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Research on Cooperation Incentives for Emergency Logistics Capacity Reserve from Humanitarian Organization Perspective

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Abstract: Recently, catastrophic events have occurred frequently, seriously threatening the safety of people's lives and property. The uncertainty in the demand for emergency logistics resources poses a huge challenge for emergency stockpiling. From the perspective of humanitarian organizations, cooperation with third-party logistics providers for emergency logistics capacity reserve can improve the efficiency and reduce the cost of reserve. However, in practice, there is a lack of unity of purpose, capacity mismatch and information asymmetry between the two rescue parties, which makes cooperative emergency reserve a problem worth studying. This paper addresses the emergency logistics capacity reserve problem and take a two-level supply chain consisting of humanitarian organization and third-party logistics provider as the research object to explore the cooperative reserve model between the two sides. This paper establishes a Stackelberg game model with humanitarian organization as the leader and third-party logistics provider as the follower based on the premise of mutual cooperation. Under different incentive models of cooperation, the humanitarian organization executes the price decision to minimize the deprivation cost and disaster relief cost, and the third-party logistics provider executes the stockpiling decision to maximize the revenue. Secondly, this paper discusses the equilibrium decisions of both sides of the game under different scenarios and provides corresponding numerical analysis. Finally, this paper finds that for the possible moral hazard problem of third-party logistics provider, humanitarian organization incentives and government subsidies have a positive effect on third-party logistics provider's stockpiling; while the effect of corporate reputation depends on their donation behavior.

Keywords: Humanitarian Organization; Emergency Reserve; Cooperative Incentives; Stackelberg Game.

1. Introduction

In recent years, catastrophic events such as emergencies, natural disasters and public health crises have occurred frequently, seriously threatening people's lives and health while causing huge property losses. The frequency of catastrophic events has drawn significant attention to emergency management from humanitarian organizations (HO), governmental organizations, private sector (PS), and academics [1]. However, due to the uncertainty of disaster occurrence, relief organizations engaged in emergency management usually pre-stock emergency supplies and logistics facilities to ensure that supplies can be delivered to the point of need as soon as a disaster occurs.

Given that HOs usually rely on 3PLP for logistics activities, both parties usually enter into framework agreements for logistics capacity reserve activities during the preparation period of a disaster [2]. This is because if a disaster occurs, all relief participants face enormous time pressure and extreme pressure on the market, and it becomes very difficult for HO to procure supplies on an ad hoc basis as well as to coordinate logistics resources. However, if various resources and facilities and equipment are prepared before a crisis occurs, the relief needs can be met quickly by simply activating contingency plans in the event of a crisis. However, HO and 3PLP need to develop these agreements under very uncertain circumstances, such as when future needs or budgets available for operations are not known. Not only that, but the nature of the parties and the information they have are different. The existence of these issues poses certain challenges for both parties to cooperate in logistics capacity reserve activities. If both parties have a sound cooperation mechanism, then the risk for both parties can be greatly reduced and their ability to cope with disasters can be improved [3]. Besides, the reputation mechanism of 3PLP and the government's regulatory subsidy policy are also important factors that influence the cooperation between HO and 3PLP. 3PLP's participation in the cooperation is not only influenced by the economic rewards given by HO, but also by non-economic benefits, such as the brand image of the company, corporate social responsibility and employee incentives, etc. In addition, government policies such as regulation and incentives can facilitate 3PLPs to fulfill their social mission and therefore provide the level of 3PLP-HO cooperation. For example, the government can, motivate 3PLPs to improve the level of cooperation. Thus, it can be seen that it is meaningful to study the 3PLP reputation mechanism and the incentive effect of government policies on 3PLP.

Based on the above background, this paper investigates the issue of emergency logistics capacity reserve with HO as the main perspective under the uncertain disaster occurrence and uncertain logistics resource demand. First, this paper explores the impact that 3PLP participation can have on HO reserve decisions and benefits. Then, this paper considers the possible moral hazard problem of 3PLPs and investigates how HOs can incentivize 3PLPs to cooperate in stockpiling. The price incentive of HO to 3PLPs needs to be properly decided when there is information asymmetry between the two parties. In addition, we discuss the role of corporate reputation and government subsidies in facilitating cooperation between the two parties.

