Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 7, No. 3, 2023

Research on Supply Chain Pricing Strategies under Carbon Emission Quota Constraints

Jing Wang*, Fengshan Si

School of Management Science and Engineering, Anhui University of Finance and Economics, Bengbu 233030, China
* Corresponding author: Jing Wang (Email: crystalstella @126.com)

Abstract: In order to reduce the carbon emissions of manufacturers and retailers in their business activities, carbon emission limits must be set for manufacturers and retailers respectively, and they must make favorable decisions within the limits. This paper will focus on a two-level supply chain system composed of a single manufacturer and a single retailer, and explore the optimal wholesale price, optimal retail price, and optimal profit under four scenarios: neither is constrained by carbon quotas, only the manufacturer is constrained by carbon quotas, only the retailer is constrained by carbon quotas, and both are constrained by carbon quotas, by constructing Lagrange functions. Comparative analysis will be conducted. Research has shown that only when manufacturers are subject to carbon quotas, the optimal wholesale and retail prices will rise, and the optimal profits of both manufacturers and retailers will decrease; When retailers are constrained by carbon quotas, whether manufacturers are constrained by carbon quotas does not affect the optimal price and profit; When both are subject to carbon emission restrictions and retailers increase their carbon emission quotas, manufacturers will lower wholesale prices and retailers will lower retail prices.

Keywords: Carbon quotas; Carbon emissions; Supply chain; Lagrangian function; Price game.

1. Introduction

In order to reduce carbon emissions of manufacturing enterprises, regulatory authorities have set carbon emission limits for enterprises. Therefore, only the optimal strategy made by manufacturing enterprises within the carbon limit is effective. This paper will explore the optimal wholesale price and product retail price for a bipolar supply chain system composed of one manufacturer and one retailer.

Scholars have conducted extensive preliminary research on carbon emission and carbon quotas in the supply chain. Zhou et al [1] explored the optimal production and emission reduction of manufacturing enterprises, analyzes the impact of carbon tariffs on carbon emissions and social welfare, and analyzes strategic choices in low-carbon regulation. Research shows that when the cost of carbon reduction is relatively low, manufacturers' production and profits will increase with the increase of carbon tariffs. Carbon tariffs always have a negative impact on the social welfare of low-carbon regulatory countries. Yu et al.[2] studied the carbon reduction efforts and pricing decisions of a two-stage system under a carbon tax. In the vertical direction, two manufacturers make carbon reduction decisions separately. In the horizontal direction, two manufacturers make carbon reduction decisions simultaneously. Research shows that as long as a carbon tax is implemented, vertical cooperation among each supply chain member will lead to a decrease in carbon emission rates and product prices. Kang et al. [3] established an evolutionary game model to study the investment decisions of suppliers and manufacturers under cap and trade rules. Analyzed the strategic stability of suppliers and manufacturers, and discussed the evolutionary stability strategy of the game under relevant conditions. The results indicate that the parameters related to carbon total control and trading affect their willingness to invest in carbon reduction. Zhu and Ma[4]under mixed carbon regulation, a two-level supply chain model consisting of one manufacturer and one supplier is proposed, taking into account consumers' low-carbon preferences and carbon trading within the supply chain. The optimal decisions under four different carbon trading scenarios were presented, and comparisons and sensitivity analysis were conducted. The results indicate that internal carbon trading may not affect manufacturers' production and carbon reduction decisions, but it always affects suppliers' wholesale prices. Hu et al.[5] in order to reveal the interactive effects of government subsidies and corporate social responsibility on carbon emissions in the supply chain system, two decentralized decision models with/without subsidies were designed to study their effects on product prices, profits, and carbon emissions. We have found that subsidies and corporate social responsibility can both reduce carbon emissions and increase the profits of the entire supply chain. Lin et al.[6] on the basis of considering social preferences, a low-carbon supply chain system consisting of a manufacturer and a retailer was constructed. The complex dynamic characteristics of pricing decisions and carbon reduction strategies in the supply chain were analyzed and studied through a dynamic game model. Research has found that retailers' higher social preferences are always beneficial for carbon reduction and manufacturers' profits, and help maintain the stability of the supply chain system. Wang et al. [7] constructed a differential game model that combines total cap and trade regulations with consumers' low-carbon preferences. The emission reduction decisions of two supply chain members were studied under three scenarios. The results indicate that in the scenario of a two-way cooperation contract, both the supply chain profit and emission reduction level are the highest, and channel members put in the greatest effort. Compared to the non-cooperative scenario, both companies have made more efforts to reduce emissions and achieved more profits in the cooperative plan scenario.

