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Research on Supply Chain Decision Making of Cold Chain Logistics Service Under Different Government Subsidy Policies

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Abstract: In the context of prioritizing environmental protection gradually becoming a general trend, how to achieve a balance between paying carbon tax and seeking government subsidies for cold chain logistics service supply chain members to further reduce carbon dioxide emissions of products will be an important decision faced by CCLSP. Based on the influence of the government's carbon tax on the cold chain logistics service supply chain, this paper analyzes the influence of different government subsidy policies on the carbon emission reduction decisions of cold chain logistics service providers (CCLSP), logistics information integrators (LSI) and the supply chain as a whole under the two scenarios of joint emission reduction and independent emission reduction. The effects of different subsidy methods and subsidy rates on carbon emission reduction, wholesale price, retail price and profit of CCLSP and LSI were explored, and the results were analyzed by numerical simulation. The results show that: in the case of joint emission reduction, emission reduction subsidy has a more positive impact on supply chain emission reduction and profit. In the case of independent emission reduction, both subsidy methods have a positive impact on the wholesale price, retail price and the profit of CCLSP and LSI. Which method is more effective needs to be selected according to the size of subsidy rate. To a certain extent, this paper provides opinions for the government to formulate a scientific and reasonable subsidy policy, which can provide a basis for CCLSP to reduce carbon emissions for inquiries.

Keywords: Carbon tax, Subsidy strategy, Logistics service supply chain, Stackelberg competition.

1. Introduction

Since the industrial revolution, the massive emission of greenhouse gases has led to an increasingly severe global climate situation, and the control of carbon emissions has become a global consensus, and low-carbon development has become a necessary path for countries around the world to address climate change. In the global low-carbon transition process, China has also announced that it will continue to increase its independent national contribution and strive to achieve "carbon peaking" by 2030 and "carbon neutrality" by 2060, which indicates that China is further accelerating its low-carbon development. On February 9, 2023, the EU adopted the revised ETS and the Carbon Border Adjustment Mechanism (CBAM), and the European "carbon tariff" will be officially imposed from 2026. Facing the pressure from the EU, China has started to consider a carbon tax to complement carbon quotas and carbon trading to strengthen the carbon reduction effect.

"Low carbon" has become the transformation of China's economic development and the direction of industrial restructuring, and is also an inevitable choice for the sustainable development of the logistics industry. With the improvement of consumers' level and consumption concept, the demand for fresh products is increasing day by day, cold chain logistics will usher in new development opportunities and become one of the important transportation methods. However, China's cold chain logistics has a single transport structure, backward refrigeration technology and equipment, unreasonable distribution management and other problems, which makes its energy consumption serious and also causes serious carbon emission effect on the environment. Therefore, under the current trend of energy conservation, emission reduction and environmental protection, how to consider the sustainable development of cold chain logistics from a low-carbon perspective has become one of the important issues that need to be solved. To achieve the double carbon goal, the emission reduction actions of individual enterprises are often difficult to meet the increasingly stringent carbon emission reduction requirements, and carbon emission reduction from the perspective of the supply chain can make up for these shortcomings. However, in traditional supply chain networks, rational decision makers often play with each other with the goal of obtaining maximum profit. In the process of achieving carbon emission reduction in the supply chain, the behavior of supply chain members pursuing individual profit maximization is contrary to the purpose of minimizing carbon emissions in the whole supply chain. There are a lot of research problems in how to allocate responsibilities and benefits to satisfy all parties when the goals of individual members conflict with the overall goals of the supply chain. Based on this background, this paper proposes a study on the equilibrium decision of cold chain logistics service supply chain under the dual carbon objectives, and it is important to investigate the impact of carbon tax and government subsidy policy on the carbon emission reduction of the supply chain.

Foreign research on cold chain logistics started earlier and is more abundant. According to the results of literature search, the research on cold chain logistics can be mainly divided into four aspects about temperature, environment, technology and transportation and distribution, and this paper mainly discusses the research on environment. Babagolzadeh et al. [1] established a two-stage stochastic programming model to minimize the operational and emission costs considering the carbon emission of cold chain under demand uncertainty. Accorsi et al. [2] considered the interaction of weather conditions, based on which they developed a mixed integer linear programming model on the production, storage and distribution operations of perishable products, demonstrating the effect of weather conditions on the energy cost of refrigerated products in vehicles and warehouses during transportation. Ma et al. [3] considered carbon emission rules and consumer preferences for low carbon fresh products and developed a three-way game model consisting of government, carbon emission suppliers and a retailer in a two-level cold chain system.

Regarding carbon policy, many scholars have conducted studies on carbon quotas, carbon tax and carbon trading, and other carbon reduction methods. Lin et al. [4] studied that the government must carry out a fair and equitable allocation of carbon quotas when implementing a carbon trading system, and this premise will lead companies to go to the carbon trading market to sell or buy additional carbon credits if needed. Hong et al. [5] discussed the interaction between the government and companies to levy carbon taxes at tax levels considering greenhouse gas emissions. Fahimnia et al. [6] proposed a bi-objective optimization model integrating economy and carbon emissions under carbon tax policy and a modified cross-entropy solution algorithm to study the potential impact of carbon tax on fiscal and emission reduction performance; Marti et al. [7] proposed an integer programming model considering carbon tax policy and analyzed the impact of different policies on firms' production costs and optimal network structure. Li et al. [8] studied the impact of two carbon tax systems, differential carbon tax and uniform carbon tax, on the carbon abatement cost of production enterprises, the competitiveness of enterprises, and the socio-economic welfare of local governments, respectively. Xu et al. [9] studied an inventory optimization model for perishable products based on inventory-influenced sales patterns under emission reduction regulation.

Low carbon management from the perspective of supply chain, enterprises should not only consider their own production operations and carbon reduction decisions, but also optimize the global resource allocation and coordinate the overall carbon emissions from the perspective of the whole network of supply chain. Plambeck et al. [10] managed the carbon footprint of products from the perspective of supply chain and found that enterprises could not only reduce carbon emissions, but also gain financial benefits. Therefore, it is meaningful to explore the game relationship among supply chain member firms under low carbon policy and study the impact of carbon tax policy on emission reduction. Zhang et al. [11] study the equilibrium decision behavior of supply chain under the effect of mandatory carbon limit policy. Wu et al. [12] construct an equilibrium model of electricity supply chain including carbon tax to study the network equilibrium decision under different carbon taxes. Also for electricity supply chain networks, Prof. Nagurney et al. [13] explored the problem of optimal government carbon tax in equilibrium. Mohammed et al. [14] built a stochastic programming model to design a multi-cycle, multi-product closed-loop supply chain network and analyzed the effects of policies such as carbon tax and total carbon control on the network design scheme. Liu et al. [15] compared three carbon emission policies based on, constructed and analyzed three optimization models, and finally obtained a reasonable and scientific product quantity decision. Haddadsisakht et al. [16] considered the uncertainty of carbon tax rate and demand, and proposed a three-stage stochastic planning model to design a closed-loop supply chain. Zhang et al. [17] studied the conditions for the introduction of carbon tax and the dynamic adjustment strategy of carbon tax in China.

In recent years, government support for industry has been increasing, and academics have conducted in-depth research on this aspect of supply chain subsidies. Mitra et al. [18] constructed a two-period model consisting of manufacturers and remanufacturers to explore the impact of government subsidy policy as an incentive instrument on remanufacturing operations. Sheng et al. [19] proposed two policy incentives, innovation input subsidies and innovation product subsidies, in terms of innovation subsidies, and studied their impact on technology alliances by building a model to compare them. Zhu et al. [20] constructed a three-stage game model considering product greenness and government subsidies based on green supply chain management in which the impact of several parameters, namely subsidy coefficient and greenness level, on the decision of final product producers was discussed. Xu et al. [21] explored and analyzed the impact of the differential pricing problem on the supply chain for two products of different nature based on the current situation that both low-carbon products and common products exist in the market. Li et al. [22] explored the relationship between subsidy policies and the cooperation strategies of enterprises to reduce emissions based on the two influencing parameters of optimal abatement cost input and optimal subsidy rate. Liu et al. [23] compared and studied two different scenarios of separate and simultaneous subsidies based on an improved newsboy model, and the results showed that simultaneous subsidies to two nodal enterprises had better effects on supply chain coordination than subsidizing only one of them. Yu et al. [24] explored government subsidies to manufacturers producing environmentally friendly products, considering factors such as the greenness of the products, and found through modeling analysis that there is an absolute positive relationship between consumers' green awareness and manufacturers' green production level. Fan et al. [25] modeled and analyzed three different cooperation scenarios of supply chain enterprises on the basis of government subsidy policies, and found that the most significant effect was achieved when the three enterprises in the supply chain jointly reduced emissions with respect to the emission reduction per unit product and the profit target function of each enterprise.