2. Literature Review

Emergency stockpiling generally refers to an activity in

which prepositioning of assets or materials is performed in the pre-disaster preparation phase [4], and these items are assembled in pre-standardized and modularized sets [5]. In the complex network that is the humanitarian ecosystem, successful disaster response requires coordination among organizations, which is specifically defined as the relationships and interactions between different participants operating in the relief environment [6]. Only through cooperation can participants achieve what they cannot achieve unilaterally [7]. In studying the use of various incentive approaches to improve the level of corporate reserves, scholars have mainly expanded on the incentive cycle and regulatory or incentive approaches. Studies such as incentive cycle extend the incentive model of single-period emergency material production capacity reserve system into a multi-period model [8] and transform the long-term government-firm partnership contract into an inter-period incentive contract [9] to improve agents' motivation and provide moral risk prevention strategies for cedants.

From the domestic and international literature on contingency reserves, the main research approaches are mixed integer planning modeling approaches, simulation modeling approaches, and newsboy modeling approaches. In terms of research content, unilateral stockpiling research mainly lies in multiple stages of stockpiling to meet randomly occurring demands in different periods, while multiparty stockpiling mainly focuses on the cooperative model research of joint stockpiling emergency logistics between government and enterprises. Therefore, this paper studies HO and 3PLP cooperative emergency reserve as a supplement to this direction. In terms of HO-PS cooperation, many literatures qualitatively study the significance of PS participation in humanitarian relief to the whole disaster relief supply chain and the motivation of PS participation in humanitarian relief. In terms of the specific content of cooperation, these literatures suggest that PS can provide solutions to the problems faced in relief activities, such as having PS provide supplies before a disaster and participate in inventory management, transportation decisions, and distribution of supplies after a disaster. In contrast, this paper focuses on the cooperation between HO and PS in stockpiling emergency logistics capacity. In terms of incentives for emergency reserve cooperation, studies have multi-cycle incentives and explicit and implicit incentives. Single most of these current studies assume that both participants are completely rational and information symmetric, which is somewhat different from the actual situation.

3. Problem Description

First, we assume that the probability of a disaster is uncertain, and the demand for logistics resources to transport materials after a disaster is also uncertain. The purpose of pre-disaster logistics capacity pre-stocking activities is to prevent the sudden arrival of a disaster, when logistics resources are not available in time and at great cost.

As a public benefit organization, the mission of HO is to reduce human suffering, so its goal is to minimize its own costs while meeting the needs of the affected people as much as possible. the source of HO revenue is mainly donations from various parties, but this point is not the focus of analysis in this paper. The HO objective function in this paper consists of HO reserve cost and deprivation cost. On the one hand, HO brings high costs to itself when it carries out disaster relief activities; on the other hand, HO generates certain deprivation costs when it has too little reserves and cannot meet the needs of the disaster victims.

As a professional third-party logistics service provider, 3PLP has professional logistics technology and capability, which requires less cost compared to HO in stocking emergency logistics capacity. The motivation for 3PLP to participate in emergency logistics capacity stockpiling is that by entering the disaster relief logistics market through cooperation with HO, it cannot only gain profits in addition to commercial operations, but also reflect corporate social responsibility and increase corporate reputation. However, it is highly unlikely that 3PLPs themselves would stockpile emergency logistics capacity purely for disaster relief. Although 3PLPs generally have a portion of emergency logistics capacity, it exists to handle unexpected emergencies, not to meet large-scale disaster relief needs. For example, in the face of insufficient emergency logistics capacity during the double 11 express peak period, 3PLPs will plan ahead for emergency protection plans and carry out additional transportation vehicles, recruit couriers or part-time personnel, etc.

In terms of modeling, this paper considers the case where HO and 3PLP cooperate in stockpiling. HO and 3PLP form a two-level disaster relief supply chain system. In this case, HO is the proponent of cooperation and 3PLP can choose whether to accept it or not, while in the later paper we will determine whether 3PLP will participate in the cooperation by comparing its profits before and after the cooperation. If the 3PLP chooses to cooperate, both parties will agree on the price to be paid for the reserves used for disaster relief and the price to be compensated for the reserves not used for disaster relief. During the disaster preparation phase, the HO minimizes the deprivation and reserve costs by making decisions on the number of reserves, and the 3PLP performs the reserve activities for the HO's emergency logistics capacity as needed. After a disaster occurs, the HO assesses the disaster needs and has the 3PLP respond immediately by calling on emergency logistics capacity for disaster relief. After the disaster relief is completed, the HO makes payments to the 3PLP. If the disaster-induced demand for logistics resources is less than the amount of logistics capacity the 3PLP has reserved in advance, the 3PLP uses part of the reserves required for the disaster, and the HO pays the 3PLP for the portion that has been used for disaster relief, as well as compensation for the excess reserves. In contrast, if the disaster triggers a demand that is greater than the amount of logistics capacity that 3PLP has stockpiled in advance, 3PLP uses the entire stockpile for disaster relief, and HO not only pays the cost but also bears the deprivation cost, i.e., the loss caused by not meeting the disaster victims' demand.