The results of the above research have laid the foundation for this study. This paper will consider the constraint of carbon quotas and discuss the optimal strategies in four scenarios: manufacturers and retailers are not subject to carbon emission restrictions, only manufacturers are subject to carbon emission restrictions, only retailers are subject to carbon emission restrictions, and both manufacturers and retailers are subject to carbon emission restrictions. The optimal strategies in these four scenarios will be compared and analyzed. Compared to previous carbon quotas studies, this paper provides a more comprehensive analysis and strategic recommendations that manufacturers and retailers should adopt.

2. Modeling

A two-level supply chain system is composed of one manufacturer and one retailer, The production cost per unit product is c. The manufacturer supplies the retailer at wholesale price w for offline sales, with a retail price is p and a product demand is q. Manufacturers generate carbon emissions during the production process, with a carbon emission per unit product is e_m and a total carbon emission is E_m. Retailers also generate carbon emissions during transportation and sales, with a unit product carbon emission is e_r and a total carbon emission is E_r. In order to achieve green production and operation in the supply chain, regulatory authorities have set carbon emission limits for manufacturers and retailers respectively. The manufacturer's carbon emission limit is E_{m0}, and the retailer's carbon emission limit is E_{r0}.

Assumptions:

(1) To ensure that manufacturers and retailers are profitable, it is necessary to meet $p > w > c > 0$.

(2) This paper studies the Stackelberg game model, where the manufacturer, as the dominant player, decides the wholesale price w first; Retailers, as followers, make decisions on the retail price p.

3. Lagrange Function

Based on the above description, the market demand function of the product is:

$$q = a - \alpha p \tag{1}$$

where, a is the potential maximum demand for the product, and α is the sensitivity coefficient of demand to price.

In the following analysis process, the superscript * represents the optimal strategy, the superscripts a1, a2, b1, and b2 represent four combinations of whether manufacturers and retailers are constrained by carbon emission quotas, π represents profit.

The profit functions of manufacturers and retailers are:

$$\pi_m(w) = (w - c)q \tag{2}$$

$$\pi_r(p) = (p - w)q \tag{3}$$

The carbon emissions of manufacturers and retailers are:

$$E_m = qe_m \tag{4}$$

$$E_r = qe_r \tag{5}$$

The models for manufacturers and retailers constrained by carbon emission quotas are:

$$\begin{cases} \max \pi_m(w) \\ s.t.\ \ E_m \le E_{m0} \end{cases} \tag{6}$$

$$\begin{cases} \max \pi_r(p) \\ s.t.\ \ E_r \le E_{r0} \end{cases} \tag{7}$$

Obviously, models (6) and (7) belong to constrained optimization problems, and the Lagrange functions constructed separately are:

$$L_m(w,\lambda_1) = \pi_m(w) + \lambda_1(E_{m0} - E_m) \tag{8}$$

$$L_r(p,\lambda_2) = \pi_r(p) + \lambda_2(E_{r0} - E_r) \tag{9}$$

where, $\lambda_1 \ge 0$ and $\lambda_2 \ge 0$ are Lagrange multipliers.

It is easy to prove that $\pi_r(p)$ is a strictly convex function about p, and the inequality constraint $qe_r \le E_{r0}$ is convex. Therefore, Eq. (7) is a convex programming problem, and its optimal solution is uniquely determined by the *KKT* condition.