Based on this, some experts started the impact of the simultaneous effect of carbon tax and government subsidies on supply chain emission reduction. Xu et al. [26] constructed a supply chain model based on carbon tax constraints regarding two different products, end-of-season surplus and scrap, discussed the issue of supply chain improvement strategies regarding buy-back contracts for end-of-season surplus products, and studied two different types of government low-carbon subsidies for scrap products. Yi et al. [27] investigated how carbon taxes and subsidies for energy-efficient products affect firms' business decisions and found that subsidies and carbon taxes produce different effects. Cao et al. [28] found that the optimal carbon emission reduction, order quantity and expected profit of the supply chain would change according to the proportion of subsidies for carbon emission reduction technology innovation inputs, based on the consideration of carbon tax policy and government subsidies for manufacturers' carbon emission reduction technology innovation inputs through modeling analysis. Xu et al. [29] considered two influencing factors, carbon tax and green subsidies, to explore their effects on social welfare. Bian et al. [30] studied the impact of two environmental policies, emission reduction subsidies and emission taxes, on a three-tier supply chain in which manufacturers distribute through competitive retailers and invest in emission reduction manufacturing technologies.

In summary, based on the results of existing service supply chain research, this paper establishes a cold chain logistics service supply chain equilibrium model based on the consideration of carbon tax constraints, and studies the emission reduction subsidy strategies of low-carbon supply chain enterprises under different government subsidies to find the optimal solution in the supply chain equilibrium model, which includes the optimal wholesale price and unit emission reduction of logistics enterprises, and the optimal retail price charged by integrators. Under the national society advocating low carbon production environment, considering factors such as carbon tax and carbon emission, as well as carbon emission reduction cost coefficient and cost sharing ratio, can promote the implementation of energy saving and emission reduction policies and provide guidance significance for the production and operation activities of enterprises.

2. Organization of the Text

2.1. Section Headings

As a special part of logistics services, cold chain logistics not only consumes a lot of energy but also emits a lot of CO_2, which accelerates the process of global warming. Related studies have found that China's annual carbon emissions from logistics (mainly transportation) are second only to those of the electric power industry. Among them, cold chain logistics services, as an important part of logistics services, are characterized by high transportation difficulties and high technical equipment requirements, resulting in much higher emissions per unit of service than ordinary services. Yet few studies have integrated the emission reduction strategies of logistics enterprises into the supply chain. Meanwhile, carbon tax is proposed as an important means to reduce energy consumption intensity and limit carbon emissions, which poses new challenges to the production and operation management of cold chain logistics and supply chain. The government levies carbon tax will affect the profit of CCLSP, so in order to reduce the pressure of CCLSP to reduce emissions and encourage enterprises to actively participate in carbon emission reduction, the government will give CCLSP certain subsidies in different ways. Logistics services as an important part of the service supply chain system, what impact will carbon tax policy and government subsidies have on the emission reduction strategy of the supply chain, and what is the most appropriate subsidy policy?

To address the above issues, this chapter establishes a supply chain consisting of logistics service integrators(LPI) and cold chain logistics service providers (CCLSP) and the demand market, designs a linear function of cold chain logistics services regarding carbon emissions, and explores the effects of different subsidy policies on the unit emission reduction of CCLSP as well as the pricing of the supply chain and the overall benefits under the constraint of determining carbon tax policies, and analyzes the feedback equilibrium strategies of CCLSP, LPI and the supply chain under different circumstances.

2.2. Figures

Since the real situation is complex and multiple variables are difficult to quantify, in order to facilitate the study, this paper makes reasonable assumptions on the model by referring to Guo et al. [31]. Firstly, both CCLPS and LSI are risk-neutral with symmetric information between members, while it is assumed that both the government and logistics service supply chain enterprises are completely open and transparent with each other, and there is no deception.

Hypothesis 1: CCLSP strives to increase the unit emission reduction e in order to respond to the dual carbon target and reduce carbon emissions, and its abatement cost satisfies the law of increasing marginal cost as a convex function of emission reduction. c_1 is the abatement cost coefficient.

$$C(x) = \frac{1}{2}c_1e^2 \tag{2.1}$$

At the same time, CCLSP needs to spend corresponding cost to improve the cold chain service level, and the service cost mainly considers the temperature control cost during transportation, c_2 is the convex function of service level y, and is the logistics service cost coefficient.

$$C(y) = \frac{1}{2}c_2y^2 \tag{2.2}$$

Hypothesis 2: LSI integrates market demand information and provides logistics order demand information integration service for CCLSP, whose information service cost is a convex function of informationization level Z, and c_3 is the information service cost coefficient.

$$C(z) = \frac{1}{2}c_3z^2 \tag{2.3}$$

Hypothesis 3: The carbon emission of LSI is not considered because the carbon emission of LSI in the process of planning logistics services is small. the carbon emission per unit product when CCLSP does not use emission reduction technology is E_0 , and E_0 is a constant. Therefore, the unit carbon emission when CCLSP uses cold chain technology is E, the unit carbon emission reduction of cold chain logistics service is $e = E_0 - E$. In order to incentivize CCLSP to reduce carbon emissions, the government will charge k yuan carbon tax for each unit of carbon emission, and the actual carbon emission is E, after the enterprise implements the emission reduction action, and the carbon tax at this time is:

$$v = \lambda QE = \lambda Q(E_0 - e) \tag{2.4}$$

Hypothesis 4: The market demand of cold chain logistics services is uncertain demand, influenced by service price, unit emission reduction and cold chain service level, information technology level, this paper is a simplified model, without considering the influence of other factors on the market, the market demand function is.

$$Q = a - bp + \alpha e + \beta y + uz \tag{2.5}$$

It reflects that market demand will increase with the increase of carbon emission reduction and service level of

CCLSP, and the increase of information level of LSI. Where, a is the potential market demand, b is the sensitivity coefficient of consumers to the price of cold chain logistics services, $\alpha$is the sensitivity coefficient of demand to carbon emission reduction, β is the sensitivity coefficient of service level, and u is the sensitivity coefficient of information service level, $(\alpha, \beta, u) > 0, a > bp$.

First, LSI collects information, determines the logistics order quantity from the market demand, and makes a reservation to CCLSP. Subsequently, the CCLSP provides the logistics capacity to the LSI with the unit abatement volume, service level and wholesale price w determined by its own utility maximization as the decision objective. Finally, LSI then determines the market price p with the decision objective of maximizing its own utility level and sells the product.

The profit functions of the supply chain members of cold chain logistics services can be obtained as follows, respectively

$$\pi_C = (w - c - \lambda(E_0 - e))Q - \frac{1}{2}c_1e^2 - \frac{1}{2}c_2y^2 \quad (2.6)$$

$$\pi_I = (p - w)Q - \frac{1}{2}c_3z^2 \quad (2.7)$$

The profit function of the overall supply chain of cold chain logistics services is further obtained as:

$$\pi = (p - c - \lambda(E_0 - e))Q - \frac{1}{2}c_1e^2 - \frac{1}{2}c_2y^2 - \frac{1}{2}c_3z^2 \quad (2.8)$$

3. Literature References

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

3.1. Journal style

In the case of joint emission reduction, CCLSP and LSI make decisions from the perspective of the supply chain of cold chain logistics services, realize the goal of maximizing the profit of the supply chain, and jointly decide the sales price and unit emission reduction of logistics products. The benefits and costs of each entity in this model are closely integrated with the supply chain system, and the profit of the supply chain system at this time is as follows.

$$\pi = (p - c - \lambda(E_0 - e))(a - bp + \alpha e + \beta y + uz) - \frac{1}{2}c_1e^2 - \frac{1}{2}c_2y^2 - \frac{1}{2}c_3z^2 \quad (3.1)$$

In the centralized decision situation, the common goal of CCLSP and LSI is committed to maximize the profit of the cold chain logistics supply chain system, and the retail price of cold chain service p, wholesale price of cold chain service w, emission reduction e and cold chain service level y and information level z are taken as decision variables and $\frac{\partial \pi}{\partial p} = 0$, $\frac{\partial \pi}{\partial x} = 0$, $\frac{\partial \pi}{\partial y} = 0$, $\frac{\partial \pi}{\partial z} = 0$, the optimal cold chain service retail price, cold chain service wholesale price, unit emission reduction and cold chain service level, and information level under centralized decision making can be obtained as:

$$p^{T^*} = \frac{c_2c_3(c_1 - \lambda(\alpha + \lambda b))(a - b(c + \lambda E_0))}{A_1} + c \quad (3.2)$$

$$e^{T^*} = \frac{c_2c_3(\alpha + \lambda b)(a - b(c + \lambda E_0))}{A_1} \quad (3.3)$$

$$y^{T^*} = \frac{\beta c_1c_3(a - b(c + \lambda E_0))}{A_1} \quad (3.4)$$

$$z^{T^*} = \frac{\mu c_1c_2(a - b(c + \lambda E_0))}{A_1} \quad (3.5)$$

Substituting p^{T^*}, e^{T^*}, y^{T^*}, z^{T^*} into the equation (3.1), the optimal profit of the supply chain system of cold chain logistics service under the centralized decision situation can be obtained as:

$$\pi^{T^*} = \frac{c_1c_2c_3(a - b(c + \lambda E_0))^2}{2A_1} \quad (3.6)$$

Where $A_1 = 2bc_1c_2c_3 - c_2c_3(\alpha + \lambda b)^2 - c_1c_3\beta^2 - c_1c_2u^2$.

