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CONTRACT COORDINATION FOR GREEN LOGISTICS CAPABILITIES INVOLVING THE LOGISTICS SERVICE DEMAND SIDE

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Abstract

In order to study how to effectively green the logistics capability, we establish a Stackelberg game model of logistics service demand side and logistics service provider. Taking the logistics service provider as the leading factor, this paper analyzes the coordination effect of revenue-sharing contract, cost-sharing contract and combination contract of revenue-sharing contract and cost-sharing contract on the enthusiasm of logistics service providers to rebuild green logistics capability. At the same time, the impact of different contracts on the wholesale price of unit logistics capacity, the price of unit products and the enforceability of the combination contract are discussed. The research results show that the single contract cannot achieve the optimal green level of logistics capability, the combination contract can effectively coordinate the green level of logistics capability and the wholesale price of logistics capacity and the market price of products have been improved. However, the combination contract is unfavorable to the profit of the demand side of the logistics service, and the government financial subsidy is needed to promote the execution of the combination contract.

Key words: environment, logistics capability, service supply chain

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1. Introduction

Due to the IHIP characteristics of the service, the service supply chain relies mainly on capacity coordination to resolve the contradiction between supply and demand. In logistics services, service providers usually need to prepare vehicles, warehouses and other facilities in advance to meet the demand side's demand for transportation capacity and storage capacity. As society's demands for environmental protection continue to increase, the concept of "green" gradually extends from tangible products to intangible services, especially in the field of logistics, where logistics activities are required to be as green and environmentally friendly as possible. Moreover, consumers are paying more and more attention to whether enterprises take the initiative to assume social responsibility, forcing enterprises to consider the environmental pollution problems in their own production and operation. For the logistics and transportation demand side, especially for enterprises with large cargo transportation needs, it is related to the long-term development of the enterprise whether the transportation process can meet the relevant environmental protection standards to satisfy the environmental protection needs of consumers (Cao et al., 2018).

In addition, with the adjustment of China's transportation structure, transportation emission reduction has been mentioned as an important position as the industrial structure and energy structure emission reduction. However, on the basis of the inherent logistics capabilities (The logistics capability referred to in this article refers to the ability of a logistics service provider to use its own and controlled resources to meet customer logistics and related needs, such as transportation capabilities, Distribution capabilities etc.), it takes a huge cost to re-integrate

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and rebuild the green logistics transportation capacity for the logistics and transportation service providers (Zhang and Wang, 2019). Except for some industry giants who are capable of implementing environmental protection measures, most companies are unable to implement them themselves. For example, the shipping giant Maersk launched the supply chain carbon emission reduction service as early as 2007, which greatly reduced the impact of its own development on the climate, while no other shipping companies had followed suit. Improving the environmental problems caused by logistics operations cannot be accomplished by one company alone. It is urgent to exert the incentive effect of national environmental protection policies on enterprises, improve the responsiveness of relevant enterprises, and promote the overall improvement of logistics capabilities.

Relevant research shows that the service supply chain end-customer enterprises have coordination and control over the activities of their downstream supply chain members (Maull et al., 2012; Sampson and Spring, 2012). The attention and participation of logistics service demanders for environmental protection operations is also more conducive to the greening of logistics service supply chain. In conjunction with relevant policy measures, it is of great practical significance to study the positive role of the logistics service demand side in improving the greening level of logistics capabilities, and promote the cooperation between participants to realize the green sustainable development of the logistics industry and accelerate the promotion of transportation emission reduction. Therefore, this paper will establish a two-echelon logistics service supply chain and study the incentive effect of logistics service demand side on logistics service provider logistics capabilities under different contract models.

2. Literature review

Since Ellam et al. (2004) pioneered the construction of a service supply chain framework, research on service supply chains has begun to receive widespread attention. With the rapid development of the logistics industry, the logistics service supply chain has become a research hotspot in the service supply chain, focusing on models and development strategies (Choy et al., 2007; Persson and Virum, 2001; Rabinovich and Knemeyer, 2006), logistics service provider selection and performance evaluation (Narkhede et al., 2017; Williams et al., 2019; Yuan et al., 2016), supply chain coordination etc.

The specific researches on the coordination of logistics capability and logistics service level which is more relevant to the research content of this paper are given. The research of Chan et al. (2015) showed that the improvement of logistics service level was conducive to the increase in demand for logistics services. He et al., 2016; He and Liu (2015) studied on the capability coordination of automobile LSSC (Logistics service supply chain) consisting of single LSI (Logistics service integrator) and FLSP (Functional logistics service subcontractor). They investigated the optimal strategies of the LSI and FLSP under no contract and buyback contract. By comparing two situations, they found buyback contract coordinated automobile LSSC better, and with the reliability FLSP to ensure the logistics capability increasing, the optimal logistics capability order quantity decrease.

Based on the single-cycle quality coordination model, Liu et al. (2013) established a multi-cycle logistics service quality coordination model for the secondary logistics service supply chain consisting of one LSI and one FLSP. Furthermore, the logistics service quality coordination model of the three-level LSSC consisting of primarily LSI, sub-LSI and FLSP was analyzed, and it was found that the higher penalty strength helped to improve the quality of logistics services. Wang et al. (2016) discussed the optimal logistics capability reservation quantity of logistics service integrators in the two-level logistics service supply chain composed of logistics service integrators and functional logistics service providers considering the procurement cost, the potential shortage cost, and the operation cost.

It can be observed from the above literature that whether in the two-level logistics service supply chain or the multi-level logistics service supply chain, the research on logistics capacity coordination or logistics service improvement issues are concentrated on the logistics service provider side, while the logistics services demand side as one of the member of the logistics service supply chain is hardly mentioned. However, the service demand side does not exist only as a service recipient in the service supply chain. It also has its own contribution to the service provider meeting its requirements for quality, satisfaction and value (Bitner et al., 1997). Maull et al. (2012) proposed that the customer essentially acted as an operations manager or project manager, selecting service providers, controlling and coordinating their activities to create the desired service in the service supply chain. Sampson and Spring (2012) found that customers played an active role in the service process and the result quality with managing and supervising the quality of the supply chain in the service supply chain. For example, in the related research of logistics service supply chain, Abbasi and Nilsson (2016) had confirmed through empirical research that the purchasers of logistics services (such as cargo owners, shippers) had a direct influence on the sustainability strategies of LSPs by demanding environmentally and socially responsible services. Therefore, it is not possible for product owners to maintain their position in the competitive market only through green manufacturing processes, but all parties, including logistics service providers in the supply chain, must also be "green" (Sureeyatanapas et al., 2018). It is necessary to study how the demand side of logistics service can improve the enthusiasm of logistics service providers to transform their logistics capabilities.

Research on green supply chain contract incentives is mostly focused on the product supply chain. Hong and Guo (2019) studied price-only, green-marketing cost-sharing, and two-part tariff contracts within a green product supply chain and investigate their environmental performance. They found the green-marketing cost-sharing contract also encouraged cooperation in promoting consumer demand, but couldn't fully coordinate the supply chain, while two-part price contract could promote high cooperation among members of the supply chain, thus achieving full coordination of the supply chain. In the research of Ghosh and Shah (2015), cost sharing contract no matter offered by the retailer or obtained through bargaining leaded to a higher greening level in a single retailer–manufacturer set up. Some researchers have also studied the issue of contract incentives among service supply chain members to improve service levels or information sharing levels. Jiang et al. (2016) set up a supply chain cost sharing contract for logistics service providers who were not willing to undertake the cost of improving logistics service. It was found that the logistics service level was effectively improved only when the marginal profit of the supply chain members was sufficient to compensate the logistics service provider's cost. Zhao et al. (2014) expanded a dynamic differential model in LSSC, which is composed of one LSI and one FLSP and takes time and reputation into account. The result showed the cost sharing contract encouraged FLSP to make greater efforts to improve the reputation and profit of the supply chain in the long-term relationship between LSI and FLSP. Liu et al. (2015) proposed a revenue sharing incentive model in the E-commerce Service Supply Chain, which proved a higher percentage of revenue induced a more service providers' knowledge-sharing effort especially in the case of the high knowledge complementarity of service providers.

It can be seen that the researches mentioned above mainly investigate the cost sharing contract or revenue sharing contract alone. Different from them, the article analyzes single revenue-sharing contract, single cost-sharing contract and the combination contract of the revenue-sharing contract and cost-sharing contract. The influences of different contracts on improvement of green logistics capacity, optimization of product price and the wholesale price of unit logistics capacity and the profits of supply chain members are explored.