The optimal retail price obtained from first-order optimization conditions is:

$$p = \frac{a + w\alpha + \alpha e_r \lambda_2}{2\alpha} \tag{10}$$

when $\lambda_2 = 0$, i.e. retailers are not constrained by carbon emissions, the optimal retail price is:

$$p = \frac{a + w\alpha}{2\alpha} \tag{11}$$

when $\lambda_2 > 0$, according to the complementary relaxation condition, it can be seen that:

$$E_{r0} - qe_r = 0 \tag{12}$$

Bringing Eq. (10) into Eq.(12) yields:

$$\lambda_2(w) = \frac{ae_r - w\alpha e_r - 2E_{r0}}{\alpha e_r^2} \tag{13}$$

Bringing Eq. (13) into Eq. (10) yields:

$$p = \frac{ae_r - E_{r0}}{\alpha e_r} \tag{14}$$

4. Analysis of Optimal Strategies

The following is a discussion on the optimal prices and profits of manufacturers and retailers in the Stackelberg game in four cases:

(a) When $E_r \le E_{r0}$, that is, the retailer is not constrained by the carbon emission limit $(\lambda_2 = 0)$.

(a1) When $E_m \le E_{m0}$, meaning that the manufacturer is not bound by the carbon emission limit $(\lambda_1 = 0)$. This situation is $\lambda_2 = 0, \lambda_1 = 0$, that is, neither retailers nor manufacturers are bound by carbon emission quotas.

(a2) When $E_m > E_{m0}$, meaning that the manufacturer is constrained by the carbon emission limit $(\lambda_1 > 0)$. This situation is $\lambda_2 = 0, \lambda_1 > 0$, that is, retailers are not constrained by carbon emission quotas, while manufacturers are constrained by carbon emission quotas.

(b) When $E_r > E_{r0}$, it means that the retailer is constrained by the carbon emission limit $(\lambda_2 > 0)$.

(b1) When $E_m \le E_{m0}$, meaning that the manufacturer is not bound by the carbon emission limit $(\lambda_1 = 0)$. This situation is $\lambda_2 > 0, \lambda_1 = 0$, where retailers are constrained by carbon emission quotas, while manufacturers are not constrained by carbon emission quotas.

(b2) When $E_m > E_{m0}$, meaning that the manufacturer is constrained by the carbon emission limit $(\lambda_1 > 0)$. This scenario is $\lambda_2 > 0, \lambda_1 > 0$, where both retailers and manufacturers are constrained by carbon emission quotas.

4.1. Pricing Strategy in Case (A)

Proposition 1: In case (a2), when $\lambda_2 = 0, \lambda_1 > 0$, the optimal retail price is $p^{(a2*)}$, the optimal wholesale price is $w^{(a2*)}$, the manufacturer's optimal profit is $\pi_m^{(a2*)}$, and the retailer's optimal profit is $\pi_r^{(a2*)}$.

Proof: In case (a), when $\lambda_2 = 0$, Eq.(11) is introduced into Eq. (2), it is easy to prove that $\pi_m(w)$ is a strictly convex function with respect to w, and the inequality constraint $qe_m \le E_{m0}$ is convex. Therefore, model (6) is a convex programming problem, and its optimal solution is uniquely determined by KKT conditions.

Simultaneous Eq. (11) and $\frac{\partial L_m(w, \lambda_1)}{\partial w} = 0$ can be obtained:

$$w^{(a2*)} = \frac{a + c\alpha + \alpha e_m \lambda_1}{2\alpha} \tag{15}$$

Bringing Eq. (15) into Eq. (11) yields:

$$p^{(a2*)} = \frac{3a + c\alpha + \alpha e_m \lambda_1}{4\alpha} \tag{16}$$

Taking Eqs. (15) - (16) into Eqs. (2) - (3) respectively, the optimal profits for manufacturers and retailers are:

$$\pi_m^{(a2*)} = \frac{(a - c\alpha)^2 - \alpha^2 e_m^2 \lambda_1^2}{8\alpha} \tag{17}$$

$$\pi_r^{(a2*)} = \frac{(a - c\alpha - \alpha e_m \lambda_1)^2}{16\alpha} \tag{18}$$

So far, proposition 1 has been proven.