Proof: In order to make the overall utility function π of the cold chain logistics service supply chain exist in great value, it is necessary to satisfy $A_1 > 0$. Continuing to find the second-order partial derivatives of the system of first-order derivative equations of π with respect to p, e, y, z. The Hessian matrix of the profit function π of the cold chain logistics service supply chain system with respect to the decision variables p, e, y, z in the centralized decision case is:

$$\nabla^2\pi = \begin{bmatrix} -2b & \alpha - \lambda b & \beta & \mu \\ \alpha - \lambda b & 2\lambda\alpha - c_1 & 0 & 0 \\ \beta & 0 & -c_2 & 0 \\ \mu & 0 & 0 & -c_3 \end{bmatrix} \quad (3.7)$$

It can be found that $\frac{\partial^2\pi}{\partial p^2}$, $\frac{\partial^2\pi}{\partial x^2}$, $\frac{\partial^2\pi}{\partial p^2}$, $\frac{\partial^2\pi}{\partial x^2}$ are less than 0. Therefore, when the constraints of each order of principal subformula are less than 0 and $A_1 > 0$ are satisfied, after calculation, the above Hessian matrix can be judged as a negative definite matrix, and thus it can be judged that there is a unique optimal solution for p, e, x, y. At this point, the utility function π is a joint concave function of p, e, x and y and there is an optimal solution.

3.2. Acknowledgment

In order to reduce the pressure of abatement costs and encourage enterprises to abate production, the government will provide corresponding subsidies, assuming that the government subsidizes the abatement cost input of CCLSP at a certain rate. Government subsidies for abatement costs can help enterprises reduce the pressure of abatement R&D costs and share part of the R&D risks for enterprises. Assuming that the government subsidizes the abatement costs of CCLSP at a certain rate θ_1, the overall profit at the time of centralized decision making in the supply chain under the CCLSP abatement strategy:

$$\pi = (p - c - \lambda(E_0 - e))(a - bp + \alpha e + \beta y + uz) - \frac{1}{2}(1 - \theta_1)c_1e^2 - \frac{1}{2}c_2y^2 - \frac{1}{2}c_3z^2 \quad (3.8)$$

When the government subsidizes according to the abatement cost, the common goal of CCLSP and LSI under the centralized decision situation is to devote to maximize the profit of the cold chain logistics supply chain system, and the retail price of cold chain service p, the wholesale price of cold chain service w, the abatement amount e and the level of cold chain y, informatization level z. By calculation, the Hesse matrix of the profit function π of the cold chain logistics service supply chain system with respect to the decision variables p, e y and z in the centralized decision situation is:

$$\nabla^2\pi = \begin{bmatrix} -2b & \alpha-\lambda b & \beta & \mu \\ \alpha-\lambda b & 2\lambda\alpha - c_1(1-\theta_1) & 0 & 0 \\ \beta & 0 & -c_2 & 0 \\ \mu & 0 & 0 & -c_3 \end{bmatrix} \quad (3.9)$$

After calculation, the Hesse matrix can be determined to be negative definite and it is known that π is a concave function. Find the first order derivatives of equation (3.8) with respect to p, e, y and z, with $\frac{\partial\pi}{\partial p}=0$, $\frac{\partial\pi}{\partial e}=0$, $\frac{\partial\pi}{\partial y}=0$, $\frac{\partial\pi}{\partial z}=0$, the optimal cold chain service retail price, cold chain service wholesale price, unit emission reduction and cold chain service level, and information level under centralized decision making can be obtained as:

$$p_c^{T^*} = \frac{c_2c_3(c_1(1-\theta_1)-\lambda(\alpha+\lambda b))(a-b(c+\lambda E_0))}{A_2} + c \quad (3.10)$$

$$e_c^{T^*} = \frac{c_2c_3(\alpha+\lambda b)(a-b(c+\lambda E_0))}{A_2} \quad (3.11)$$

$$y_c^{T^*} = \frac{\beta c_1c_3(1-\theta_1)(a-b(c+\lambda E_0))}{A_2} \quad (3.12)$$

$$z^{T^*} = \frac{\mu c_1c_2(1-\theta_1)(a-b(c+\lambda E_0))}{A_2} \quad (3.13)$$

Substituting $p_c^{T^*}$, $e_c^{T^*}$, $y_c^{T^*}$, $z_c^{T^*}$ into equation (8), the optimal profit of the supply chain system of cold chain logistics services under the centralized decision situation can be obtained as:

$$\pi_c^{T^*} = \frac{c_1(1-\theta_1)c_2c_3(a-b(c+\lambda E_0))^2}{2A_2} \quad (3.14)$$

Where $A_2 = 2bc_1(1-\theta_1)c_2c_3 - c_2c_3(\alpha+\lambda b)^2 - c_1(1-\theta_1)c_3\beta^2 - c_1(1-\theta_1)c_2u^2$.

3.3. Journal style

In order to reduce the cost pressure on enterprises to reduce emissions and encourage them to reduce production, the government will provide corresponding subsidies, assuming that the government subsidizes CCLSP emission reductions at a certain rate θ_2. Government subsidies for CCLSP emission reductions can better focus on the low-carbon emission reduction effect obtained after cooperative R&D, and also encourage enterprises to actively innovate in R&D for emission reduction. In contrast to subsidies based on emission reduction inputs, government subsidies based on emission reductions are intended to study the impact of ex-post subsidies on participants' emission reductions. At this point, the profit function of CCLSP in the decentralized decision of supply chain under CCLSP emission reduction strategy is:

$$\pi_e^T = (p-c-\lambda(E_0-e)+\theta_2 e)(a-bp+\alpha e+\beta y+uz) - \frac{1}{2}c_1e^2 - \frac{1}{2}c_2y^2 - \frac{1}{2}c_3z^2 \quad (3.15)$$

When the government subsidizes according to the abatement cost, the common goal of CCLSP and LSI under the centralized decision situation is to devote to maximize the profit of the cold chain logistics supply chain system, and the retail price of cold chain service p, the wholesale price of cold chain service w, the abatement amount e and the level of cold chain service y and the level of informationization z are taken as the decision variables. By calculation, the Hesse matrix of the profit function π of the cold chain logistics service supply chain system with respect to the decision variables p , e , y and z in the centralized decision situation is:

$$\nabla^2\pi_e^T = \begin{bmatrix} -2b & \alpha & \beta & \mu \\ \alpha & -c_1 & 0 & 0 \\ \beta & 0 & -c_2 & 0 \\ \mu & 0 & 0 & -c_3 \end{bmatrix} \quad (3.16)$$

After calculation, the Hesse matrix can be determined to be negative definite and it is known that π is a concave function. Find the first order derivatives of equation (3.15) with respect to p, e, y, z, and $\frac{\partial\pi}{\partial p}=0$, $\frac{\partial\pi}{\partial e}=0$, $\frac{\partial\pi}{\partial y}=0$, $\frac{\partial\pi}{\partial z}=0$, The optimal cold chain service retail price, cold chain service wholesale price, unit emission reduction and cold chain service level, and information level under centralized decision making can be obtained as:

$$p_e^{T*} = \frac{c_2c_3(c_1-\lambda(\alpha+\lambda b+b\theta_2))(a-b(c+\lambda E_0))}{A_3} + c \quad (3.17)$$

$$e_e^{T*} = \frac{c_2c_3(\alpha+\lambda b+b\theta_2)(a-b(c+\lambda E_0))}{A_3} \quad (3.18)$$

$$y_e^{T*} = \frac{\beta c_1c_3(a-b(c+\lambda E_0))}{A_3} \quad (3.19)$$

$$z_e^{T*} = \frac{\mu c_1c_2(a-b(c+\lambda E_0))}{A_3} \quad (3.20)$$

Substituting p_e^{T*}, e_e^{T*}, y_e^{T*}, z_e^{T*} into equation (3.16), the optimal profit of the supply chain system of cold chain logistics services under the centralized decision situation can be obtained as:

$$\pi = \frac{c_1c_2c_3(a-b(c+\lambda E_0))^2}{2A_3} \quad (3.21)$$

Where $A_3 = 2bc_1c_2c_3 - c_2c_3(\alpha+\lambda b+b\theta_2)^2 - c_1c_3\beta^2 - c_1c_2u^2$.