3. Model description and hypotheses

The article considers a two-echelon logistics service supply chain comprised of a logistics service demand side and a logistics service provider. Under the background of the national environmental protection strategy and the increasing awareness of consumers' environmental protection, the logistics service demand enterprises hope to minimize the harm to the environment caused by the transportation process of their products, so as to better establish the product green environmental protection brand and expand the product market demand. However, the greening of logistics capacity requires a lot of investment. If the logistics service provider bears all the risks alone, it will seriously affect its enthusiasm for rebuilding green logistics capabilities. In order to enable logistics service provider to quickly improve the green level of logistics and transportation capacity, logistics service demand side should take the initiative to undertake supply chain environmental management responsibility, and improve the greening level of logistics capabilities through contract coordination. The B2C model established in this paper is shown in Fig. 1.

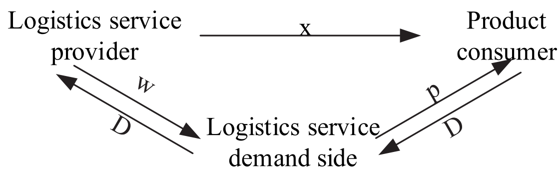

Fig. 1. The incentive model of Logistics service supply chain

The following hypotheses and symbol definitions are proposed:

(1) The article considers the logistics service provider as the leader and the logistics service demand side as the follower. The information of the logistics service demand side and the logistics service provider is symmetrical and the two have a stable cooperative relationship. The logistics capability inherent in the logistics service provider can meet the logistics service demand of the demand side, and the unit product corresponds to the unit logistics service demand, which is satisfied by the unit logistics capability.

(2) When consumers have a strong sense of environmental protection, the greening of product transportation can increase consumers' willingness to pay (Zhang and Wang, 2019). According to the research of Song and Gao (2017), it is assumed that the market demand for logistics service demand side products is $D=a-\alpha p+\beta x$, where a is the basic market demand, α indicates the market's sensitivity coefficient to product prices, β is the market's sensitivity to the greening level of logistics capabilities and x represents the green level of logistics capability reshaped by logistics service provider.

(3) The cost of the logistics service provider to rebuild the green logistics capability level is $c(x)=\frac{1}{2}\lambda x^2$ (Taleizadeh et al., 2018), and λ is the cost coefficient of the logistics service provider to improve the green logistics capability.

(4) The logistics service provider sells the unit logistics capacity to the logistics service demand side at the wholesale price of ω, and it has a unit logistics capacity operational cost c.The demand side of the logistics service sells the product to the consumer at the unit price p.

(5) Due to the need of the article, β^2/λ is named as the green logistics capability market expansion efficiency coefficient.

(6) Based on the above assumptions, the profit functions for the logistics service demand side, the logistics service provider, and the logistics service supply chain are shown in Eqs. (1-3), respectively.

$$\pi_n = (p-\omega)(a-\alpha p+\beta x) \quad (1)$$

$$\pi_p = (\omega - c)(a-\alpha p+\beta x) - \frac{1}{2}\lambda x^2 \quad (2)$$

$$\pi = (p-c)(a-\alpha p+\beta x) - \frac{1}{2}\lambda x^2 \quad (3)$$

The specific symbol description is shown in Table 1. In addition, the first letter *d* of the superscript indicates decentralized decision, c indicates the combination contract, and the second letter *i* of the superscript indicates a single contract under the combination contract (*i = 1, 2*) is the revenue sharing-contract and the cost-sharing contract respectively); subscript *n* indicates the logistics service demand side, and *p* indicates the logistics service provider.

4. Basic model analysis

4. 1. Centralized decision analysis of logistics service supply chain

Under the centralized decision-making, the logistics service demand side and the logistics service provider can be regarded as a unified whole, and the product price and the green level of the logistics capability ability are determined with the goal of maximizing the overall profit of the supply chain. Derivative of p and x from the logistics service supply chain profit function (Eq. 3a):

$$\frac{\partial^2\pi}{\partial p^2} = -2\alpha, \frac{\partial^2\pi}{\partial x^2} = -\lambda, \frac{\partial^2\pi}{\partial p\partial x} = \frac{\partial^2\pi}{\partial x\partial p} = \beta, -2\alpha < 0 \quad (3a)$$

As $2\alpha\lambda - \beta^2 > 0$, the total profit function of the logistics service supply chain is the joint concave function of the product price and the greening level of the logistics capability. There is a unique product price and the green level of logistics capacity to maximize the overall profit of the logistics service supply chain. Find the partial derivatives of p and x for the overall profit of the logistics service supply chain and make them zero, and solving these equations can get the optimal product price and the green level of logistics capacity under centralized decision (Eqs. 4-5):

$$p^* = c + \frac{\lambda(a-\alpha c)}{2\alpha\lambda - \beta^2} \quad (4)$$

$$x^* = \frac{\beta(a-\alpha c)}{2\alpha\lambda - \beta^2} \quad (5)$$

Substituting them into Eq. (3), we can know (Eq. 6):

$$\pi^* = \frac{\lambda(a-\alpha c)^2}{2(2\alpha\lambda - \beta^2)} \quad (6)$$

4.2. Decentralized decision analysis of logistics service supply chain

Under the decentralized decision-making, both parties of the logistics service supply chain make independent decisions with the goal of maximizing their respective profits. The logistics service demand side first proposes the logistics service demand of D to the logistics service provider according to the market forecast. Then the logistics service provider determines the green level and wholesale price of the logistics capability. Finally the logistics service demand side determines the product market price.

According to the inverse induction method, we first maximize the profit of the logistics service demand side. Let $\frac{\partial \pi_n}{\partial p} = 0$, we get (Eq. 7)

$$p = \frac{a+\alpha\omega+\beta x}{2\alpha} \quad (7)$$

Table. 1. Symbol description

Symbol	*Definitions*
a	Basic market demand for logistics service demand side products
p	Unit product price
c	Unit logistics capacity operation cost
x	Green level of logistics capability provided by logistics service provider
ω	Unit logistics capacity wholesale price provided by logistics service provider
α	The market's sensitivity coefficient to product prices
β	The market's sensitivity to the greening level of logistics capabilities
λ	Cost coefficient of logistics service provider rebuilding green logistics capability
D	Market demand for the products of logistics service demander side
t	Proportion of revenue retained by the demand side of the logistics service in the revenue sharing contract
r	The cost-sharing ratio provided by the demand side of the logistics service in the cost-sharing contract
π	The profit of logistics service supply chain
s	Government subsidy coefficient for green level of logistics capability

Substituting (Eq. 4) into (Eq. 2), the logistics service provider profit function is a joint concave function of ω and x, when $4\alpha\lambda-\beta^2>0$. Find the first derivative of ω and x from (Eq. 2), and let it be zero. Combine with (Eq. 7) to solve the optimal wholesale price, green level and product price under the wholesale price contract.

$$\omega^d = c + \frac{2\lambda(a-\alpha c)}{4\alpha\lambda-\beta^2} \tag{8}$$

$$x^d = \frac{\beta(a-\alpha c)}{4\alpha\lambda-\beta^2} \tag{9}$$

$$p^d = c + \frac{3\lambda(a-\alpha c)}{4\alpha\lambda-\beta^2} \tag{10}$$

Substituting the Eqs.(8-10) into the (Eq.1), (Eq.2), and (Eq.3), we can know that the optimal profit of the logistics service demand side and the logistics service provider, and the total profit of the supply chain under the wholesale price contract are as follows (Eq. 11):

$$\pi_n^d = \frac{\alpha\lambda^2(a-\alpha c)^2}{(4\alpha\lambda-\beta^2)^2},\ \pi_p^d = \frac{\lambda(a-\alpha c)^2}{2(4\alpha\lambda-\beta^2)},\ \pi^d = \frac{\lambda(6\alpha\lambda-\beta^2)(a-\alpha c)^2}{2(4\alpha\lambda-\beta^2)^2} \tag{11}$$

Proposition 1.

The green level of logistics capability under decentralized decision-making cannot reach the optimal state, and it does not exceed 1/2 times the green level of logistics capability under centralized decision-making. For the prices at which consumers purchase products under decentralized decision making, we have: If $\frac{\beta^2}{\lambda} < \alpha$, then $p^d > p*$; If $2\alpha > \frac{\beta^2}{\lambda} > \alpha$, then we can easily know that $p^d < p*$; If $\frac{\beta^2}{\lambda} = \alpha$, then $p^d = p*$.