Second, this paper studies the cooperative reserve situation between HO and 3PLP under the consideration of corporate moral hazard problem with asymmetric information between the two parties. In this scenario, the 3PLP, after stockpiling as required by the HO, will consider calling on these reserves for commercial profit before the disaster, which will result in insufficient reserves to meet the disaster needs after the disaster, compared to the case when the corporate moral hazard issue is not considered. Due to the asymmetric information relationship between the parties, the HO has no way of knowing what the actual reserves of the 3PLP are. The HO therefore penalizes and incentivizes such behavior, and the HO's decision is to determine the optimal price to pay in order to incentivize the 3PLP to reserve for itself, thereby

minimizing its own deprivation and relief costs. the 3PLP's decision is to determine its own safety reserves with the goal of maximizing its own benefits.

Finally, based on the previous consideration of corporate moral hazard, the effects of corporate reputation and government subsidy mechanism on 3PLP decision making and cost-benefit of both parties are considered. After the introduction of corporate reputation, 3PLPs will improve their reputation by donating logistics resources in order to gain more benefits in the future. In this case, the 3PLP will not only decide the amount of safety reserves but also the amount of donations to maximize the benefits. After the introduction of government subsidies, the government will subsidize 3PLPs' behavior of making contingency reserves to increase 3PLPs' motivation to reserve, thus influencing 3PLPs' decision making.

The notation used in formulating the model is presented below.

ε : Probability of disaster

x : The resource demand caused by the disaster

q_2: The amount of emergency logistics capacity required by HO under the moral hazard of the enterprise

c_H : HO reserve required unit reserve cost

c_E:3PLP The required unit reserve cost of reserve

d : The deprivation cost per unit that HO fails to meet the demand of the affected people

r : Residual value of contingency logistics capacity

i:3PLP Unit revenue that can be obtained by using reserve capacity for transporting daily commodities

q_0: HO's own reserve of emergency logistics production capacity

p_w : Consider the unit payment price of HO under corporate moral hazard when cooperating

q_3 : The amount of 3PLP security reserve under the consideration of corporate moral hazard when cooperating

In order to make the model more realistic, the following assumptions are made without loss of generality in this paper, and the following constraints are placed on the relevant parameters:

(1) The duration of cooperation between HO and 3PLP is equal to the duration from the reserve logistics capacity to the end of disaster relief, i.e., it indicates that the model in this paper is single-cycle.

(2) The logistics capacity of HO and 3PLP cooperative reserve is decided before the disaster, which is consistent with the actual situation.

(3) In a single study cycle, only one disaster is considered to have occurred.

(4): In the case of HO alone stockpiling, it is guaranteed that HO will stockpile and use it for disaster relief whenever it is available.

(5): Demonstrate 3PLP's expertise in logistics, and that 3PLP's stockpiled resources will not be treated as salvage value in the event of a disaster relief need.

(6): Ensure that HO will definitely choose disaster relief after the cooperative reserve.

(7): To ensure that 3PLP will go for disaster relief after reserving logistics capacity without considering corporate moral hazard.

(8): When considering corporate moral hazard, ensure that 3PLP will go to disaster relief after reserving.

4. Models

First, we model the HO as a separate reserve of emergency logistics capacity. In the disaster preparation stage, HO reserves emergency logistics capacity at the price of the unit. After a disaster occurs, if the disaster-induced demand is less than the reserve quantity, i.e., when all the disaster demands are met, the excess resources are disposed of according to the residual value; if the disaster-induced demand is greater than the reserve quantity, i.e., when all the reserves are put into the disaster relief, and the excess of the HO reserves will bring a certain deprivation cost to the HO. The HO will make a benefit-cost analysis based on its own reserve cost and deprivation cost, and make a decision on the optimal amount of emergency logistics capacity reserve under the cost minimization objective. Therefore, the cost function under the HO separate reserve model is

$$L_0 = c_H q_0 - (1-\varepsilon) r q_0 - \varepsilon \int_0^{q_0} r(q_0 - x) f(x) dx + \varepsilon \int_{q_0}^{u} d(x - q_0) f(x) dx$$

Theorem 1 Under the separate reserve model, the cost function of HO is convex with respect to the reserve quantity. the optimal reserve quantity of HO is.