3.4. Acknowledgment

In this paper, based on the assumptions proposed in the previous paper, we assume that the relevant parameters of a product are: $a=3000$, $b=500$, $c_1=30$, $c_2=20$, $c_3=20$, $E_0=800$, $\alpha=0.8$, $\beta=0.6$, $\mu=0.6$, $\chi=2$. The graphs are drawn to compare and analyze the CCLSP carbon emission reduction without government subsidies, subsidies by emission reduction input, and subsidies by emission reduction under the three decisions of joint supply chain emission reduction. Then, we discuss the impact of the government subsidy coefficient s on the unit emission reduction θ, CCLSP retail price p, and enterprise profit before and after emission reduction under different subsidy scenarios. (No suffix in the following graphs represents no government subsidy, _c represents subsidy by abatement input, and _e represents subsidy by abatement volume)

3.4.1. Impact of government subsidy policies on optimal emission reductions

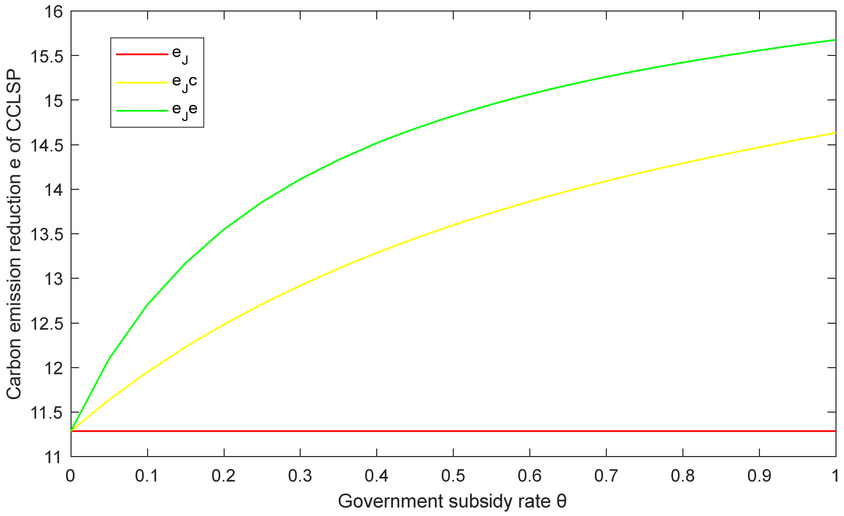

Figure 1. The effect of government subsidy rate on the extent of emission reduction in joint emission reduction

According to Fig.1, the carbon emission reductions of both emission reduction methods under the joint emission reduction decision are higher than the unsubsidized case when other parameters remain unchanged. In the centralized supply chain decision, the emission reduction before and after both government subsidies is larger than that without subsidies, and the unit emission reduction x before and after emission reduction decreases with the increase of the government subsidy rate. This indicates that both abatement subsidies can increase product emission reductions, and the abatement effect gets better as the government subsidy rate increases. Because x represents the carbon emission per unit product after abatement and the emission reduction per unit before abatement, the smaller x means the smaller the carbon emission per unit product after abatement, then the higher the degree of carbon abatement and the more successful the carbon abatement measures. It shows that the existence of government subsidy policy lacks the effect of promoting the enthusiasm of carbon emission reduction of CCLSP, but the specific emission reduction effect is related to the way of subsidy.

In addition, the trend of x decreases faster when subsidized by emission reduction than when subsidized by emission reduction input, which indicates that the emission reduction effect obtained by government subsidy by enterprise emission reduction is better than that obtained by enterprise emission reduction input subsidy when the supply chain is centralized in decision making.

3.4.2. The impact of government subsidy policies on retail prices

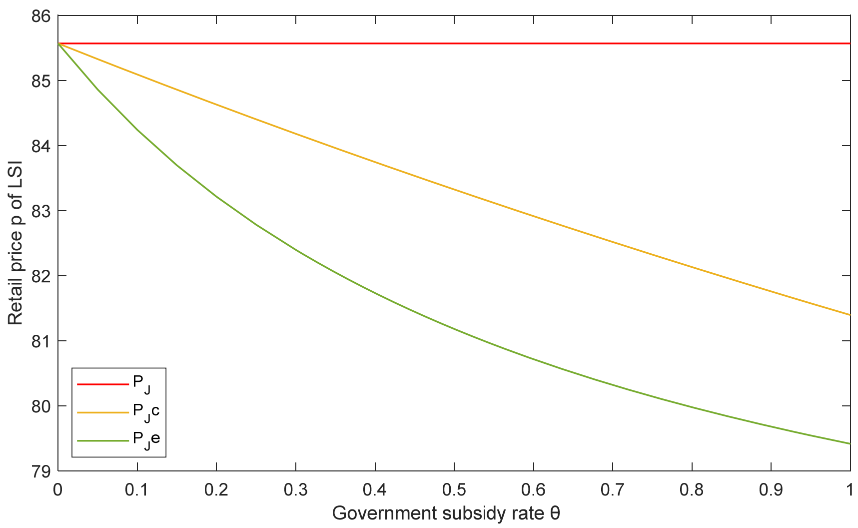

Figure 2. The impact of government subsidy policies on retail prices

According to Figure 2, when other parameters are held constant and the supply chain is combined to reduce emissions, the subsidized LSI sales price is lower than the unsubsidized sales price, and the LSI sales price decreases with the increase of the government subsidy rate s. This indicates that both abatement subsidies can reduce the LSI price, and the LSI price gets lower as the government subsidy rate increases. This may be because, the abatement subsidy given by the government to CCLSP reduces the abatement pressure of CCLSP, and the wholesale price w given by CCLSP to LSI will be reduced appropriately, which is the premise that LSI will also choose to reduce the sales price appropriately in order to attract more consumers and to ensure its own profit. However, relative to the abatement input subsidy, the retail price is lower in the case of government subsidy by abatement, indicating that the retail price in the case of government subsidy by abatement will be lower and more attractive to consumers than the retail price in the case of subsidy by abatement input when the supply chain is jointly abated.

3.4.3. Impact of government subsidy policy on supply chain profitability

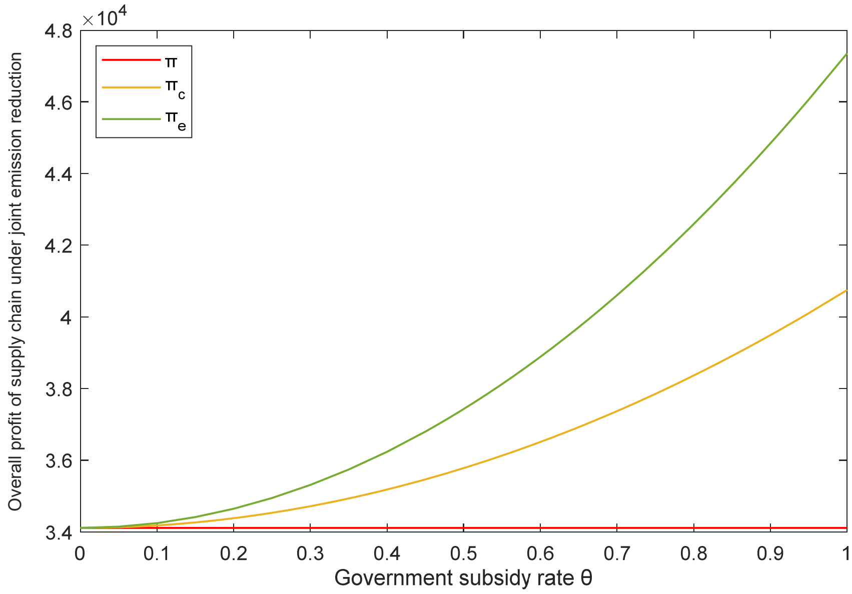

Figure 3. Impact of government subsidy rates on overall supply chain profitability

According to Figure 3, the overall profit of the supply chain after government subsidies is higher than the profit without subsidies when other parameters remain unchanged, and the overall profit of the supply chain increases with the increase of the government subsidy ratio θ. This indicates that both types of emission reduction subsidies can improve the overall profit of the supply chain, and government subsidies have a positive effect on the profit of enterprises.

4. Literature References

On the basis of considering the carbon tax constraint, assuming CCLSP as the dominant player and LSI as the follower, a two-stage game decision model for carbon emission reduction is established by considering the government to subsidize CCLSPs who implement carbon emission reduction in different ways, and then the game decision model is solved and analyzed by using the inverse induction method.