The market demand for products is affected by the green level of logistics capacity and the market price of products. When $\frac{\beta^2}{\lambda} < \alpha$, the green logistics capacity market expansion efficiency coefficient is less than the market price sensitivity coefficient, that is, the market demand for the product is greatly affected by the market price. As a result, the improvement of the greening level of logistics capacity has made the supply chain efficiency increase insufficient, and there is still a "double marginal effect" of the supply chain; when $\frac{\beta^2}{\lambda} > \alpha$, the green logistics capacity market expansion efficiency coefficient is greater than the market price sensitivity coefficient and it also indicates that consumers have stronger environmental awareness. At this point, the improvement of the greening level of logistics capacity can increase the market demand for products, and the resulting supply chain benefits are enough to offset the negative impact of product market prices on supply chain efficiency.

It can be seen that the relationship between $\frac{\beta^2}{\lambda}$ and α affects the optimal product market price under centralized decision and decentralized decision-making. Regardless of the relationship between $\frac{\beta^2}{\lambda}$ and α, the level of greening of logistics capacity under decentralized decision-making is always lower than that under centralized decision-making.

5. Contract-based model analysis

5.1. Contract model analysis

We can know from the above discussion that the level of greening of logistics capacity under decentralized decision-making is seriously lower than that under centralized decision-making. In view of the fact that the logistics service provider alone bears the full cost of rebuilding the logistics capacity and the greening of the logistics capability also benefits the demand side of the logistics service, this paper proposes that the logistics service demand side allocates the cost of the logistics service provider to rebuild the logistics capability and shares its benefits with the logistics service provider, to promote the enthusiasm of logistics service provider to renovate green logistics capabilities.

The demand side of the logistics service proposes the combination contract and proposes that the ratio of its retained sales revenue and the cost of contribution is (t, r).

Subsequently, the logistics service provider determines the wholesale price of the unit logistics capacity and the green level of the logistics capacity of the transformation according to the ratio of the contractual contract $(1-t, 1-r)$.

Finally, the market price of the product is determined by the demand side of the logistics service according to the wholesale price and the green level of the logistics capability provided by the logistics service provider. Under the condition that the demander of the logistics service provides the combination contract to the logistics service provider (Eq. 12-13).

$$\pi_n^c = (tp-\omega)(a-\alpha p+\beta x) - r\left(\tfrac{1}{2}\lambda x^2\right) \tag{12}$$

$$\pi_p^c = \left[\omega - c + (1-t)p\right](a-\alpha p+\beta x) - (1-r)\left(\tfrac{1}{2}\lambda x^2\right) \tag{13}$$

We also apply the inverse induction method to solve the decision model. Firstly, the logistics service demand side decides the product price (Eq. 14):

$$\frac{\partial \pi_n^c}{\partial p} = t(a - \alpha p + \beta x) - \alpha(tp - \omega) \tag{14}$$

Make it equal to 0, and we get (Eq. 15)

$$p = \frac{t(a + \beta x) + \alpha\omega}{2\alpha t} \tag{15}$$

Next, the logistics provider decides the wholesale price of the unit logistics capacity and the green level of the logistics capacity. Substituting the (Eq. 15) into the (Eq. 14) shows that π_p^c is a joint concave function with respect to ω and x when $2(1-r)(1+t)\alpha - \beta^2 > 0$. Then solving the derivatives of ω and x from (Eq. 9), making them to 0 and combined with (Eq.10), we can get optimal wholesale price, optimal green level and optimal market price of logistics products under combined contract as followed (Eqs. 16-18):

$$\omega^c = tc + \frac{2t^2(1-r)\lambda(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda - \beta^2} \tag{16}$$

$$x^c = \frac{\beta(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda - \beta^2} \tag{17}$$

$$p^c = c + \frac{(1-r)(1+2t)\lambda(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda - \beta^2} \tag{18}$$

Substituting the Eqs. (16-18) into the (Eq. 12), (Eq. 13), and (Eq.3), it is easily to obtain Eq. (19):

$$\pi_n^c = \frac{\lambda(a-\alpha c)^2\left[2t(1-r)^2\alpha\lambda - r\beta^2\right]}{2\left[2(1-r)(1+t)\alpha\lambda - \beta^2\right]^2},\quad \pi_p^c = \frac{\lambda(1-r)(a-\alpha c)^2}{2\left[2(1-r)(1+t)\alpha\lambda - \beta^2\right]}$$

$$\pi^c = \frac{\lambda(a-\alpha c)^2\left[2(1-r)^2(1+2t)\alpha\lambda - \beta^2\right]}{2\left[2(1-r)(1+t)\alpha\lambda - \beta^2\right]^2} \tag{19}$$

when: $r = 0$ and $0 < t < 1$, the decision of the supply chain members under the revenue-sharing contract can be obtained; when $0 < r < 1$ and $t = 1$, the decision situation under the cost-sharing contract can be known. In summary of the above, Table 2 can be obtained.

Proposition 2.

The revenue sharing contract cannot coordinate the greening level of logistics capability. The cost sharing contract coordination ability is unstable, and there is a situation in which, when the consumer's environmental awareness is insufficient, the greening level of logistics capability cannot be coordinated. The greening level of logistics capacity under any single contract is higher than the greening level of logistics capacity under the wholesale price contract.

Proposition 3.

Compared with the decentralized decision model, the wholesale price of unit logistics capacity under the revenue-sharing contract is reduced, and the wholesale price of unit logistics capacity under the cost-sharing contract is increased. For any single contract, the market price of the product is also affected by the efficiency coefficient of the green logistics capability market expansion and the market price sensitivity coefficient of the product. However, the market price of the product under the cost sharing contract is always higher than that under the wholesale price contract.

Table. 2. Comparison of different models

Variable	*Decentralized decision model*	*Revenue sharing contract model (r=0, 0<t<1)*	*Cost-sharing contract model (0<r<1, t=1)*	*Combined contract model (0<r<1, 0<t<1)*	*Centralized decision model*
x	$\frac{\beta(a-\alpha c)}{4\alpha\lambda-\beta^2}$	$\frac{\beta(a-\alpha c)}{2(1+t)\alpha\lambda-\beta^2}$	$\frac{\beta(a-\alpha c)}{4(1-r)\alpha\lambda-\beta^2}$	$\frac{\beta(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}$	$\frac{\beta(a-\alpha c)}{2\alpha\lambda-\beta^2}$
ω	$c+\frac{2\lambda(a-\alpha c)}{4\alpha\lambda-\beta^2}$	$tc+\frac{2t^2\lambda(a-\alpha c)}{2(1+t)\alpha\lambda-\beta^2}$	$c+\frac{2(1-r)\lambda(a-\alpha c)}{4(1-r)\alpha\lambda-\beta^2}$	$tc+\frac{2t^2(1-r)\lambda(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}$	—
p	$c+\frac{3\lambda(a-\alpha c)}{4\alpha\lambda-\beta^2}$	$c+\frac{(1+2t)\lambda(a-\alpha c)}{2(1+t)\alpha\lambda-\beta^2}$	$c+\frac{3(1-r)\lambda(a-\alpha c)}{4(1-r)\alpha\lambda-\beta^2}$	$c+\frac{(1-r)(1+2t)\lambda(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}$	$c+\frac{\lambda(a-\alpha c)}{2\alpha\lambda-\beta^2}$
π_n	$\frac{\alpha\lambda^2(a-\alpha c)^2}{(4\alpha\lambda-\beta^2)^2}$	$\frac{t\alpha\lambda^2(a-\alpha c)^2}{\left[2(1+t)\alpha\lambda-\beta^2\right]^2}$	$\frac{\lambda(a-\alpha c)^2\left[2(1-r)^2\alpha\lambda-r\beta^2\right]}{2\left[4(1-r)\alpha\lambda-\beta^2\right]^2}$	$\frac{\lambda(a-\alpha c)^2\left[2(1-r)^2t\alpha\lambda-r\beta^2\right]}{2\left[2(1-r)(1+t)\alpha\lambda-\beta^2\right]^2}$	—
π_p	$\frac{\lambda(a-\alpha c)^2}{2(4\alpha\lambda-\beta^2)}$	$\frac{\lambda(a-\alpha c)^2}{2\left[2(1+t)\alpha\lambda-\beta^2\right]}$	$\frac{(1-r)\lambda(a-\alpha c)^2}{2\left[4(1-r)\alpha\lambda-\beta^2\right]}$	$\frac{(1-r)\lambda(a-\alpha c)^2}{2\left[2(1-r)(1+t)\alpha\lambda-\beta^2\right]}$	—
π	$\frac{\lambda(a-\alpha c)^2(6\alpha\lambda-\beta^2)}{2(4\alpha\lambda-\beta^2)^2}$	$\frac{\lambda(a-\alpha c)^2\left[2(1+2t)\alpha\lambda-\beta^2\right]}{2\left[2(1+t)\alpha\lambda-\beta^2\right]^2}$	$\frac{\lambda(a-\alpha c)^2\left[6(1-r)^2\alpha\lambda-\beta^2\right]}{2\left[4(1-r)\alpha\lambda-\beta^2\right]^2}$	$\frac{\lambda(a-\alpha c)^2\left[2(1-r)^2(1+2t)\alpha\lambda-\beta^2\right]}{2\left[2(1-r)(1+t)\alpha\lambda-\beta^2\right]^2}$	$\frac{\lambda(a-\alpha c)^2}{2(2\alpha\lambda-\beta^2)}$