Proof Solving the first- and second-order conditions on q_0 for equation yields

$$\frac{\partial L_0}{\partial q_0} = c_H - r - \varepsilon(d - r)(1 - F(q_0))$$

$$\frac{\partial^2 L_0}{\partial q_0^2} = \varepsilon(d - r) f(q_0)$$

From $r + c_H < d$, we have $r < d$, and combining with equation, we obtain. This shows that the HO cost function is a convex function of the reserve quantity, and there exists a reserve quantity that minimizes the HO cost. Therefore, Theorem 1 is proved.

From Theorem 1, it can be seen that the factors affecting the optimal reserve decision of HO under the HO individual reserve model are the probability of disaster, reserve cost, deprivation cost, and salvage value, respectively. Among these parameters, the reserve cost is the factor that inhibits the HO from conducting reserve activities, while the larger the deprivation cost, the probability of disaster occurrence, and the salvage value, the more the HO is promoted to reserve in advance. At this point, the HO cost under the HO separate reserve model is.

1. Decision-making process of HO and 3PLP

In the cooperation model considering the moral hazard of enterprises under asymmetric information, we take into account the possible default of 3PLP and the inability of HO to recognize such behavior. Specifically, after stockpiling as required by the HO, the 3PLP will choose to put part of the stockpiled emergency logistics capacity into its own daily operation, so that the part of daily operation capacity cannot be used for disaster relief immediately after a disaster. The HO and the 3PLP make decisions as follow:

(1) At the beginning of the reserve cycle, HO will forecast the number of materials needed after a disaster event based on past historical data, and thus forecast the amount of logistics resources needed. Before the disaster occurs, the HO will determine the logistics capacity that the 3PLP needs to reserve in advance. The reserve capacity determined by HO in this case is an exogenous variable, because the reserve quantity determined by HO may be different from the actual safe

reserve quantity of 3PLP.

(2) In the specific reserve activities, 3PLP will reserve the amount required by HO. However, there is the same uncertainty due to the commercial transportation demand of 3PLP. When there is a sudden increase in 3PLP's commercial transportation demand, it will decide to leave a part of the safety reserve capacity, and use the rest of the reserve logistics capacity to transport daily commodities for its own benefit, i.e.

(3) In this reserve cycle, if a catastrophic event occurs, the 3PLP needs to call on the corresponding logistics capacity for disaster relief activities. ho will decide to provide unit payment price. Considering the possibility of 3PLP calling reserve logistics capacity, i.e., the existence of corporate moral hazard, HO will give a unit penalty. That is, when the 3PLP is unable to provide the logistics capacity identified in the agreement immediately at the time of disaster, it needs to pay a unit penalty.

(4) After the reserve cycle is over, the remaining reserve capacity of 3PLP can still be disposed of according to the corresponding residual value.

Based on the above decision process, it can be seen that the decision sequence of HO and 3PLP in this cooperative reserve model is shown in Figure 3.3. This model is a Stackelberg game model with HO as the dominant player and 3PLP as the follower, where the objective of HO is to minimize the cost and the decision variable is the price paid, and the objective of 3PLP is to maximize the revenue and the decision variable is the actual safe reserve capacity. Based on this, the optimal decision of HO and 3PLP will be solved by the inverse order derivation method.

2. In the reserve cycle, if 3PLP accepts the cooperation agreement offered by HO for its reserve logistics capacity, the cost, the safe reserve logistics capacity is.

(1) If the disaster does not occur during the reserve cycle, 3PLP transports the commodity at a profit, and the residual value gains.

(2) If a disaster occurs, when the logistics demand is less than the 3PLP's safe reserve capacity, i.e., when the 3PLP can fully meet the disaster relief demand, the 3PLP obtains disaster relief revenue, commodity transportation revenue, and residual value revenue.

(3) When the logistics demand is greater than the 3PLP safety reserve and less than the reserve amount specified in the HO agreement, i.e., when the 3PLP puts all the safety reserve capacity into disaster relief, but still cannot meet the relief demand. 3PLP obtains the relief revenue, commodity transportation revenue, and handover penalty.

(4) When the logistics demand is greater than the reserve capacity specified in the HO agreement, i.e., when the 3PLP's revenue in this case is consistent with case (3), and the penalty is.