4.1. Journal style

The sales activities of LSI are not subject to carbon tax. At this point, the decision functions of CCLSP, LSI and the supply chain are:

$$\pi_C = (w - c - \lambda(E_0 - e))(a - bp + \alpha x + \beta y + uz) - \frac{1}{2}c_1 e^2 - \frac{1}{2}c_2 y^2 \quad (4.1)$$

$$\pi_I = (p - w)(a - bp + \alpha x + \beta y + uz) - \frac{1}{2}c_3 z^2 \quad (4.2)$$

In the independent emission reduction of cold chain logistics service supply chain members, both decision makers are committed to maximizing their own profits. In the first stage of the Stackelberg game, the upstream CCLSP, as the dominant player in the game, first determines the wholesale price w, product greenness level e and service level y of cold chain logistics services. In the second stage of the Stackelberg Competition, the downstream LSI, as the follower, makes a decision based on the wholesale price of cold chain logistics service, the greenness level of the product and the sales effort provided by the CCLSP, and chooses the optimal retail price of cold chain logistics service and the supporting service level under the premise of maximizing its own profit. Next, the whole dynamic game is solved by using the inverse induction method.

When $2bc_3 - u^2 > 0$, its Hessian matrix with respect to retail price p and information service level z is obtained from the LSI profit function π_I as: $\nabla^2\pi_I = \begin{bmatrix} -2b & u \\ u & -c_3 \end{bmatrix}$, after calculating the determination matrix as negative definite, it is a concave function. By maximizing the LSI profit function equation (3.2), the response function of the retail price of cold chain services and the information service level of LSI can be obtained as:

$$p = \frac{c_3(a + bw + \alpha e + \beta y) - w\mu^2}{2bc_3 - \mu^2} \quad (4.3)$$

$$z^d = \frac{(a - bw + \alpha e + \beta y)\mu}{2bc_3 - \mu^2} \quad (4.4)$$

Substituting equations (4.3) and (4.4) into equation (4.1) we get:

$$\pi_c = \frac{bc_3(w - c - \lambda(E_0 - e))(a - bw + \alpha e + \beta y)}{2bc_3 - \mu^2} - \frac{1}{2}c_1 e^2 - \frac{1}{2}c_2 y^2 \quad (4.5)$$

Then, find the Hessian matrix of π_c with respect to the wholesale price w, the reduced carbon emissions E and the logistics service level z as:

$$\nabla^2\pi_C=\begin{bmatrix}-\frac{2b^2c_3}{2bc_3-\mu^2} & -\frac{bc_3\alpha}{2bc_3-\mu^2} & \frac{bc_3\beta}{2bc_3-\mu^2}\\ -\frac{bc_3\alpha}{2bc_3-\mu^2} & -c_1 & 0\\ \frac{bc_3\beta}{2bc_3-\mu^2} & 0 & -c_2\end{bmatrix} \quad (4.6)$$

It can be calculated that the CCLSP profit function π is a strictly concave function with respect to w, g and y. The first-order partial derivatives of the conjunction (4.5) with respect to w, g and y are equal to 0. The optimal wholesale price w, product greenness g and sales effort y in the case of independent emission reduction can be obtained by calculating the solution as:

$$w=\frac{(a-b(c+\lambda E_0))(A_1+c_2c_3\alpha(\alpha+\lambda b)+c_1c_3\beta^2)}{bB_1}+(c+\lambda E_0) \quad (4.7)$$

$$e=\frac{c_2c_3(\alpha+\lambda b)(a-b(c+\lambda E_0))}{B_1} \quad (4.8)$$

$$y=\frac{\beta c_1(1-m_1)c_3(a-b(c+\lambda E_0))}{B_1} \quad (4.9)$$

Substituting equations (4.7), (4.8), and (4.9) into equations (4.3) and (4.4), we obtain the optimal retail price of the logistics service product and the optimal information level of LSI, respectively:

$$p=\frac{(a-b(c+\lambda E_0))(A_1+c_1c_2c_3b+c_2c_3\alpha(\alpha+\lambda b)+c_1c_3\beta^2)}{bB_1}+c \quad (4.10)$$

$$z^d=\frac{\mu c_1c_2(a-b(c+\lambda E_0))}{B_1} \quad (4.11)$$

Substituting all optimal values into (3.1), (3.2) and (3.3), the optimal profits of CCLSP, LSI and the system as a whole in the cold chain logistics service supply chain are obtained as follows:

$$\pi_C=\frac{c_1c_2c_3(a-b(c+\lambda E_0))^2}{2B_1} \quad (4.12)$$

$$\pi_I=\frac{3{c_1}^2{c_2}^2c_3(2bc_3-u^2)(a-b(c+\lambda E_0))^2}{2B_1^2} \quad (4.13)$$

Where $B_1=4bc_1c_2c_3-c_2c_3(\alpha+\lambda b)^2-c_1c_3\beta^2-2c_1c_2\mu^2>0$.

4.2. Acknowledgment

In order to reduce the cost pressure of emission reduction and encourage enterprises to reduce emissions production, the government will provide corresponding subsidies, assuming that the government subsidizes CCLSP emission reduction inputs at a certain rate. Government subsidies for emission reduction inputs can help enterprises reduce the pressure of emission reduction R&D costs and share part of the R&D risks for enterprises, and government subsidies according to emission reduction inputs are intended to encourage enterprises to participate in emission reduction and stimulate the enthusiasm of R&D emission reduction. Assuming that the government subsidizes CCLSP's emission reduction inputs at a certain rate θ_1^c, the profit function of CCLSP in the decentralized supply chain decision under CCLSP's emission reduction strategy is that in this case, the sales activities of the LSI are not subject to carbon tax. The government is the first to set the cost reduction subsidy factor for the CCLSP, and then both the CCLSP and the LSI determine their own decision variables with the goal of maximizing their own profits. The CCLSP and the LSI are independent of each other and on equal footing. The CCLSP makes efforts to improve its own unit emission reduction and service level, and the LSI makes efforts to improve its information technology level, and each makes independent decisions with the goal of maximizing its own profit. At this time, the decision functions of CCLSP, LSI and supply chain are:

$$\pi_C=(w-c-\lambda(E_0-e))(a-bp+\alpha e+\beta y+uz)-\frac{1}{2}(1-\theta_1)c_1e^2-\frac{1}{2}c_2y^2 \quad (4.14)$$

$$\pi_I=(p-w)(a-bp+\alpha e+\beta y+uz)-\frac{1}{2}c_3z^2 \quad (4.15)$$

When $2bc_3-u^2>0$, its Hessian matrix with respect to retail price p and information service level z is obtained from the LSI profit function π_I as: $\nabla^2\pi_I=\begin{bmatrix}-2b & u\\ u & -c_3\end{bmatrix}$, after calculating the determination matrix as negative definite, it is a concave function. By maximizing the LSI profit function equation (4.15), the response function of the retail price of the cold chain service and the information service level of the LSI can be obtained as:

$$p=\frac{c_3(a+bw+\alpha e+\beta y)-w\mu^2}{2bc_3-\mu^2} \quad (4.16)$$

$$z^d=\frac{\mu(a-bw+\alpha e+\beta y)}{2bc_3-\mu^2} \quad (4.17)$$

Substituting equations (4.16) and (4.17) into equation (4.14) we get:

$$\pi_c=\frac{bc_3(w-c)(a-bw+\alpha e+\beta y)}{2bc_3-\mu^2}-\frac{1}{2}(1-\theta_1)c_1e^2-\frac{1}{2}c_2y^2-\lambda(E_0-1) \quad (4.18)$$

Then, find the Hessian matrix of π_c with respect to the wholesale price w, the emission reduction e and the logistics service level z as:

$$\nabla^2\pi_C=\begin{bmatrix}-\frac{2b^2c_3}{2bc_3-\mu^2} & \frac{bc_3\alpha}{2bc_3-\mu^2} & \frac{bc_3\beta}{2bc_3-\mu^2}\\ \frac{bc_3\alpha}{2bc_3-\mu^2} & -(1-\theta_1)c_1 & 0\\ \frac{bc_3\beta}{2bc_3-\mu^2} & 0 & -c_2\end{bmatrix} \quad (4.19)$$