In summary, under the revenue-sharing contract, the optimal greening level of the logistics capacity is improved and the optimal wholesale price of the unit logistics capacity is lowered, which is conducive to the stability of the cooperation between the logistics service demand side and the logistics service provider. And the optimal market price of the product of the logistics service demand side is affected by the relationship between the efficiency coefficient of the green logistics capability market expansion and the product market price sensitivity coefficient:

①When $\frac{\beta^2}{\lambda} < \alpha$, the market price sensitivity coefficient of the product has a greater impact on the market demand of the product. In this case, the market price of the product under the revenue-sharing contract is lower than that under the decentralized decision model.

②When $\frac{\beta^2}{\lambda} > \alpha$, the green logistics capability market expansion efficiency coefficient has a greater impact on the product market demand. Under the circumstance that the market demand increases with the greening level of logistics capacity, the appropriate increase in the market price of products under the revenue-sharing contract is beneficial to expand the marginal profit.

③When $\frac{\beta^2}{\lambda} = \alpha$, the green logistics capability market expansion efficiency coefficient and the product market price sensitivity coefficient have the same degree of influence on the product market demand and the product market price under the revenue-sharing contract is equal to the product market price under the decentralized decision model.

Therefore, to a certain extent, the revenue-sharing contract can improve the enthusiasm of logistics service provider to participate in the transformation of green logistics capabilities, strengthen the stability of logistics service providers and logistics service demand side cooperation, and achieve Pareto improvement of supply chain members' profits. However, it is not possible to maximize the greening level of logistics capabilities.

Compared with decentralized decision-making, the optimal logistics capability greening level is improved under the cost-sharing contract incentive, and with the improvement of the greening level of logistics capability, the logistics service provider will increase the wholesale price of the unit logistics capacity to ensure the profit level. Regardless of the relationship between the efficiency coefficient of the green logistics capability market expansion and the sensitivity coefficient of the market to the product market price, the product price of the logistics service demander is always greater than that under the decentralized decision. Once $\frac{\beta^2}{\lambda} < \alpha$, the consumer environmental awareness is insufficient, then high product market prices will hinder market demand and reduce the overall profit growth of the logistics service supply chain. Although the cost-sharing contract can improve the enthusiasm of logistics service providers to rebuild green logistics capabilities, due to the limited proportion of costs shared by demand side of logistics services, the wholesale price of logistics capacity is further increased, which is not conducive to the stability of the supply chain. And the cost-sharing contract has failed to maximize the green level of logistics capabilities.

Proposition 4.

The combination contract can coordinate the green level of logistics capabilities. And within a certain cost sharing ratio, compared with the decentralized decision model, the unit market logistics capacity under the combination contract is lower and no matter the relationship between $\frac{\beta^2}{\lambda}$ and α, the product market price is better.

Proposition 4 shows that when the cost-sharing and revenue-sharing ratio meets $(1-r)(1+t)=1$ and $0 < r < r'$, the combination contract can coordinate the green level of logistics capability to the optimal level under centralized decision. At the same time, the combination contract can reduce the wholesale price of unit logistics to stabilize the cooperation between logistics service provider and logistics service demand side. And when $\frac{\beta^2}{\lambda} < \alpha$, the market demand of products is greatly affected by the market price of the products, and the optimal products price under the combination contract is more conducive to expanding market demand; when $\frac{\beta^2}{\lambda} \geq \alpha$, the market demand of products is greatly affected by the market expansion efficiency coefficient of green logistics capability, and the market price of products can be appropriately adjusted to increase the profit margin of supply chain when the green level of logistics capability is optimal.

Proposition 5.

When the greening level of logistics capability is optimized under the coordination of the combination contract, the profit of logistics service provider increases, the overall profit of logistics service supply chain increases, while the profit of logistics service demand side decreases.

Proposition 4 and Proposition 5 indicate that the combination contract can make the logistics capability green level reach the highest level under the centralized decision, minimize the negative impact of the logistics process on the environment and stabilize the cooperation between the members of the logistics service supply chain at the same time. Under the combination contract, the profit of logistics service provider and the overall profit of the supply chain have been greatly improved. However, in order to improve the enthusiasm of logistics service provider to rebuild its logistics capabilities, logistics service demand side has paid excessively high costs and reduced profit levels, which hinders logistics service demand side from implementing combination contracts and is not conducive to the support of logistics service demand side to the logistics service provider to rebuild the green logistics capability level. Therefore, in the initial stage of greening and rebuilding of logistics capacity, market regulation alone cannot promote the rapid and efficient transformation of the logistics service supply chain. The government should provide appropriate subsidy support to help the smooth development of the combination contract and better play the role of the government.

5.2. Research on portfolio contract incentive considering government subsidy

On the basis of the above research, according to the research of Cao et al. (2019), this paper will adopt the internal subsidy strategy in the coordinated subsidy strategy, which means that the government directly subsidizes the demand side of logistics services according to the green level of logistics capacity. The logistics service demand side shares the environmental cost of the logistics service supply chain with the logistics service provider through the cost-sharing and revenue-sharing contract, in order to encourage the logistics service provider to rebuild the green logistics capability.

On the one hand, the internal subsidy strategy can encourage logistics service demand side to actively assume the responsibility of supply chain environmental management, and stimulate the enthusiasm of the supply chain to participate in the transformation of logistics capacity. On the other hand, it is conducive to the logistics service supply chain to gradually establish a coordination mechanism in the logistics capacity. In the later stage of the reconstruction, it can be carried out smoothly without the need for a government subsidy contract. Therefore, under the coordination subsidy strategy within the logistics service supply chain, the profit function of the logistics service demand side and the logistics service provider are shown in (Eqs.20-21) respectively.

$$BT\pi_n^c = (tp-\omega)(a-\alpha p+\beta x) - r\left(\tfrac{1}{2}\lambda x^2\right) + sx \quad (20)$$

$$BT\pi_p^c = \pi_p^{zc} = \left[\omega - c + (1-t)p\right](a-\alpha p+\beta x) - (1-r)\left(\tfrac{1}{2}\lambda x^2\right) \quad (21)$$

It can be seen from the solution process that the government's internal coordination subsidy strategy does not affect the greening level of logistics capacity, the wholesale price of unit logistics capacity, and the market price of products, but only affects the profit of logistics services demander. Substituting equations (11), (12), and (13) into $BT\pi_n^c$, we have Eq. (22):

$$BT\pi_n^c = \frac{s\beta(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda - \beta^2} + \pi_n^c \quad (22)$$

Proposition 6.

In order to facilitate the smooth implementation of the logistics service supply chain portfolio contract, the government's minimum subsidy for the logistics service demand side under the internal coordination subsidy strategy is Eq. (23):

$$s\min = \frac{\beta\lambda(a-\alpha c)(2\alpha\lambda-\beta^2)(8\alpha\lambda-\beta^2)}{16\alpha\lambda(4\alpha\lambda-\beta^2)^2} \quad (23)$$

6. Numerical analysis

In order to test the correctness of the model and the proposition, we make a further analysis through specific examples to more intuitively observe the effect of each contract on the greening level of the logistics service supply chain and the impact on the main variables. Since the effect of coordinating the green level of logistics capacity has nothing to do with consumers' environmental awareness, we take the case of strong consumer environmental awareness as an example and suppose that $a = 120$, $\alpha = 1$, $\beta = 1.3$, $\lambda = 1$, $c = 20$.

According to the set parameters, we can obtain the greening level of logistics capability $x^* = 419.3548$ under the centralized decision, $x^d = 56.2771$ under decentralized decision, and the executable conditions of the revenue-sharing contract and the cost-sharing contract are $0.024025 \le t < 1$ and $0 < r \le 0.3093423138$, respectively. As shown in Fig. 2, the greening level of logistics capacity under a single contract is lower than the greening level of logistics capacity under centralized decision-making, and higher than the green level of logistics capacity under decentralized decision-making, indicating that a single contract can motivate logistics service providers to rebuild green logistics, but not enough to fully mobilize its enthusiasm.