By introducing $\lambda_1 = 0$ into Eqs. (15) - (18), the optimal wholesale price is $w^{(a1*)}$, the optimal retail price is $p^{(a1*)}$, the manufacturer's optimal profit is $\pi_m^{(a1*)}$, and the retailer's optimal profit is $\pi_r^{(a1*)}$ in case (a1) $(\lambda_2 = 0, \lambda_1 = 0)$.

$$w^{(a1*)} = \frac{a + c\alpha}{2\alpha}, \quad p^{(a1*)} = \frac{3a + c\alpha}{4\alpha},$$

$$\pi_m^{(a1*)} = \frac{(a - c\alpha)^2}{8\alpha}, \quad \pi_r^{(a1*)} = \frac{(a - c\alpha)^2}{16\alpha}.$$

Based on proposition 1, the following conclusion can be drawn:

Conclusion 1: Comparing $\pi_m^{(a1*)}$ and $\pi_r^{(a1*)}$, it is found that when both manufacturers and retailers have sufficient carbon quotas, the profits of retailers are smaller than those obtained by manufacturers, and the profits of manufacturers are twice that of retailers.

Conclusion 2: From Eqs. (15)- (16), it can be seen that due to $\alpha e_m > 0$, the optimal wholesale price $w^{(a1*)}$ and optimal retail price $p^{(a1*)}$ in case (a1) $(\lambda_1 = 0)$ are both lower than the price values in case (a2). When the retailer's carbon limit is sufficient, both the optimal wholesale price and the optimal retail price will increase when the manufacturer's carbon emissions exceed the carbon limit.

Conclusion 3: From Eqs. (17) and (18), it can be seen that the manufacturer's optimal profit $\pi_m^{(a1*)}$ and retailer's optimal profit $\pi_r^{(a1*)}$ in case (a1) are both greater than the profit values in case (a2). When the carbon limit of retailers is sufficient, the optimal profits of both manufacturers and retailers will decrease when the carbon emissions of manufacturers exceed the carbon limit.

In addition, the following inference was obtained:

Corollary 1:

(1) When $\lambda_2 = 0$, $\lambda_1 = 0$, the condition for the existence of the optimal strategy in Stackelberg games is to satisfy Eqs. (19) and (20).

(2) When $\lambda_2 = 0$， $\lambda_1 > 0$, the condition for the existence of the optimal strategy in Stackelberg games is to satisfy Eqs. (19) and (22).

Proof: When $\lambda_2 = 0$, it can be inferred from the complementary relaxation condition that $E_{r0} - qe_r \ge 0$, and by introducing Eq. (16) into it, it can be obtained that:

$$E_{r0} \ge \frac{1}{4} e_r (a - c\alpha - \alpha e_m \lambda_1) \tag{19}$$

(1) When $\lambda_1 = 0$, according to the complementary relaxation condition, it can be inferred that $E_{m0} - qe_m \ge 0$. By introducing Eq. (16) into it, it can be obtained that:

$$E_{m0} \ge \frac{1}{4} e_m (a - c\alpha - \alpha e_m \lambda_1) \tag{20}$$

(2) When $\lambda_1 > 0$, $E_{m0} - qe_m = 0$ is known according to the complementary relaxation condition, and Eq. (16) is introduced into it, the following can be obtained:

$$\lambda_1 = \frac{ae_m - c\alpha e_m - 4E_{m0}}{\alpha e_m^2} \tag{21}$$

Since the denominator in Eq. (21) is greater than zero, the numerator must be greater than zero, that is:

$$E_{m0} < \frac{(a - c\alpha) e_m}{4} \tag{22}$$

So far, corollary 1 is proved.