As a follower of the Stackelberg game, 3PLP conducts cost-benefit analysis based on its own cost and capacity, and makes the decision to safely reserve logistics capacity under the profit maximization objective.

Therefore, we can get the profit function of 3PLP

$$\pi_2 = -c_E q_2 + i(q_2 - q_3) + (1-\varepsilon) r q_3 + \varepsilon \int_0^{q_3} [p_n x + r(q_3 - x)] f(x) dx +$$

$$\varepsilon \int_{q_3}^{q_2} [p_n q_3 - p_p (x - q_3)] f(x) dx + \varepsilon \int_{q_2}^{u} [p_n q_3 - p_p (q_2 - q_3)] f(x) dx$$

Theorem 2 For a given payment price, the profit function of 3PLP is a concave function with respect to the safety reserve quantity, and the optimal reserve quantity of 3PLP is. and the 3PLP safety reserve is an increasing function with respect to the HO penalty.

Proof Finding the first-order derivative and second-order derivative of equation with respect to

$$\frac{\partial \pi_2}{\partial q_3} = r - i + \varepsilon (p_n + p_p - r)[1 - F(q_3)]$$

$$\frac{\partial^2 \pi_2}{\partial q_3^2} = -\varepsilon (p_n + p_p - r) f(q_3)$$

Since the benefit of using the reserve logistics capacity for disaster relief by the 3PLP is greater than the benefit of using the reserve as a salvage value, we have

$$p_n + p_p > r$$

Combining with equation, we get. Thus, the profit function of 3PLP is a concave function with respect to its safety reserve capacity. Thus let, be obtained.

The optimal response function of the 3PLP safety reserve capacity with respect to the HO penalty under the cooperative reserve model considering the moral hazard of the firm can thus be obtained, and it is easy to conclude that the 3PLP safety reserve capacity is an increasing function with respect to the HO penalty. Therefore, Theorem 2 is proved.

From Theorem 2, it can be seen that the main parameters affecting the 3PLP reserve decision are the probability of a disaster, the commodity transportation revenue, the HO shortage penalty, the HO payment price, and the residual value. Among them, the commodity transportation revenue is the constraint for 3PLP to make safe reserves, i.e., the higher the commodity transportation revenue is, the more 3PLP is willing to invest the reserve capacity in transporting daily commodities. The probability of catastrophe and the payment and penalty from HO are the factors that stimulate 3PLPs to make safety reserves. Derivation of with respect to gives.

When, i.e., when the sum of the price of payment and the price of penalty given by HO is greater than the revenue of 3PLP to transport commodities, the amount of 3PLP's safety reserve increases with the increase of residual value.

It is also clear from this that the higher the incentive and penalty given by the HO to the 3PLP, the more willing the 3PLP is to reserve. Moreover, when the incentives and penalties given exceed, the benefits gained by the HO from calling the reserves into service, the higher the residual value, the more willing the 3PLP is to keep these logistics capacities.

3. HO Decision

During the reserve cycle, the HO provides a cooperation agreement to determine the logistics capacity that the 3PLP needs to reserve for it.

(1) If a disaster occurs, when the logistics demand is less than the 3PLP's safe reserve capacity, that is, when the 3PLP can fully meet the disaster relief demand and the HO pays the relief cost.

(2) When the logistics demand is greater than the 3PLP safety reserve and less than the reserve amount stipulated in the HO agreement, i.e., when the 3PLP puts all the safety reserve capacity into disaster relief, but still cannot meet the relief demand. the HO pays the relief cost and gets the penalty from the 3PLP).

(3) When the logistics demand is greater than the reserve capacity specified in the HO agreement, i.e., when the cost loss of 3PLP in this case is consistent with case (2), and the penalty gain is).