It can be calculated that the CCLSP profit function π is a strictly concave function with respect to w, e and y. The first-order partial derivatives of the conjunction (4.18) with respect to w, e and y are equal to 0. The optimal wholesale price w, emission reduction e and service level y for the independent abatement scenario can be obtained by calculating the solution as:

$$w=\frac{(a-b(c+\lambda E_0))(A_2+c_2c_3(\alpha+\lambda b)^2+c_1(1-\theta_1)c_3\beta^2)}{bB_2}+c \quad (4.20)$$

$$e = \frac{c_2c_3(\alpha+\lambda b)(a-b(c+\lambda E_0))}{B_2} \quad (4.21)$$

$$y = \frac{\beta c_1c_3(1-\theta_1)(a-b(c+\lambda E_0))}{B_2} \quad (4.22)$$

Substituting equations (4.20), (4.21), and (4.22) into equations (4.16) and (4.17), we obtain the optimal retail price and the optimal informationization level of LSI for logistics service products, respectively.:

$$p = \frac{(a-b(c+\lambda E_0))(A_2+c_1(1-\theta_1)c_2c_3b+c_2c_3\alpha(\alpha+\lambda b)+c_1(1-\theta_1)c_3\beta^2)}{bB_2} + c \quad (4.23)$$

$$z^d = \frac{\mu c_1(1-\theta_1)c_2(a-b(c+\lambda E_0))}{B_2} \quad (4.24)$$

Substituting all optimal values into (4.14) and (4.15), the optimal profits of CCLSP and LSI in the cold chain logistics service supply chain can be obtained as follows:

$$\pi_C = \frac{c_1c_2c_3(1-\theta_1)(a-b(c+\lambda E_0))^2}{2B_2} \quad (4.25)$$

$$\pi_I = \frac{3{c_1}^2{c_2}^2c_3(2bc_3-u^2)(a-b(c+\lambda E_0))^2}{2B_2^2} \quad (4.26)$$

Where , $B_2 = 4bc_1(1-\theta_1)c_2c_3 - c_2c_3(\alpha+\lambda b)^2 - c_1(1-\theta_1)c_3\beta^2 - 2c_1(1-\theta_1)c_2\mu^2 > 0$.

4.3. Journal style

In order to reduce the cost pressure on enterprises to reduce emissions and encourage them to reduce production, the government will provide corresponding subsidies, assuming that the government subsidizes CCLSP emission reductions at a certain rate. Government subsidies for CCLSP emission reductions can better focus on the low-carbon emission reduction effect obtained after cooperative R&D, and also encourage enterprises to actively innovate in R&D for emission reduction. Compared with subsidies based on emission reduction inputs, government subsidies based on emission reductions are intended to study the impact of ex-post subsidies on participants' emission reductions. Assuming that the government provides subsidies to CCLSP by final emission reductions, with subsidy coefficient σ_E^S, the profit function of CCLSP at the time of decentralized supply chain decision under CCLSP emission reduction strategy is:

$$\pi_C = (w - c - \lambda(E_0 - e) + \theta_2 e)(a - bp + \alpha e + \beta y + uz - \frac{1}{2}c_1e^2 - \frac{1}{2}c_2y^2 \quad (4.27)$$

$$\pi_I = (p - w)(a - bp + \alpha e + \beta y + uz) - \frac{1}{2}c_3z^2 \quad (4.28)$$

When $2bc_3 - u^2 > 0$, the LSI profit function gets its Hessian matrix with respect to retail price p and information service level z as: $\nabla^2\pi_I = \begin{bmatrix} -2b & u \\ u & -c_3 \end{bmatrix}$, after calculating the determination matrix as negative definite, it is a concave function. By maximizing the LSI profit function equation (4.28), the response function of the retail price of the cold chain service and the information service level of the LSI can be obtained as:

$$p = \frac{c_3(a+bw+\alpha(E_0-E)+\beta y)-w\mu^2}{2bc_3-\mu^2} \quad (4.29)$$

$$z^d = \frac{(a-bw+\alpha(E_0-E)+\beta y)\mu}{2bc_3-\mu^2} \quad (4.30)$$

Substitute Equation (4.29) and Equation (4.30) into Equation (4.27) to obtain:

$$\pi_c = \frac{bc_3(w-c)(a-bw+\alpha(E_0-E)+\beta y)}{2bc_3-\mu^2} - \frac{1}{2}c_1(E_0-E)^2 - \frac{1}{2}c_2y^2 - \lambda E \quad (4.31)$$

Then, find the Hessian matrix of π_c with respect to wholesale price w, emission reduction e and logistics service level z as:

$$\nabla^2\pi_C = \begin{bmatrix} -\frac{2b^2c_3}{2bc_3-\mu^2} & \frac{bc_3\alpha}{2bc_3-\mu^2} & \frac{bc_3\beta}{2bc_3-\mu^2} \\ \frac{bc_3\alpha}{2bc_3-\mu^2} & -c_1 & 0 \\ \frac{bc_3\beta}{2bc_3-\mu^2} & 0 & -c_2 \end{bmatrix} \quad (4.32)$$

It can be calculated that the CCLSP profit function π is a strictly concave function with respect to w, e and y. The first-order partial derivatives of the conjunction (4.31) with respect to w, e and y are equal to 0. The optimal wholesale price w, emission reduction e and service level y for the independent abatement case can be obtained by calculating the solution as:

$$w = \frac{(a-b(c+\lambda E_0))(A_3+c_2c_3\alpha(\alpha+b(\lambda+\theta_2))+c_1c_3\beta^2)}{bB_3} + c \quad (4.33)$$

$$e = \frac{c_2c_3(\alpha+\lambda b+b\theta_2)(a-b(c+\lambda E_0))}{B_3} \quad (4.34)$$

$$y = \frac{\beta c_1c_3(a-b(c+\lambda E_0))}{B_3} \quad (4.35)$$

Substituting equations (4.33), (4.34), and (4.35) into equations (4.29) and (4.30), the optimal retail price and the optimal information level of LSI for logistics service products are obtained as:

$$p = \frac{(a-b(c+\lambda E_0))(A_3+c_1c_2c_3b+c_2c_3\alpha(\alpha+b(\lambda+\theta_2))+c_1c_3\beta^2)}{bB_3} + c \quad (4.36)$$

$$z^d = \frac{\mu c_1c_2(a-b(c+\lambda E_0))}{B_3} \quad (4.37)$$

Substituting all optimal values into (4.27) and (4.28), the optimal profits of CCLSP, LSI and the system as a whole in the cold chain logistics service supply chain are obtained as follows:

$$\pi_C = \frac{c_1c_2c_3(a-b(c+\lambda E_0))^2}{2B_3} \quad (4.38)$$

$$\pi_I = \frac{3{c_1}^2{c_2}^2c_3(2bc_3-u^2)(a-b(c+\lambda E_0))^2}{2B_3^2} \quad (4.39)$$

Where $B_3 = 4bc_1c_2c_3 - c_2c_3(\alpha+\lambda b+b\theta_2)^2 - c_1c_3\beta^2 - 2c_1c_2\mu^2 > 0$.

4.4. Acknowledgment

In this paper, according to the assumptions proposed in the previous paper, the relevant parameters of a product are: $a = 3000$, $b = 500$, $c_1 = 30$, $c_2 = 20$, $c_3 = 20$, $E_0 = 800$,

$\alpha = 0.8,\ \beta = 0.6,\ \mu = 0.6,\ \chi = 2$. The graphs are drawn to compare and analyze the carbon emission reduction of enterprises under three scenarios: no government subsidy, subsidy by emission reduction input, and subsidy by emission reduction when the supply chain is independent. Then, we discuss the effect of the government subsidy coefficient θ on the unit emission reduction e, wholesale price w, retail price p, and enterprise profit π before and after the emission reduction under different subsidy scenarios. (No suffix means no government subsidies, $\_c$ means subsidies based on abatement costs, $\_e$ means abatement volume subsidies)

4.4.1. Impact of subsidy rates on emission reductions under different government subsidy mechanisms

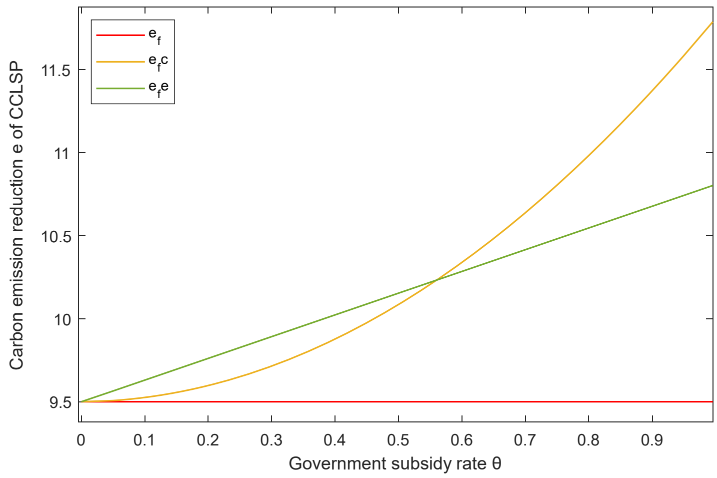

Figure 4. Impact of government subsidy rates on carbon emission reductions

According to Fig.4, when other parameters are constant and the supply chain is decentralized, the carbon emission reduction under both government subsidies is larger than that without subsidies, and the carbon emission reduction e increases with the increase of the government subsidy rate. This indicates that both emission reduction subsidies can increase the product emission reduction, and the emission reduction effect becomes better as the government subsidy rate increases. In addition, it can be seen from Fig. 4 that when the government subsidy rate is small, the emission reduction e is larger when the government subsidizes by emission reduction than when the government subsidizes by emission reduction cost, and the emission reduction effect obtained by the government subsidy by emission reduction is better than that obtained by the enterprise emission reduction input subsidy; as the government subsidy rate increases, the growth rate of e becomes slower when the government subsidizes by emission reduction input, and the emission reduction effect obtained by the government subsidy by emission reduction cost is better at this time. The government subsidizes the cost of emission reduction.