According to proposition 1 and corollary 1, the following conclusions are drawn:

Conclusion 4: From Eqs. (15) - (16), when $\lambda_1 > 0$, the optimal retail price and the optimal wholesale price are increasing functions of λ_1. From Eqs. (17) and (18), it can be seen that the optimal profits of manufacturers and retailers are a subtractive function of λ_1. In addition, Eq. (21) shows that λ_1 is a subtractive function of E_{m0}. Therefore, when $\lambda_2 = 0, \lambda_1 > 0$ (case (a2)), the optimal wholesale price $w^{(a2*)}$ and the optimal retail price $p^{(a2*)}$ are subtractive functions of E_{m0}; Both the manufacturer's optimal profit $\pi_m^{(a2*)}$ and the retailer's optimal profit $\pi_r^{(a2*)}$ are increasing functions of E_{m0}.

Conclusion 4 shows that when retailers are not constrained by carbon emissions and manufacturers are constrained by carbon emissions, the increase of manufacturers' carbon emissions quota is beneficial to manufacturers, retailers and consumers.

4.2. Pricing Strategy in Case (B)

Proposition 2: In case (b2), when $\lambda_2 > 0, \lambda_1 > 0$, the optimal retail price is $p^{(b2*)}$, the optimal wholesale price is $w^{(b2*)}$, the optimal profit of the manufacturer is $\pi_m^{(b2*)}$, and the optimal profit of the retailer is $\pi_r^{(b2*)}$.

Proof: In case (b), when $\lambda_2 > 0$, $ae_r - w^{(b2*)}\alpha e_r - 2E_{r0} > 0$ can be known from Eq. (13), so $w^{(b2*)} < (ae_r - 2E_{r0}) / \alpha e_r$ is obtained. Because the manufacturer's profit π_m is an increasing function of the wholesale price w, when the optimal wholesale price $w^{(b2*)}$ is closest to $(ae_r - 2E_{r0}) / \alpha e_r$, the manufacturer's profit is the largest. Therefore, the optimal wholesale price can be expressed as:

$$w^{(b2*)} = \frac{ae_r - 2E_{r0}}{\alpha e_r} - \varepsilon \tag{23}$$

where, $\varepsilon > 0$ and $\varepsilon \to 0$.

In addition, taking Eq. (14) and Eq. (23) into Eq. (3) and Eq. (4) respectively, the optimal profits of manufacturers and retailers can be obtained as follows:

$$\pi_m^{(b2*)} = (w^{(b2*)} - c)(a - \alpha p^{(b2*)}) \tag{24}$$

$$\pi_r^{(b2*)} = (p^{(b2*)} - w^{(b2*)})(a - \alpha p^{(b2*)}) \tag{25}$$

where, $p^{(b2*)} = (ae_r - E_{r0}) / \alpha e_r$.

According to Eqs. (14) and (23), in case (b2), the optimal wholesale price, the optimal retail price, and the optimal profit of the manufacturer and retailer are not affected by λ_1, that is, when the retailer is restricted by the carbon quota, whether the manufacturer is restricted by the carbon quota does not affect the optimal price and profit. I.e. $w^{(b1*)} = w^{(b2*)}$, $p^{(b1*)} = p^{(b2*)}$, $\pi_m^{(b1*)} = \pi_m^{(b2*)}$, $\pi_r^{(b1*)} = \pi_r^{(b2*)}$.

So far, proposition 2 has been proved.

According to proposition 2, the following conclusions are drawn:

Conclusion 5: From Eq. (14) and Eq. (23), we can see that the optimal retail price $p^{(b2*)}$ and the optimal wholesale price $w^{(b2*)}$ in case (b2) $(\lambda_2 > 0, \lambda_1 > 0)$ are negatively correlated with the retailer's carbon quota E_{r0}. That is, when the carbon emission limit of retailers is raised, manufacturers will reduce the wholesale price and retailers will reduce the retail price.