HO, as the leader of the Stackelberg game, performs a cost-benefit analysis after the 3PLP makes the optimal safety reserve quantity decision and makes the price paid decision under the cost minimization objective.

$$L_2 = \varepsilon\int_0^{q_3} p_n x f(x)dx + \varepsilon\int_{q_3}^{q_2}[d(x-q_3)+p_n q_3 - p_p(x-q_3)]f(x)dx +$$
$$\varepsilon\int_{q_2}^{u}[d(x-q_3)+p_n q_3 - p_p(q_2-q_3)]f(x)dx$$

Simplifying equation and organizing it leads to

$$\varepsilon q_3^* - \varepsilon\frac{(q_3^*)^2}{2U} + \varepsilon(d-p_p-p_n^*)(\frac{q_3^*}{U}-1)(\frac{(i-r)U}{\varepsilon(p_n^*+p_p-r)^2})=0$$

Considering the complexity of the model, if the specific form of the emergency logistics demand distribution at the time of the disaster event is unknown, it is impossible to obtain the HO decision, and it is also impossible to analyze the health decision and cost-benefit of both HO and 3PLP. Therefore, the assumption that the emergency logistics demand obeys uniform distribution in reference to literature, that is. Then, equations can be simplified as

$$\frac{\partial L_2}{\partial p_n} = \varepsilon q_3^* - \varepsilon\int_0^{q_3^*} F(x)dx + \varepsilon(d-p_p-p_n)\frac{\partial q_3^*}{\partial p_n}[F(q_3^*)-1]$$

$$\frac{\partial^2 L_2}{\partial p_n^2} = \varepsilon[2(1-F(q_3^*))\frac{\partial q_3^*}{\partial p_n}] + (d-p_p-p_n)[\frac{\partial^2 q_3^*}{\partial p_n^2}[F(q_3^*)-1] + f(q_3^*)\frac{\partial q_3^*}{\partial p_n}]$$

$$\frac{\partial q_3^*}{\partial p_n} = \frac{i-r}{\varepsilon(p_n+p_p-r)^2 f(q_3^*)}\quad \frac{\partial^2 q_3^*}{\partial p_n^2} = -\frac{1}{f(q_3^*)}[\frac{i-r}{\varepsilon(p_n+p_p-r)^3} + f'(q_3^*)\frac{\partial q_3^*}{\partial p_n}]$$

From, it can be obtained that, and when 3PLP accepts the cooperation agreement offered by HO, it should satisfy, satisfying. There exists a minimum value of the expected cost function of HO, and therefore the optimal price paid by HO should satisfy. In summary, Theorem 7 is proved.

Accordingly, it can be seen that when the optimal decision of 3PLP is and the optimal payment price of HO is satisfied, the equilibrium state of both HO and 3PLP is reached, and their costs and profits are

$$L_2 = \varepsilon\int_0^{q_3} p_n x f(x)dx + \varepsilon\int_{q_3}^{q_2}[d(x-q_3)+p_n q_3 - p_p(x-q_3)]f(x)dx +$$
$$\varepsilon\int_{q_2}^{u}[d(x-q_3)+p_n q_3 - p_p(q_2-q_3)]f(x)dx$$

Combining equations, it is known that compared with the HO separate reserve model, the cost reduction of HO and the profit increase of 3PLP in the cooperative reserve model under the consideration of corporate moral hazard are.

From Theorem 3, it is clear that with the increase of 3PLP's commercial revenue, 3PLP will be more inclined to use the reserve resources for its own profit, which makes 3PLP's profit to be improved. However, at this time, HO will set a higher payment price in order to reduce its own losses, and the higher price improves 3PLP's incentive to reserve emergency logistics capacity. Moreover, although the higher price paid by HO makes the cost of HO higher, doing so increases the amount of 3PLP safety reserves, making the cooperative reserve model save more cost for HO compared to individual reserves.

Based on the consideration of HO incentives in the previous section, this section considers the effect of corporate reputation on the model. After the introduction of corporate reputation, 3PLP will try to improve its performance, i.e., actively fulfill its social responsibility through the donation of logistics resources to gain more benefits. In this case, 3PLPs not only need to consider the game with HO, but also need to consider the cost of fulfilling social responsibility and the resulting implicit benefits to decide the amount of their own reserves. Therefore, this section adjusts the payoff function of 3PLP and discusses the impact of corporate donation behavior on HO and 3PLP decisions.

Based on the literature [12], this paper sets up that firms fulfill their sense of social responsibility by making additional donations of logistics capacity to the HO, and the donations give firms a boost in profits. After the disaster, 3PLP will donate units of logistics resources to HO in addition to the agreed delivery of the reserves needed by HO, and the size of the donated resources is decided by 3PLP. the cost of the 3PLP donation is, and the benefit obtained from the donation is, where is the donation cost impact coefficient, and, because if, is always less than at this time, the enterprise will definitely suffer a loss by making the donation, and thus the enterprise will refuse to donate logistics capacity.

