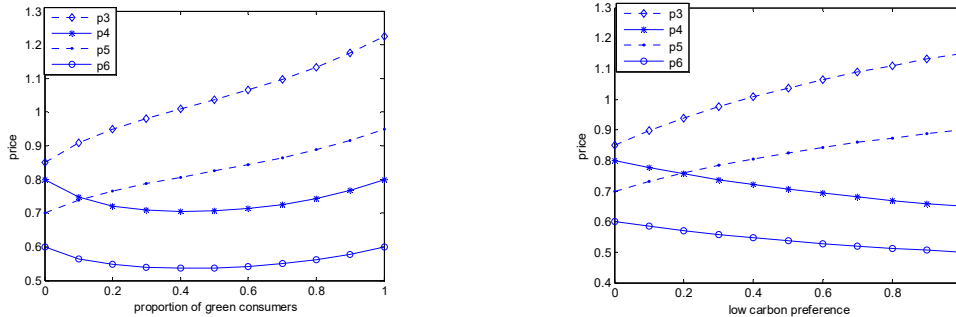
Figure 2. The impacts of r and θ on supply chain profit under centralized decision-making.

5.2. The Effect of r and θ on the Prices and Profits of Manufacturers and Distributors under Decentralized Decision-Making

Figure 3a,b show the effect the proportion of green consumers and those with low carbon preferences has on the selling and ex-factory prices of NEVs and traditional vehicles under decentralized decision-making. The variables p_3 and p_4 are the selling prices of NEVs and traditional vehicles, respectively, while p_5 and p_6 are their ex-factory prices. Figure 3a,b illustrate that the overall impact of the proportion of green consumers and those with low carbon preferences on the selling price of NEVs and traditional vehicles is the same as under centralized decision-making, but its rises and falls are more obvious. At the same time, Figure 3a,b both demonstrate that the selling prices of NEVs and traditional vehicles under decentralized decision-making are greater than under centralized decision-making, which verifies the conclusion from Proposition 6. The proportion of green consumers and those with low carbon preference are directly proportional to the ex-factory price of NEVs. As low carbon preference increases, the ex-factory price of traditional vehicles decreases. However, an increase in the proportion of green consumers leads to a decline in the ex-factory price of traditional vehicles, a trend that is consistent with the trend in selling prices.

Figure 4a,b illustrate the effect the proportion of green consumers and those with low carbon preferences has on the profitability of automakers and dealers under decentralized decision-making. Figure 4a,b indicate that an increase in the proportion of green consumers is inversely related to the profits of manufacturers and distributors. As low carbon preference grows, the profits of manufacturers and distributors decline at first and then rise, which is consistent with the trend under centralized decision-making. Nevertheless, the profits of the manufacturers are greater than the profits of the distributors. Under decentralized decision-making, the manufacturer obtains its optimal profit in the two-tier supply chain that is dominated by the manufacturer. Simultaneously, we compared the total

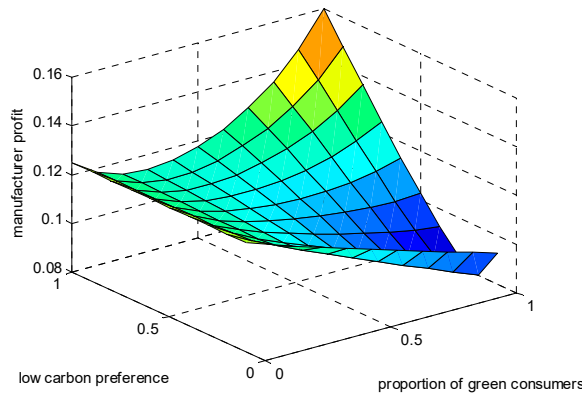
supply chain profit under centralized decision-making to the total profits of manufacturers and dealers under decentralized decision-making. We discovered that the total supply chain profit was higher under centralized decision-making than under decentralized decision-making.



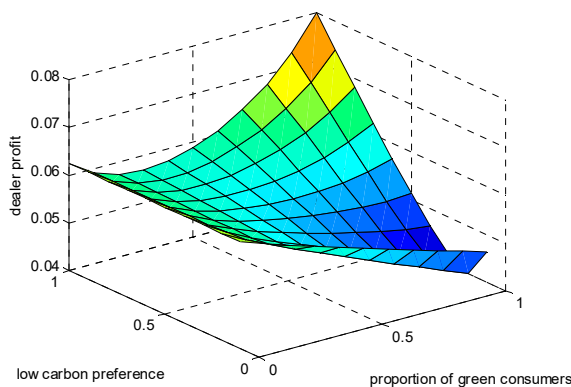
(a) The impact of r on the selling price and ex-factory prices of NEVs and traditional vehicles under decentralized decision-making.

(b) The impact of θ on the selling price and ex-factory prices of NEVs and traditional vehicles under decentralized decision-making.

Figure 3. The impact of r and θ on the selling price and ex-factory prices of NEVs and traditional vehicles under decentralized decision-making.



(a) The impact of r and θ on the profit of the automaker under decentralized decision-making



(b) The impact of r and θ on the profit of the dealer under decentralized decision-making

Figure 4. The impact of r and θ on the profits of the automaker and the dealer under decentralized decision-making.

6. Discussion

This study considered the differences in the willingness to pay of ordinary and green consumers, constructed two types of consumer utility and product demand functions, and established centralized decision and decentralized decision-making models for the NEV supply chain. It examined optimal prices, supply chain profit functions, and demand for traditional vehicles and NEVs. It analyzed the influence of consumers' low carbon preferences and the proportion of green consumers on prices and supply chain profits under two conditions. This study finds that the proportions of green consumers and those with a low carbon preference under centralized decision-making are directly proportional to the selling prices of NEVs. An increase in the proportion of green consumers does not result in an increase of total profits in the supply chain. An increase in the proportion of those with low carbon preferences initially reduces supply chain profits, but as the proportion continues to increase, total profits in the supply chain begin to grow. The proportions of green consumers and those with low carbon preferences under decentralized decision-making are also proportional to the selling price of NEVs. However, under a two-tier supply chain where the manufacturer is the leader and the dealer is the follower, the profit of the manufacturer is greater than the profit of the dealer, thus obtaining optimal profits under decentralized decision-making. The total profit of the supply chain under centralized decision-making is greater than the total profit of the supply chain under decentralized decision-making. Through a design coordination mechanism, the relationship between the manufacturer and the dealer can be coordinated to achieve Pareto optimality. This manuscript discusses the influence of green preference and proportion of green consumers on the price and profit of NEVs. According to the trend shown in these conclusions, the relevant members of the supply chain can make corresponding decision-making plans to increase the profits of enterprises. Therefore, it has important practical significance. Besides, the model in this manuscript can also be applied to other supply chain members' decision-making bodies in the product market similar to the NEV market, that is to say, different descriptions can be made according to specific product and market characteristics, and the conclusions with different product characteristics are of practical significance.

This study examined only the influence the proportion of green consumers and the change in consumers' low carbon preferences have on supply chain pricing decisions from the perspective of consumers. However, in the real world, factors such as service levels and product performances also affect consumer purchasing behavior. How these changes impact the NEV market and supply chain decision-making is an important area for future research. In addition, for some uncertain factors in the supply chain network such as partner selection and resource allocation [22,23], it is also worth studying to implement effective decision-making and risk control from the perspective of the large system composed of NEVs and traditional vehicles.

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