In addition, the following corollaries are obtained:

Corollary 2:

(1) When $\lambda_2 > 0$, $\lambda_1 = 0$, the condition for the existence of optimal strategy in Stackelberg game is satisfied (26).

(2) When $\lambda_2 > 0$, $\lambda_1 > 0$, the condition for the existence of optimal strategy in Stackelberg game is satisfied (28).

Proof: when $\lambda_2 > 0$, according to the complementary relaxation condition, then $E_{r0} - qe_r = 0$, the Eq. (14) is brought into it, and the verification shows that the equation is true.

(1) When $\lambda_1 = 0$, we can know $E_{m0} - qe_m \geq 0$ according to the complementary relaxation condition. By introducing Eq. (14), we can get:

$$E_{m0} \geq \frac{E_{r0}e_m}{e_r} \tag{26}$$

(2) When $\lambda_1 > 0$, we can know $E_{m0} - qe_m = 0$ according to the complementary relaxation condition. By introducing Eq. (10), we can get:

$$\lambda_2 = \frac{-2E_{m0} + ae_m - w\alpha e_m}{\alpha e_m e_r} \tag{27}$$

Because the denominator of Eq. (27) is greater than zero, the numerator must be greater than zero, so we get:

$$E_{m0} < \frac{(a - w\alpha)e_m}{2} \tag{28}$$

So far, corollary 2 is proved.

5. Numerical Simulation

This section discusses the impact of carbon emission quotas on optimal profits. According to the constraints in the paper, a set of parameters in the model are taken as follows: $a = 200$, $\alpha = 0.8$, $E_{m0} = 400$ or $E_{m0} = 100$, $E_{r0} = 100$, $c = 6$, $e_m = 4$, $e_r = 2$, $\varepsilon = 0.01$.

(1) In case (b1), according to corollary 2 (1), the condition for the existence of the optimal strategy is $E_{m0} \geq 200$. Here, $E_{m0} = 400$ is set to ensure that $E_m < E_{m0}$, that is, the manufacturer is not bound by the carbon emission limit. The impact of retailers' carbon emission quota E_{r0} on the optimal profit is shown in Figure.1.

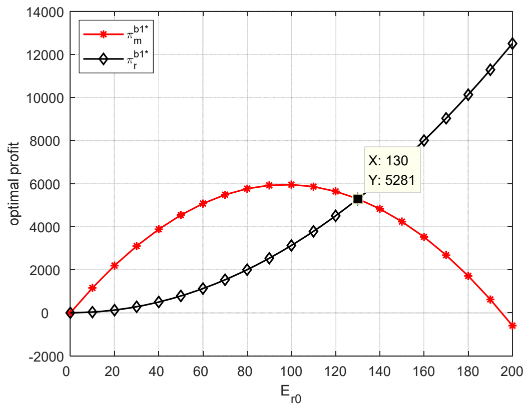

Figure 1. The effect of E_{r0} on optimal profits in case (b1)

Figure.1 shows that the manufacturer's optimal profit

$\pi_m^{(b1^*)}$ increases first and then decreases with the increase of retailer's carbon quota E_{r0}. When $E_{r0} \geq 198$, then $\pi_m^{(b1^*)} \leq 0$. And when $E_{r0} = 130$, then $\pi_m^{(b1^*)} = \pi_r^{(b1^*)}$. It can be clear that the retailer's optimal profit $\pi_r^{(b1^*)}$ is positively correlated with E_{r0}. There is an optimal carbon emission limit E_{r0} for retailers, which maximizes the manufacturer's profit $\pi_m^{(b1^*)}$.

(2) The impact of retailers' carbon emission quota E_{r0} on the optimal retail price $p^{(b1^*)}$ and the optimal wholesale price $w^{(b1^*)}$ in case (b2) is shown in Figure.2.