The decision-making process between HO and 3PLP is as follows: at the beginning of the reserve cycle, before the disaster occurs, 3PLP decides to donate a unit of logistics capacity to HO, and then HO will determine the logistics capacity that 3PLP needs to reserve in advance. Without knowing whether the 3PLP will donate or not, the HO still decides to offer unit payment prices based on known 3PLP reserve information. If a disaster event occurs, 3PLP needs to call on the corresponding logistics capacity for disaster relief activities. When the 3PLP is unable to immediately provide the logistics capacity identified in the agreement at the time of the disaster, the 3PLP needs to deliver the unit penalty. At the end of the reserve cycle, the remaining reserve capacity of the 3PLP can still be disposed of according to the corresponding residual value.

With the new objective function, HO and 3PLP will play the Stackelberg game again and get their respective optimal decisions. 3PLP, as the follower of the Stackelberg game, conducts a cost-benefit analysis based on its own costs, capabilities, and external conditions, and makes a decision on the safe reserve logistics capacity under the profit maximization objective. HO, as the leader of the game, makes a decision on the optimal safe reserve quantity after 3PLP The HO, as the leader of the game, makes a decision on the optimal safety reserve quantity after the 3PLP makes a cost-benefit analysis and makes a decision on the price to pay under the cost minimization objective.

Therefore, the profit function of the 3PLP is

$$\pi_{2a} = -c_E(q_2+q_d) + i(q_2-q_{3a}) + (1-\varepsilon)rq_{3a} + \varepsilon\int_0^{q_d} rq_{3a}f(x)dx$$
$$+\varepsilon\int_{q_d}^{q_{3a}+q_d}[p_n(x-q_d)+r(q_{3a}+q_d-x)]f(x)dx$$
$$+\varepsilon\int_{q_{3a}+q_d}^{q_2+q_d}[-p_p(x-q_{3a}-q_d)+p_n q_{3a}]f(x)dx$$
$$+\varepsilon\int_{q_2+q_d}^{u}[p_w q_{3a} - p_p(q_2-q_{3a})]f(x)dx + \lambda(i-c_E)\sqrt{p_w q_d}$$

where the first term is the cost of 3PLP to reserve all the logistics capacity; the second term is the benefit of 3PLP to use some of it as its own profit; the third and fourth terms are the benefit of 3PLP to treat the safety reserve capacity as salvage value when there is no disaster and when the logistics capacity donated by 3PLP is sufficient to respond to the need of disaster, respectively; the fifth term is the benefit of 3PLP when the safety logistics capacity reserved by 3PLP is sufficient to respond to the need of disaster The sixth term is the gain of 3PLP when the safe logistics capacity is not enough to cope with the disaster need, but the HO initially requires 3PLP to reserve enough logistics capacity; the seventh term is the gain of 3PLP when all the reserve capacity is not enough to cope with the disaster need; and the eighth term is the incremental profit gained by 3PLP through donation.

The cost function of HO also changes with the donation of 3PLP

$$L_{2a} = \varepsilon \int_{q_d}^{q_{3a}+q_d} p_n (x - q_d) f(x) dx +$$
$$\varepsilon \int_{q_{3a}+q_d}^{q_2+q_d} [d(x - q_{3a} - q_d) + p_n q_{3a} - p_p (x - q_{3a} - q_d)] f(x) dx +$$
$$\varepsilon \int_{q_2+q_d}^{u} [d(x - q_{3a} - q_d) + p_n q_{3a} - p_p (q_2 - q_{3a})] f(x) dx$$

From the above, it can be seen that in the model considering the moral hazard of the firm, the donation behavior of the firm is considered to transfer this risk to the HO by making the 3PLP's safety reserve decrease and reducing the risk of the reserve logistics capacity not being used. at the same time, the 3PLP can not only make itself gain from the reputation by the donation of the HO logistics capacity, but also use more logistics capacity for daily profit; however, the donation However, the donation cannot be too much, otherwise the revenue is not as good as the revenue gained by selling to HO. As for HO, it gets 3PLP donation and does not have to pay the price of this logistics capacity when the disaster demand is less than the number of 3PLP donations; and reduces the expenses when the disaster demand is more than the number of donations, thus its own disaster relief cost is reduced. Therefore, the factor of corporate reputation is well worth adding to the model to consider that the act of 3PLP making donations does not change the overall actual reserves of the disaster relief supply chain, and under certain conditions can also increase the benefits of 3PLP and HO at the same time.