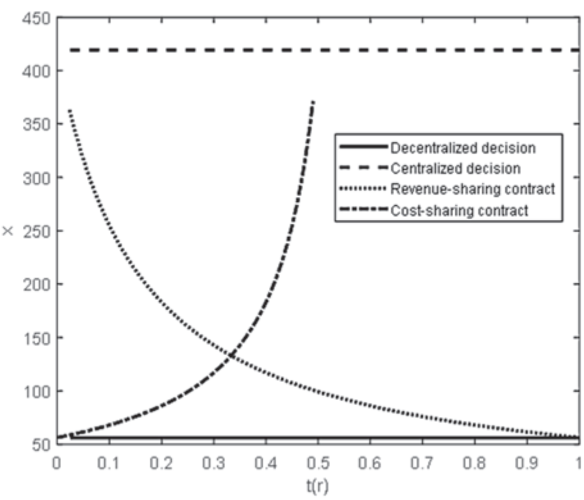

Fig. 2. Green level of logistics capacity under different contracts

For the combination contract, when the revenue-sharing contract coefficient and the cost-sharing coefficient satisfy $(1-r)(1+t)=1(0<r<\frac{1}{2})$, the greening level of the logistics capability under the combination contract is equal to that under the centralized decision.

Figs. (3-4) respectively show the relationship and trend between the market price of unit product and the wholesale price of unit logistics capacity under the five situations of decentralized decision-making, centralized decision-making, revenue-sharing contract, cost-sharing contract and combination contract.

The $t=\frac{r}{1-r}(0<r<\frac{1}{2})$ transformation is used to obtain the change rule of product market price and logistics capacity wholesale price with cost sharing coefficient in the case of combined contract coordination.

In the strong environmental awareness of consumers, the increase in the greening level of logistics capacity is more effective than the increase in market demand for products. According to Fig. 3, the market price of logistics capacity under a single contract is greater than the market price under decentralized decision-making and less than the market price under centralized decision-making, which is conducive to expanding the overall profit margin of logistics service demand side and logistics service supply chain. When the proportion of revenue retained by the logistics service demand side increases, the market price of the product is appropriately reduced to further expand the market demand for the product; when the proportion of the cost shared by the logistics service demand side increases, the market price of the product will further increase. Under the combination contract, since the demand side of the logistics service not only shares the cost but also the income, the market price of the determined product is higher than that under the centralized decision.

Fig. 4 indicates that the wholesale price of logistics capacity under revenue-sharing is always lower than the wholesale price under decentralized decision-making, which is conducive to the stability of cooperation among members of the logistics service supply chain. But the wholesale price of logistics capacity under the cost-sharing contract is higher than that under the decentralized decision-making, and increases with the increase of proportion shared by logistics services demand side.

This situation may be that the marginal cost of the logistics service provider to rebuild the green logistics capacity is always greater than the marginal revenue. As the proportion of the cost share of the logistics service demand side increases, the required green level of logistics capacity is continuously improved. To ensure the profit level, the wholesale price of the optimal logistics capacity determined by the logistics service provider is increased. Within a certain cost-sharing ratio, the combination contract can effectively reduce the wholesale price of logistics capacity.

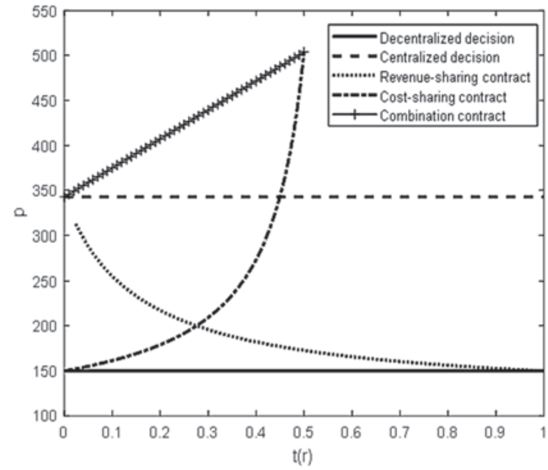

Fig. 3. Price of unit product under different contracts

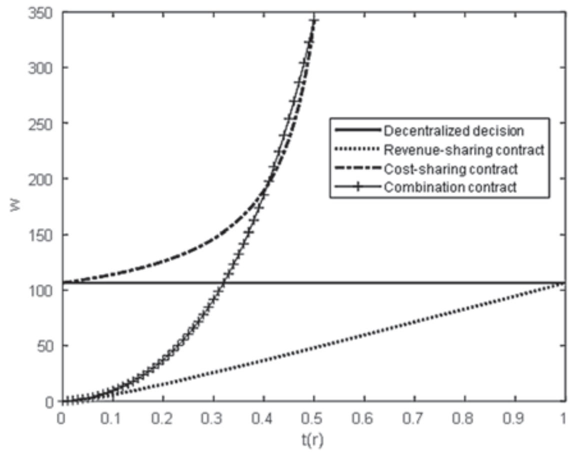

Fig. 4. Wholesale price of unit logistics capacity under different contracts

The changes in the logistics service provider's profit, the logistics service demand side’s profit and the logistics service supply chain's overall profit under different contracts are depicted from Fig. 5 to Fig. 7. The following three conclusions can be drawn from

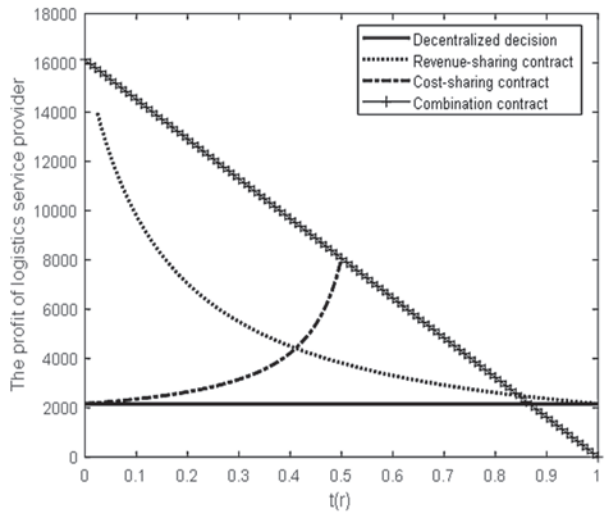

Fig. 5. The profit of logistics service provider under different contracts

Fig. 5: the profit of the logistics service provider under the decentralized decision-making is the lowest; the profit of the logistics service provider under the single contract and the combination contract is improved; as the logistics service provider has the dual support of cost-sharing and revenue-sharing, the profit increase is relatively high in the combination contract.

Fig. 6. illustrates the changes in the profit of the logistics service demand side under different contracts. Under the revenue sharing contract, the profit of the logistics service demand side is always higher than the profit under the decentralized decision, and as the proportion of income sharing increases, the profit first rises and then decreases.

Under the cost-sharing contract, the profit of the logistics service demand side is higher than the profit under the decentralized decision when $0 < r \leq 0.3093423138$, and with the increase of the proportion, the profit of the logistics service demand side increases first and then decreases rapidly; when the proportion of the cost is too large ($0.3093423138 < r < 0.5$), the profit of the logistics service demand side is lower than the profit under the decentralized decision. Under the combination contract, the profit of the logistics service demand side increases first and then decreases with the increase of the proportion of the cost-sharing, but it is always lower than the profit level under the decentralized decision-making which is not conducive to the implementation of the combination contract. At the same time, it also indicates that relying only on the market mechanism in the initial stage of rebuilding green logistics capacity cannot maximize the green level of logistics capacity, and the supports of government financial subsidies are needed.

The change law of the overall profit of the logistics service supply chain under different contracts is shown in Fig. 7. The overall profit of the supply chain is always the largest, followed by the single contract; the profit under decentralized decision is always the smallest. Although the profit of the logistics service demand side is lower than the profit under the decentralized decision, the overall profit of the supply chain under the combination contract is still higher than that under the decentralized decision. The execution of the combination contract is greatly affected by the cost-sharing ratio of the demand side of the logistics service.

Fig. 8 shows that government subsidies can significantly increase the profitability of logistics service demand side to ensure the smooth implementation of portfolio contracts. Under the set parameters, when $s = 2.9785$, the optimal profit of the logistics service demand side under the combination contract is equal to the profit under the decentralized decision which is the minimum subsidy to promote the smooth implementation of the logistics service supply chain combination contract. The government can set the minimum subsidy amount according to the actual situation with the financial subsidies playing a role in the greening of the logistics capacity.