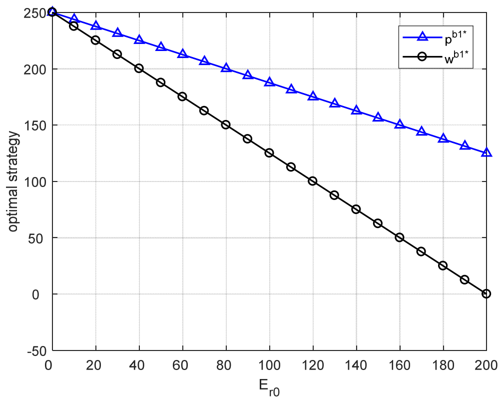

Figure 2. The effect of E_{r0} on optimal profits in case (b2)

It can be seen from Figure.2 that when E_{r0} increases, $p^{(b1^*)}$ and $w^{(b1^*)}$ gradually decrease, and the wholesale price decreases the fastest. Therefore, retailers' carbon emission quota E_{r0} cannot be blindly increased, otherwise manufacturers and retailers will be unprofitable.

6. Conclusion

Aiming at the problem of carbon emission constraints in single channel supply chain, the optimal strategy of manufacturer and retailer in Stackelberg game is analyzed by constructing a nonlinear programming model. This paper discusses whether there are four combined cases of carbon emission constraints between manufacturers and retailers, gives the conditions for the existence of optimal strategies and the analytical formula of optimal strategies in each case, compares and analyzes the differences of optimal prices and optimal profits in different cases, and analyzes the impact of retailers' carbon quotas on the optimal strategies. The research shows that when both manufacturers and retailers are not bound by the carbon quota, the profit of manufacturers is twice that of retailers. Only when the manufacturer is constrained by the carbon quota, there is an optimal carbon emission quota for the retailer to maximize the manufacturer's profit. When both manufacturers and retailers are constrained by carbon emission limits, increasing the carbon emission limits of retailers will lead to the reduction of wholesale and retail prices. Compared with manufacturers and retailers who are not bound by carbon quotas, only manufacturers who are bound by carbon quotas will have lower profits.

Acknowledgment

The authors thank the reviewers for their careful reading and pertinent suggestions. This work was supported by the Natural Science Research Project of Education Department in Anhui Province (2022AH050589); the School-level Science Research Project of Anhui University of Finance and Economics (ACKYB22015).

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] X. Y. Zhou , Q. Y. Zhu , L. Xu， et al. The effect of carbon tariffs and the associated coping strategies: A global supply chain perspective[J]. Omega, 2023.8:1-18.

[2] W. Yu, Y. Wang, W. R. Feng, et al. Low carbon strategy analysis with two competing supply chain considering carbon taxation[J]. Computers & Industrial Engineering, 2022, 4:1-14.

[3] K. Kang, B. Q. Tan. Carbon emission reduction investment in sustainable supply chains under cap-and-trade regulation: An evolutionary game-theoretical perspective[J]. Expert Systems With Applications, 2023, 5:1-16.

[4] C. Zhu , J. Ma. Optimal decisions in two-echelon supply chain under hybrid carbon regulations: The perspective of inner carbon trading[J]. Computers & Industrial Engineering, 2022, 9:1-15.

[5] X. H. He, J. X. Jiang, W. F. Hu. Cross effects of government subsidies and corporate social responsibility on carbon emissions reductions in an omnichannel supply chain system[J]. Computers & Industrial Engineering, 2022, 12:1-14.

[6] J. C. Lin, R. G. Fan, X. C. Tan et al. Dynamic decision and coordination in a low-carbon supply chain considering the retailer's social preference[J]. Socio-Economic Planning Sciences, 2021, 2:1-17.

[7] Y. L. Wang, X. Xu, Q. H. Zhu. Carbon emission reduction decisions of supply chain members under cap-and-trade regulations: A differential game analysis[J]. Computers & Industrial Engineering, 2021, 9:1-18.