5. Conclusion

This paper investigates the cooperation between HO and 3PLP in emergency logistics capacity reserve from the perspective of humanitarian organizations. This paper investigates the cooperative reserve problem from the perspective of price incentives based on asymmetric information between the two parties, and explores the effects of price incentives, corporate reputation, and government subsidies on the reserve behavior of 3PLPs. To address the possible moral hazard problem of 3PLP under asymmetric information, this paper investigates the cooperative reserve model based on price incentives. After solving the HO optimal pricing decision and the 3PLP optimal reserve decision by using the inverse order derivation method, this paper finds the effects of disaster occurrence probability, HO penalty price, and 3PLP commercial revenue on both parties' decisions. At the same time, this paper finds that 3PLP donation volume and government subsidy also have important effects on HO and 3PLP decisions in the extended model. Thus, this paper further analyzes the effects of these factors on HO costs and 3PLP benefits, and finally verifies these findings by means of numerical simulations. Based on the cooperation of 3PLP in emergency logistics capacity reserve, the optimal pricing strategy of HO is given and found to be mainly influenced by the probability of disaster, penalty price and 3PLP commercial revenue. When the probability of disaster is low, HO will not cooperate with 3PLP at a higher price; while when the probability of disaster is high, HO can cooperate with 3PLP at a lower price. The increase of penalty price can help HO to lower the price paid and increase the amount of 3PLP safety reserve; while the increase of commercial revenue makes the 3PLP reserve lower, thus HO needs to incentivize the 3PLP with high price for emergency reserve activities. The probability of a catastrophic event, penalty price, and 3PLP commercial revenue have important effects on HO cost and 3PLP revenue. In particular, as the probability of a catastrophic event increases, HO costs increase, HO offers to pay a lower price, 3PLP reserves increase, and 3PLP revenues decrease. With a constant probability of disaster occurrence, an increase in the HO penalty price reduces HO costs but decreases 3PLP gains; an increase in 3PLP commercial gains increases HO costs and 3PLP gains follow.

In the extended model of HO-3PLP cooperation based on price incentives, this paper considers the effects of corporate reputation and government subsidies on 3PLP reserve decisions and on the cost-benefit of both parties. This paper finds that the size of the donation affects the size of the amount of safety reserves made by 3PLPs, and the amount of donation is the reduction of safety reserves. The cost reduction of HO increases with the increase of donation volume for the same probability of disaster occurrence, while the 3PLP benefit increases with the increase of donation volume at low donation volume and subsequently decreases at higher donation volume. Compared to low disaster probabilities, a high probability of a disaster would allow 3PLP to gain greater benefits from a lower donation volume, but the benefits from a higher donation volume are less pronounced than under low disaster probabilities. In addition, this paper finds that government subsidies significantly increase the reserve volume of 3PLPs, and thus HOs do not need higher prices to incentivize 3PLPs to undertake reserve activities. As a result, the cost of HO is reduced and the benefit of 3PLP is increased. Therefore, in the cooperative reserve problem between HO and 3PLP considering the moral hazard of 3PLP, HO first needs to determine a reserve benchmark amount based on its judgment of disaster, and negotiate with 3PLP to pay a penalty if the reserve amount is less than this value. Moreover, HO needs to set a suitable payment price based on its judgment of the probability of disaster, which can reduce its own cost and motivate the 3PLP to carry out reserve activities. For the 3PLP, it needs to decide its own reserve amount based on the probability of disaster, commercial revenue, and penalty price, while it can consider a certain amount of donation to maximize its own revenue.

This paper focuses on the cooperative emergency logistics capacity reserve problem under the HO perspective, discusses the HO pricing decision and 3PLP reserve decision based on price incentives under asymmetric information, and analyzes the factors affecting HO costs and 3PLP benefits. However, this paper still has some limitations, and there are many directions that can be extended in future research. Based on the limitations of this paper, future research can start from the following two points: (1) The model constructed in this paper only considers the single-cycle, single-supplier case, and the model can be extended to multi-cycle, multiple-supplier, and different reserve resources in the future, in order to better provide a guiding basis for the cooperation between HO and 3PLP in complex realistic situations. (2) This paper only considers the probability of disaster occurrence, deprivation cost, reserve cost, and recovery cost, etc., but in realistic scenarios, there may be more influencing factors in actual disaster relief, such as the priority of logistics resource requirements at the disaster site, the importance of resources, and the cost of maintaining inventory. In the future, it can be combined with exploring more relevant factors to choose the appropriate cooperative reserve method.

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