7. Conclusions and perspectives

Based on the consideration of the coordination and control of the logistics service demand side on the logistics service provider's activities, the paper constructs the game model of the logistics service demand side and the logistics service provider. Comparing the decision-making of major variables under centralized decision-making and decentralized decision-making, the combination contract of revenue-sharing and cost-sharing are designed. The greening level of logistics capability, product market price and wholesale price of logistics capacity under single contract are analyzed.

Finally, the variation law of each major decision variable is visually presented through an example. The main conclusions of this paper are as follows:

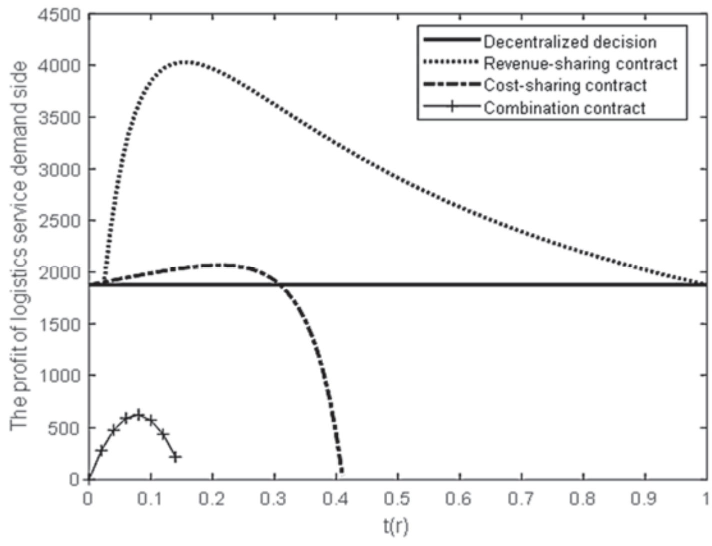

Fig. 6. The profit of logistics service demander under different contracts

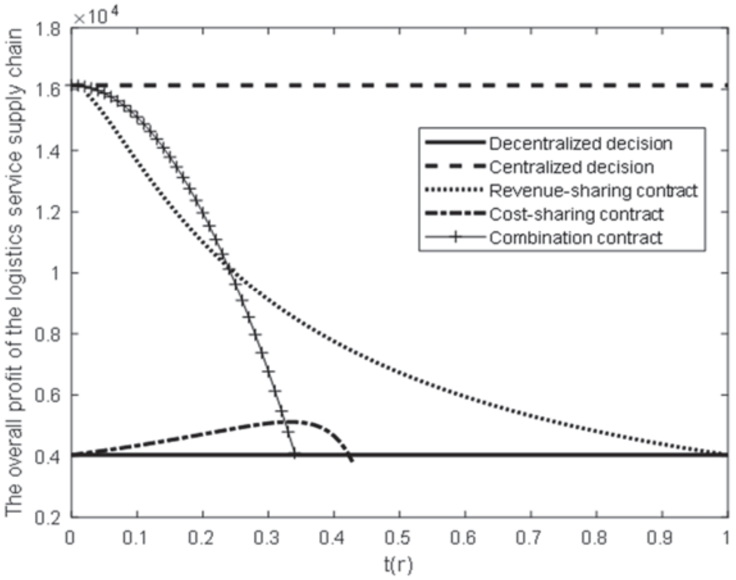

Fig. 7. Overall profit of logistics service supply chain under different contracts

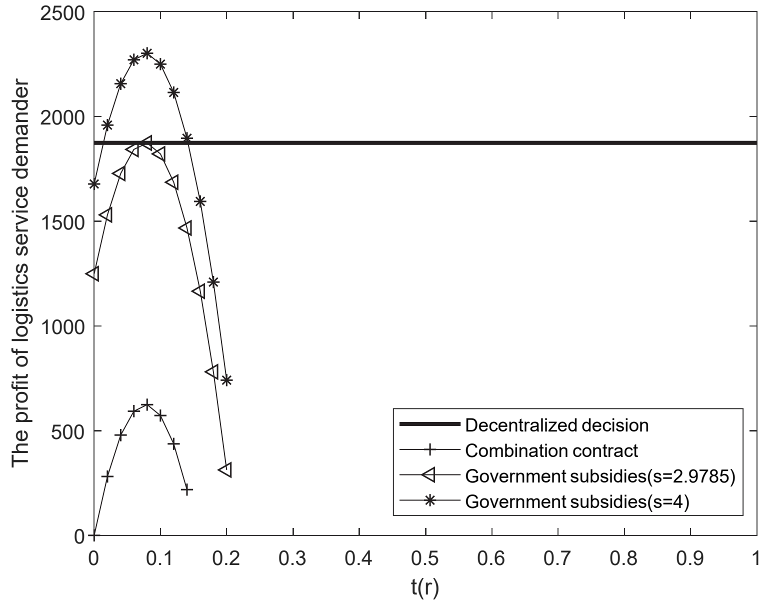

Fig. 8. Profits for logistics services demander under government subsidies

(1) Under decentralized decision-making, the green level of logistics capability does not reach the optimal state under centralized decision-making, and it has nothing to do with the market expansion efficiency coefficient of green logistics capability; only when the efficiency coefficient of the green logistics capability market expansion is equal to the market price sensitivity coefficient of the product, the price of the product is equal to that under the centralized decision.

(2) Revenue-sharing or cost-sharing contract can improve the enthusiasm of logistics service provider, so that the green level of logistics capability is higher than the level of decentralized decision-making, but the single contract cannot achieve the optimal green level of logistics capability. Under the revenue-sharing contract, the logistics capacity wholesale price and product price have been improved, and the Pareto improvement of the logistics service demand side's and the logistics service provider's profit have also been realized. Under the cost-sharing contract, the wholesale price of logistics capacity has improved and increased with the increase of the proportion of logistics services demand side; when the consumer's environmental awareness is insufficient, the cost-sharing contract cannot coordinate the product market price; the profit of both supply chain members can achieve Pareto improvement.

(3) The combination contract can coordinate the greening level of logistics capability, and the wholesale price of logistics capacity is optimized. Regardless of the relationship between the efficiency coefficient of the green logistics capability market expansion and the market price sensitivity coefficient, the product market price under the combination contract is better. However, in the initial stage of greening and rebuilding logistics capabilities, the

market mechanism alone cannot make a smooth transition of the logistics service supply chain. The implementation of the portfolio contract also needs the support of the government financial subsidies.

Through the above analysis and conclusions, the following management implications can be obtained:

(1)For the government: First of all, the government should cultivate consumers' awareness of environmental protection and enhance consumers' green consumption behavior. According to the research in this paper, the green level of logistics capability cannot be optimally affected by the lack of environmental awareness of consumers under the cost-sharing contract. And because the market price of the unit product under the contract is greater than that under the decentralized decision-making, the consumer's lack of environmental awareness causes the higher product price to narrow the overall profit margin of the green logistics service supply chain, which seriously affects the coordination effect of the cost-sharing contract. Although cultivating consumers' environmental awareness in the short-term and large-scale effect is not significant, it is a long-term solution to environmental pollution through “market hands”. As Customers’ environmental awareness increases, consumers are more inclined to green consumption preferences and purchasing behaviors, which will effectively improve the efficiency of the green logistics capacity market expansion efficiency. On this basis, the coordination ability of the contract and the greening level of logistics capacity will be further improved, which will help to form a virtuous circle of the ability to rebuild green logistics. Second, scientifically set the subsidy target and the amount. Although the combination contract can achieve the highest level of green logistics capabilities, but the logistics service demand side has paid too much for this. In the case of an increase in the overall profit of the supply chain, the profit of the demand side of the logistics service has shown a downward trend, hindering the implementation of the combination contract between the two parties. Therefore, in the initial stage of greening and rebuilding of logistics capacity, the market mechanism alone cannot make the logistics service supply chain change smoothly. It is necessary for the government to subsidize the logistics services demander to ensure the enforceability of the combination contract. In order to maximize the effect of government subsidies, the minimum unit subsidy amount should be established. Under this circumstance, although the profit of the logistics service demand side under the combination contract and the decentralized decision are in a flat state, the profit of the logistics service provider and the greening level of the provided logistics capacity are better with the help of the logistics service demand side. With the increasing awareness of consumers' environmental protection, the competitiveness of the product and profit of the logistics service demander will gradually be greatly enhanced and improved.