This shows that both subsidy methods can improve product emission reductions when the supply chain is independent, and the choice of subsidy method depends on the size of the government subsidy rate. Comparing with the previous Figure 1, it is found that the carbon emission reduction under joint emission reduction is always higher than that under independent emission reduction, and it can be seen that the existence of government subsidy policy does have the effect of promoting the enthusiasm of CCLSP carbon emission reduction, and the specific emission reduction effect is related to the way of subsidy.

4.4.2. The impact of government subsidy policy on retail prices as well as wholesale prices

The impact of government subsidies on the sales price of LSI under the three scenarios of no government subsidies, subsidies by abatement inputs, and subsidies by abatement volume under independent supply chain abatement is studied in comparison, and the simulation results are shown in Figure 5 according to the relevant research results of this paper.

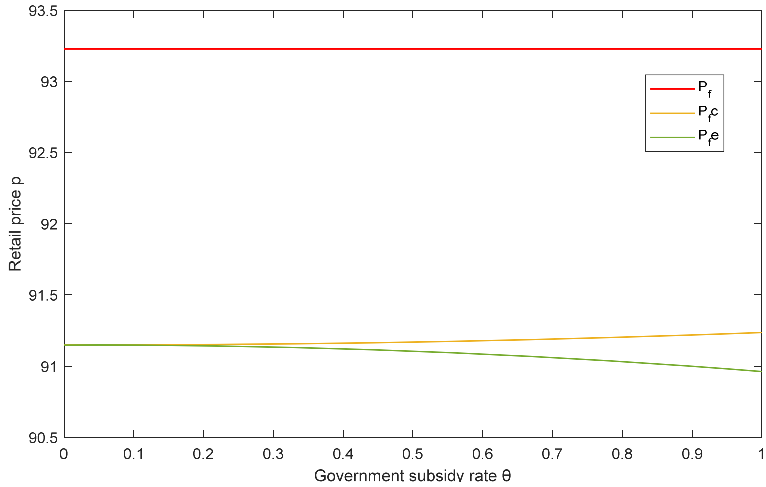

Figure 5. The effect of subsidy rate θ on LSI price p under different subsidy scenarios at independent abatement

According to Figure 5 can be learned that when other parameters remain unchanged, supply chain independent emission reduction, the retail price when subsidized by emission reduction has been lower than the sales price when unsubsidized, and decreases with the increase of the government subsidy rate θ. This may be because when subsidized by emission reduction, the greater the amount of emission reduction, the more subsidies given by the government, the better the emission reduction effect, the more significant CCLSP benefits, then the wholesale price given to LSI is much smaller than the wholesale price when input by emission reduction, LSI can appropriately reduce the retail price in order to attract more customers and under the premise of ensuring benefits.

When subsidized by abatement input, the price of LSI is lower when the government subsidy rate is small than when it is unsubsidized. As the government subsidy rate rises, the price of LSI has been increasing and is gradually larger than the sales price when it is unsubsidized, probably because when subsidized by abatement cost, the government subsidy only looks at how much abatement cost CCLSP has invested. When the government subsidy rate is small, CCLSP puts in appropriate abatement costs and gets certain abatement effects, CCLSP profits are increasing, and the wholesale price CCLSP gives to LSI is decreasing, then the LSI price is naturally lower than the price when it is not subsidized; when the government subsidy rate gradually increases, CCLSP, driven by the huge subsidy profits, will put in more abatement costs, so as to get a larger When the reduced retail price cannot meet the increased abatement cost, then LSI can only choose to increase the retail price in order to maintain its profit.

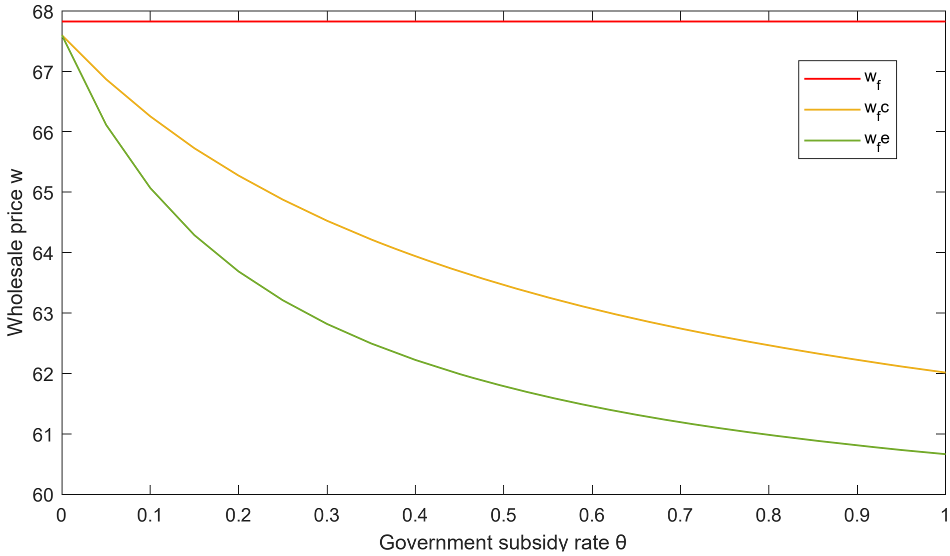

Figure 6. The effect of the subsidy rate θ on the wholesale price w under different subsidy scenarios at the time of independent emission reduction

According to Figure 6, when other parameters are held constant and the supply chain is abatement independent, the subsidized wholesale price is lower than the unsubsidized wholesale price, and the CCLSP wholesale price decreases with the increase of the government subsidy rate θ. This indicates that both abatement subsidies can reduce the wholesale price, and the wholesale price becomes lower and lower as the government subsidy rate increases. This may be because the government subsidy to CCLSP can reduce the abatement pressure of CCLSP to a certain extent, then its wholesale price to LSI will be appropriately reduced, and as the government subsidy rate increases, the abatement cost invested by CCLSP is increasingly compensated, and the wholesale price from CCLSP to LSI decreases with it. Under the supply chain independent emission reduction, the wholesale price obtained by the government subsidizing the LSI according to the enterprise emission reduction is lower than the wholesale price obtained by the emission reduction input subsidy, indicating that the subsidy according to the emission reduction is more advantageous at this time. In addition, as the government subsidy rate gradually reaches the limit, the trend of wholesale price reduction slows down, which indicates that there is a marginal effect, and too high a subsidy rate does not have a good effect on the reduction of wholesale prices in the supply chain.

4.4.3. Impact of government subsidy policy on CCLSP profits

The impact of government subsidies on CCLSP profits under the three scenarios of no government subsidies, subsidies by abatement input, and subsidies by abatement volume under independent supply chain abatement is studied comparatively, and the simulation results are shown in Figure 7 based on the relevant research results in this paper.

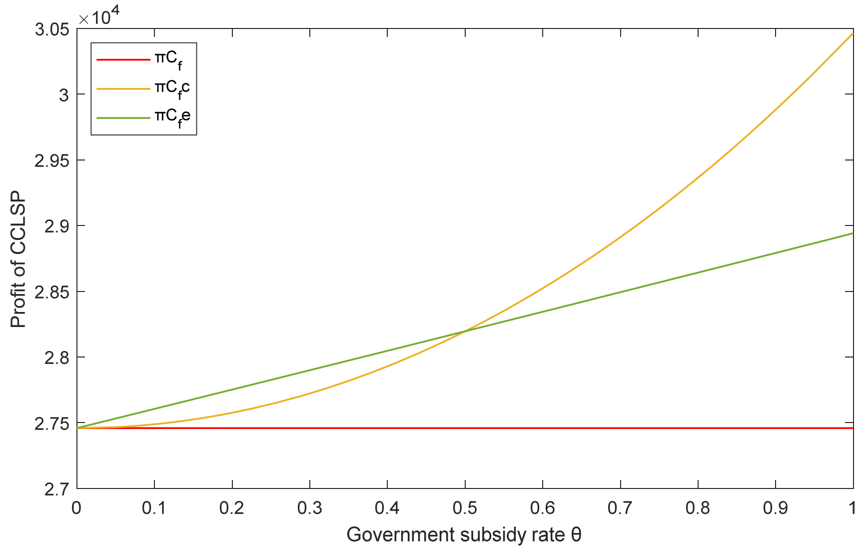

Figure 7. The effect of subsidy rate θ on CCLSP profit under different subsidy scenarios at independent emission reduction

According to Fig. 7, when other parameters remain unchanged, the CCLSP profit after the subsidy is higher than the CCLSP profit without the subsidy, and the CCLSP profit and the subsidy rate are proportional to each other. This indicates that both abatement subsidies can improve the overall supply chain profit, and the CCLSP profit becomes larger and larger as the government subsidy rate increases. However, when comparing the two types of subsidies, CCLSP profits are higher when the government subsidizes by emission reduction.