(2) For the logistics services demand side: Actively participate in the green transformation of logistics capabilities, and rationally set the contract coordination coefficient. The results illustrate that the logistics service demand side can effectively improve the enthusiasm of logistics service provider to rebuild green logistics capabilities through contract coordination. In the absence of consumer environmental awareness, it is more important to assist logistics service provider to reduce the cost of the investment required to renovate green logistics capabilities by increasing the efficiency of logistics operations, so as to reduce the wholesale price of unit green logistics capabilities and product price. With the continuous improvement of consumers' environmental awareness and the continuous introduction of government environmental governance policy regulations, logistics service demand side should continuously strengthen their environmental image and strengthen cooperation with logistics service providers. As a giant in the industry, Maersk also hopes to cooperate with shippers to improve the environmental protection of the shipping industry. It can be seen that the demand side of logistics services is indispensable in the improvement of the logistics service supply chain environment. As a giant in the industry, Maersk also hopes to cooperate with shippers to improve the environmental protection of the shipping industry. It can be seen that the logistics services demand side is indispensable in the improvement of the logistics service supply chain environment. And it is imperative to strengthen cooperation with other supply chain members and participate in the green transformation of logistics capabilities. In addition, according to the actual consumer environmental awareness level and the change rule of profit with the contract coordination coefficient, the value range of the contract coefficient should be set reasonably so that the green ability of logistics can reach the maximum level under the condition of guaranteeing its own profit.

(3) For logistics service provider: Under the background of the gradual improvement of the government's environmental protection policy and the increasing emphasis on the green operation of logistics services, logistics service provider as the main body of logistics capacity rebuilding, should actively respond to the call of the state, gradually implement environmental protection measures, and establish a sense of crisis. It is necessary to deeply understand that the improvement of the greening level of logistics capacity in the early stage is based on the participation of government financial subsidies and logistics service demand side, and the high cost brought about by the low efficiency of logistics operations has also shifted to the logistics services demand side. And it is very important to dig out the problems behind the improvement of the greening level of logistics capabilities and the increase of their own profits. In short, logistics service provider should increase R&D investment, reduce the cost of logistics required for greening and rebuilding, and continuously improve

the efficiency of logistics operations, so as to enhance the competitiveness in the future logistics industry with green logistics as the main keynote.

This paper only studies the contract incentive model between a single logistics service demander and a single logistics service provider, while the logistics service provider not only provides services to a logistics service demand side, but also the logistics service demand side not only accepts service provided by one logistics service provider.

The contract model between multiple subjects needs further study. In addition, this paper assumes that the information between the logistics service demand side and the logistics service provider is symmetrical, but in reality, the logistics service demand side knows more information about the product market demand and the consequent demand for logistics services, and logistics service provider is more aware of the cost of rebuilding logistics capabilities. And the dominant position of different subjects will also have an impact on the degree of information sharing. Therefore, the contract incentive effect under information asymmetry is a further research direction.

Appendix

Proposition 1

Proof.

It is known from the assumption that $2\alpha\lambda > \beta^2$, so $0 < 1 - \frac{\beta^2}{2\alpha\lambda} < 1$, then we can know that $\frac{x^*}{x^d} = \frac{4\alpha\lambda - \beta^2}{2\alpha\lambda - \beta^2} = 1 + \frac{1}{1 - \frac{\beta^2}{2\alpha\lambda}} > 2$. And it is easy to get $p^d - p^* = \frac{2\lambda(a - \alpha c)(\alpha\lambda - \beta^2)}{(2\alpha\lambda - \beta^2)(4\alpha\lambda - \beta^2)}$, therefore, the relationship between the size of p^d and p^* is related to $\alpha\lambda - \beta^2$.

Proposition 2

Proof.

(1) Revenue-sharing contract model ($r = 0$, $0 < t < 1$)

In order to make the members of the logistics service supply chain have the willingness to participate in the contract, the profit of the logistics service supply chain members under the revenue-sharing contract cannot be lower than the relative profit under the decentralized decision model. In this case, it is necessary to satisfy $\pi_n^{c1} \geq \pi_n^d$ and $\pi_p^{c1} \geq \pi_p^d$ at the same time. Calculated from the results listed in Table 2, the following formula can be obtained:

$$\pi_p^{c1} - \pi_p^d = \frac{(1-t)(a - \alpha c)^2 \alpha\lambda^2}{\left[2(1+t)\alpha\lambda - \beta^2\right](4\alpha\lambda - \beta^2)} > 0$$

$$\pi_n^{c1} - \pi_n^d = \alpha\lambda^2(a - \alpha c)^2 \frac{-4(\alpha\lambda)^2 t^2 + \left[8(\alpha\lambda)^2 - 4\alpha\lambda\beta^2 + \beta^4\right]t - (2\alpha\lambda - \beta^2)^2}{\left[2(1+t)\alpha\lambda - \beta^2\right]^2 (4\alpha\lambda - \beta^2)^2}$$

When $1 - \frac{\beta^2(4\alpha\lambda - \beta^2)}{4(\alpha\lambda)^2} \leq t < 1$, it is easy to get $\pi_n^{c1} \geq \pi_n^d$. So when $0 < 1 - \frac{\beta^2(4\alpha\lambda - \beta^2)}{4(\alpha\lambda)^2} \leq t < 1$, we can meet $\pi_p^{c1} > \pi_p^d$ and $\pi_n^{c1} \geq \pi_n^d$ at the same time. Because $4\alpha\lambda - \beta^2 > 2(1+t)\alpha\lambda - \beta^2 > 2\alpha\lambda - \beta^2$, it is easy to prove $x^d < x^{c1} < x^*$.

(2) Cost-sharing contract model ($0 < r < 1, t = 1$)

Similarly, only when the profits of the logistics service supply chain members under the cost-sharing contract are not lower than the relative profits under the decentralized decision-making, they are motivated to participate in the contract. Comparing the profit of the logistics service supply chain members under decentralized decision model and cost-sharing contract model in Table 2, the results are as follows:

$$\pi_p^{c2} - \pi_p^d = \frac{\lambda(a - \alpha c)^2}{2} \frac{r\beta^2}{\left[4(1-r)\alpha\lambda - \beta^2\right](4\alpha\lambda - \beta^2)} > 0$$

$$\pi_n^{c2} - \pi_n^d = \lambda(a - \alpha c)^2 \frac{-2\alpha\lambda\beta^2(8\alpha\lambda - \beta^2)r^2 + \beta^4(4\alpha\lambda - \beta^2)r}{2\left[4(1-r)\alpha\lambda - \beta^2\right]^2 (4\alpha\lambda - \beta^2)^2}$$

$\pi_n^{c2} \geq \pi_n^d$ When $0 < r \leq \frac{\beta^2(4\alpha\lambda - \beta^2)}{2\alpha\lambda(8\alpha\lambda - \beta^2)} < 1$, so the cost-sharing contract can only be implemented when $0 < r \leq \frac{\beta^2(4\alpha\lambda - \beta^2)}{2\alpha\lambda(8\alpha\lambda - \beta^2)} < 1$. Under such conditions, it can be clearly seen that $x^d < x^{c2}$, while the relationship between x^{c2} and x^* is relatively complicated. $x^{c2} - x^* = \frac{2\alpha\lambda\beta(a - \alpha c)(2r - 1)}{\left[4(1-r)\alpha\lambda - \beta^2\right](2\alpha\lambda - \beta^2)}$, if the consumer's environmental awareness is insufficient, the expansion of the green logistics capacity to the market is not enough to offset the negative impact of the market price of the product on the market demand, then $0 < r < \frac{\beta^2(4\alpha\lambda - \beta^2)}{2\alpha\lambda(8\alpha\lambda - \beta^2)} < \frac{1}{2}$ which results in $x^{c2} < x^*$.

Therefore, the coordination effect of the cost-sharing contract on the green level of logistics capacity is affected by the consumer's environmental awareness which indicates that the coordination ability is unstable.

Proposition 3

Proof.

(1) Revenue-sharing contract model ($r = 0$, $0 < t < 1$)

From Table 2, we can see that $\omega^{c1} = tc + \frac{2t^2\lambda(a - \alpha c)}{2(1+t)\alpha\lambda - \beta^2}$ and $\omega^d = c + \frac{2\lambda(a - \alpha c)}{4\alpha\lambda - \beta^2}$.

Comparing the numerical values of ω^{c1} and ω^{d}, it can get:

$$\omega^{c1}-\omega^{d}=(t-1)\left\{c+\frac{2(1+2t)\alpha\lambda-(1+t)\beta^2}{(4\alpha\lambda-\beta^2)\left[2(1+t)\alpha\lambda-\beta^2\right]}\right\}<0$$

Similarly, for p^{c1} and p^{d}, we have $p^{c1}-p^{d}=\frac{2\lambda(t-1)(a-\alpha c)(\alpha\lambda-\beta^2)}{\left[2(1+t)\alpha\lambda-\beta^2\right](4\alpha\lambda-\beta^2)}$; for p^{c1} and $p*$, we have $p^{c1}-p*=\frac{2\lambda t(a-\alpha c)(\alpha\lambda-\beta^2)}{\left[2(1+t)\alpha\lambda-\beta^2\right](2\alpha\lambda-\beta^2)}$. If $\frac{\beta^2}{\lambda}<\alpha$, then $p^{d}>p^{c1}>p*$; if $\frac{\beta^2}{\lambda}>\alpha$, then $p^{d}<p^{c1}<p*$; if $\frac{\beta^2}{\lambda}=\alpha$, then $p^{d}=p^{c1}=p*$.

(2) Cost-sharing contract model ($0<r<1$, $t=1$)

As can be seen from Table 2, $\omega^{c2}=c+\frac{2(1-r)\lambda(a-\alpha c)}{4(1-r)\alpha\lambda-\beta^2}$, comparing the numerical values of ω^{c2} and ω^{d}, we can obtained that $\omega^{c2}-\omega^{d}=\frac{2\lambda(a-\alpha c)r\beta^2}{(4\alpha\lambda-\beta^2)\left[4(1-r)\alpha\lambda-\beta^2\right]}>0$.

Similarly, for p^{c2} and p^{d}, we have:

$$p^{c2}-p^{d}=3\lambda(a-\alpha c)\frac{r\beta^2}{\left[4(1-r)\alpha\lambda-\beta^2\right](4\alpha\lambda-\beta^2)}>0.$$

For p^{c2} and $p*$, we have:

$$p^{c2}-p*=\lambda(a-\alpha c)\frac{(-2\alpha\lambda+3\beta^2)r+2(\alpha\lambda-\beta^2)}{\left[4(1-r)\alpha\lambda-\beta^2\right](2\alpha\lambda-\beta^2)}$$, when $\frac{2}{3}\alpha<\frac{\beta^2}{\lambda}\le\alpha$ or $\frac{\beta^2}{\lambda}\le\frac{2}{3}\alpha$, $p^{c2}>p*$; when $\alpha<\frac{\beta^2}{\lambda}<2\alpha$, $p^{c2}<p*$。

Proposition 4

Proof.

Let $\frac{\beta(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}=\frac{\beta(a-\alpha c)}{2\alpha\lambda-\beta^2}$, as $(1-r)(1+t)=1\left(0<r<\frac{1}{2}\right)$, we have $x^c=x*$, which means that the green level of logistics capability is optimal. Substituting $(1-r)(1+t)=1$ into the following formula, and we have:

$$\omega^{c}-\omega^{d}=tc+\frac{2t^2(1-r)\lambda(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}-c-\frac{2\lambda(a-\alpha c)}{4\alpha\lambda-\beta^2}$$
$$=(t-1)c+2\lambda(a-\alpha c)\frac{(4\alpha\lambda-\beta^2)r^2+(2\alpha\lambda-\beta^2)r-(2\alpha\lambda-\beta^2)}{(1-r)(2\alpha\lambda-\beta^2)(4\alpha\lambda-\beta^2)}$$

Existing $0<r_1<\frac{1}{2}$, when $0<r<r_1$, $(4\alpha\lambda-\beta^2)r^2+(2\alpha\lambda-\beta^2)r-(2\alpha\lambda-\beta^2)<0$, we have $\omega^{c}<\omega^{d}$.

Similarly,

$p^{c}-p^{d}=\lambda(a-\alpha c)\frac{2(5\alpha\lambda-2\beta^2)r-2(\alpha\lambda-\beta^2)}{(1-r)(2\alpha\lambda-\beta^2)(4\alpha\lambda-\beta^2)}$, when $\frac{\beta^2}{\lambda}<\alpha$, note $r_2=\frac{\alpha\lambda-\beta^2}{5\alpha\lambda-2\beta^2}$, we have $p^{c}<p^{d}$ when $0<r<r_2$; when $\frac{\beta^2}{\lambda}\ge\alpha$, $p^{c}>p^{d}$. For p^{c} and $p*$, $p^{c}-p*=\frac{r\lambda(a-\alpha c)}{2\alpha\lambda-\beta^2}>0$. Note $r'=\min\{r_1,r_2\}$, when the green logistics capability is optimal under the combined contract, take $0<r<r'$, we can get the following conclusion:

$\omega^{c}<\omega^{d}$, when $\frac{\beta^2}{\lambda}<\alpha$, $p^{c}<p^{d}$; when $\frac{\beta^2}{\lambda}\ge\alpha$, $p^{c}>p^{d}$.

Proposition 5

Proof.

Since $(1-r)(1+t)=1$ and $0<r<\frac{1}{2}$, we get:

$\pi_p^{c}-\pi_p^{d}=\frac{\lambda(a-\alpha c)^2}{2}\frac{(-4\alpha\lambda+\beta^2)r+2\alpha\lambda}{(2\alpha\lambda-\beta^2)(4\alpha\lambda-\beta^2)}$, when $0<r<\frac{1}{2}<\frac{2\alpha\lambda}{4\alpha\lambda-\beta^2}$, we can obtain $\pi_p^{c}>\pi_p^{d}$.

For π_n^{c} and π_n^{d}, we have:

$$\pi_n^{c}-\pi_n^{d}=\lambda(a-\alpha c)^2\frac{-2\alpha\lambda(4\alpha\lambda-\beta^2)^2r^2+(2\alpha\lambda-\beta^2)(4\alpha\lambda-\beta^2)^2r-2\alpha\lambda(2\alpha\lambda-\beta^2)^2}{2(2\alpha\lambda-\beta^2)^2(4\alpha\lambda-\beta^2)^2}$$

Note that:

$$y=-2\alpha\lambda(4\alpha\lambda-\beta^2)^2r^2+(2\alpha\lambda-\beta^2)(4\alpha\lambda-\beta^2)^2r-2\alpha\lambda(2\alpha\lambda-\beta^2)^2$$

since $\Delta=-\beta^2(8\alpha\lambda-\beta^2)(2\alpha\lambda-\beta^2)^2(4\alpha\lambda-\beta^2)^2<0$, $-2\alpha\lambda(4\alpha\lambda-\beta^2)^2<0$, we can know $y<0$,

$$\pi_n^{c}-\pi_n^{d}=\lambda(a-\alpha c)^2\frac{y}{2(2\alpha\lambda-\beta^2)^2(4\alpha\lambda-\beta^2)^2}<0.$$

For π^{c} and π^{d}, we have:

$$\pi^{c}-\pi^{d}=\frac{\lambda(a-\alpha c)^2}{2}\frac{-2\alpha\lambda(4\alpha\lambda-\beta^2)^2r^2+4(\alpha\lambda)^2(2\alpha\lambda-\beta^2)}{(2\alpha\lambda-\beta^2)^2(4\alpha\lambda-\beta^2)^2}$$

When $0<r<\frac{\sqrt{2\alpha\lambda(2\alpha\lambda-\beta^2)}}{4\alpha\lambda-\beta^2}<\frac{1}{2}$, we can obtain that $\pi^{c}>\pi^{d}$.

In summary, when $0<r<\frac{\sqrt{2\alpha\lambda(2\alpha\lambda-\beta^2)}}{4\alpha\lambda-\beta^2}<\frac{1}{2}$, we have $\pi_p^{c}>\pi_p^{d}$, $\pi_n^{c}<\pi_n^{d}$ and $\pi^{c}>\pi^{d}$.

Proposition 6

Proof.

Since government subsidies do not affect the decision variables of supply chain members, $BT\pi_p^c = \pi_p^c > \pi_p^d$ is still established. The combination contract can be carried out smoothly as long as $BT\pi_n^c \geq \pi_n^d$ is satisfied.

Let $BT\pi_n^c = \pi_n^d$, we have

$$-\lambda(a-\alpha c)^2 \frac{y}{2(2\alpha\lambda-\beta^2)^2(4\alpha\lambda-\beta^2)^2} = \frac{s\beta(a-\alpha c)}{2(1-r)(1+t)\alpha\lambda-\beta^2}$$

and solving the equation can obtain the government's minimum subsidy for logistics service providers is $s\min = \frac{\beta\lambda(a-\alpha c)(2\alpha\lambda-\beta^2)(8\alpha\lambda-\beta^2)}{16\alpha\lambda(4\alpha\lambda-\beta^2)^2}$.

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