4.4.4. Impact of government subsidy policy on LSI profits

The impact of government subsidies on the profit of LSI under the three scenarios of no government subsidies, subsidies based on emission reduction inputs, and subsidies based on emission reductions when the supply chain is independent of emission reduction is compared.

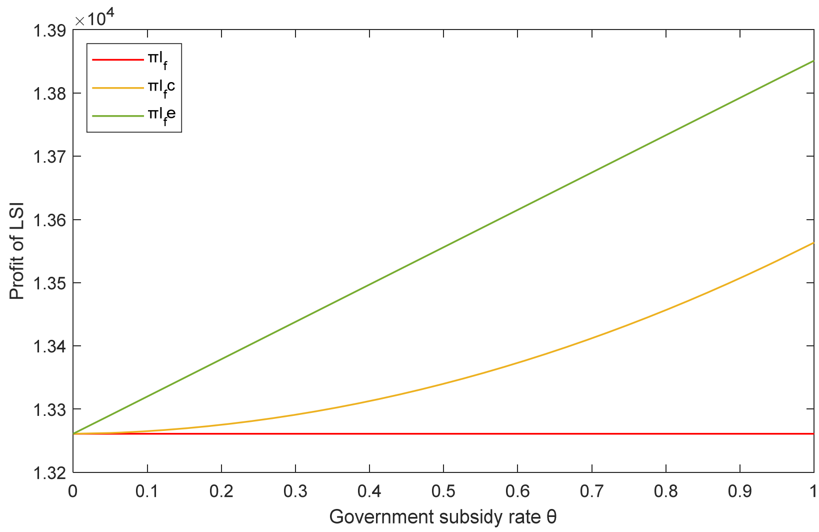

Figure 8. Impact of government subsidies θ on LSI's profit at the time of independent emission reduction

According to Figure 8, the LSI profit increases with the increase of the government subsidy rate s when other parameters are held constant and the supply chain is abatement independent. When the government subsidy rate θ is small, the LSI profit is the highest among the three scenarios, but the LSI profit is even lower than the unsubsidized profit when subsidized by abatement input, and the LSI profit increases slowly when the government subsidy rate θ increases when subsidized by abatement cost, then it is between subsidized and unsubsidized by abatement amount, and finally it is even higher than the LSI profit when subsidized by abatement amount. This may be due to the fact that CCLSP uses technology to save energy and reduce emissions, and invests a lot of abatement costs, but the abatement effect is not very satisfactory, and the government subsidizes CCLSP at this time according to the abatement input, resulting in CCLSP in turn continuing to invest in abatement costs; the cost increases, and the wholesale price to LSI decreases, but the demand decreases, resulting in the profit of LSI in the end instead of the profit when it is not subsidized. With the increase in government subsidies to make up for some of the CCLSP's losses and moderate the CCLSP's abatement costs, the wholesale price to LSI is greatly reduced and the retail price is increased, so LSI's profits naturally increase. In summary, in the supply chain independent emission reduction, both subsidy methods can improve LSI profits, but the choice of subsidy method depends on the size of the government subsidy rate to decide.

5. Literature References

In this paper, with reference to previous research experience, we construct a government-enterprise game model for CCLSP R&D emission reduction based on carbon tax constraints, introduce government subsidy influence parameters on this basis, discuss joint emission reduction of cold chain logistics service supply chain, independent emission reduction of supply chain, no government subsidy in two cases, and government subsidy on emission reduction cost and emission reduction of CCLSP, and study the impact of cold chain logistics service under different decision game models The paper also discusses the impact of different government subsidies on the amount of carbon emission reduction, wholesale price, retail price and profit of supply chain members. The main research contents and conclusions of this paper are as follows:

(1) This paper introduces the research status at home and abroad on the low-carbon supply chain, carbon tax theory and supply chain subsidies, and finds that many scholars' research focuses on the optimization analysis of cold chain logistics distribution route, but there are few papers discussing the cold chain logistics supply chain management and carbon emission reduction research. Although many studies have considered government subsidies, and some scholars have also considered carbon tax and subsidies together, most studies have discussed the object and amount of government subsidies. In terms of low-carbon, scholars have carried out a lot of in-depth research in the field of low-carbon supply chain, especially in the study of carbon emission reduction cost allocation, and achieved certain scientific achievements. However, most scholars only focus on the cost allocation among fixed agents, without considering the impact of cost allocation on the supply chain under different agent alliances.

(2) The problem of government subsidy strategy in joint supply chain emission reduction is investigated, and the modeling study finds that both government subsidies have a positive impact on emission reduction, retail price and corporate profit in joint supply chain emission reduction, but the positive effect of subsidy by emission reduction is greater, and in this case CCLSP has higher emission reduction, lower LSI sales price and higher overall supply chain benefit.

(3) The study of government subsidy strategy when supply chain independent emission reduction, through modeling research analysis found that: when supply chain independent emission reduction, two kinds of government subsidies, subsidies by emission reduction input and subsidies by emission reduction, are effective on CCLSP wholesale price, retail price and the improvement of CCLSP benefits, and the situation of government subsidies by emission reduction is more significant than the effect of input subsidies; for the emission reduction effect, in the case of government When the government subsidy is small, the emission reduction effect obtained by emission reduction subsidy is more significant than that obtained by emission reduction input subsidy, and with the increase of government subsidy rate, the emission reduction effect of emission reduction subsidy by emission reduction input will be better, so both government subsidies by emission reduction input subsidy and emission reduction subsidy can improve the emission reduction of products, but the choice of which subsidy method to choose depends on the size of government subsidy rate; for LSI profits, subsidies by emission reduction can improve LSI profits, and LSI benefits are higher as the government subsidy rate increases; however, when subsidizing by emission reduction input, LSI profits will be higher than those when not subsidized only when the government subsidy rate is greater than a certain percentage.

(4) A comprehensive analysis of the two scenarios of joint supply chain emission reduction and independent supply chain emission reduction reveals that regardless of the game situation of the supply chain, the comprehensive effect obtained when subsidized by emission reduction is always better than subsidized by emission reduction input. In addition, CCLSP carbon emission reduction always increases with the increase of government subsidies, so in order to incentivize CCLSP to better implement low-carbon emission reduction measures, the government can increase the subsidies as much as possible within a reasonable range.

On the basis of the conclusions obtained above in this chapter, some corresponding management recommendations are made for low-carbon emission reduction policies.

(1) In the process of implementing carbon emission reduction, it is effective for the government to charge carbon tax on products with high carbon emissions to limit their carbon emissions, however, for cold chain logistics enterprises with high basic carbon emissions, it will cause huge pressure to reduce emissions. At the same time, the intensity of the carbon tax needs to consider the impact of cold chain logistics products on the environment, too high a carbon tax will bring more pressure on the enterprises that already have the pressure of emission reduction costs, reducing the enthusiasm of enterprises to reduce emissions.

(2) In order to reduce the pressure of emission reduction cost of CCLSP and encourage enterprises to actively implement carbon emission reduction, the government can provide appropriate and reasonable subsidies to enterprises based on carbon tax collection mechanism, but the government needs to pay attention to the way of subsidy when subsidizing enterprises. Therefore, the government should take the cooperation mode between supply chains into consideration when granting subsidies to CCLSP for emission reduction. At the same time, within the acceptable range, the government increases the subsidies for CCLSPs that actively participate in carbon emission reduction, which can better mobilize the enthusiasm of enterprises to save energy and reduce emissions, and increase the amount of carbon emission reduction.

(3) In a comprehensive analysis, compared with subsidies based on emission reduction inputs, subsidies based on emission reduction can better motivate enterprises to reduce emissions and obtain more significant emission reduction effects, excluding the influence of enterprises' deceptive behavior, subsidies based on emission reduction can more reasonably determine the amount of subsidies.

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