The Study based on Coordination of Revenue Sharing Contract in Three-stage Port Supply Chain under Emergencies

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Abstract: On the basis of random market demand, establishing revenue sharing contract can achieve the coordination of the three-stage port supply chain system. However, the drastic fluctuations of market demand caused by emergencies will break the coordination of supply chain in stable market, which in turn affects the normal operation of each node enterprise. This paper gives an emergency optimization strategy for the multimodal transport service supply chain with the port as the integrator under the emergencies, which makes the original contract has stronger robustness; and gives the relationship of the profit distribution coefficients among the subjects when supply chain systems yield the most, and finally verifies the effectiveness of the improved revenue sharing contract through case analysis.

1 INTRODUCTION

Since the global outbreak of COVID-19, international trade has been hit. Along with the gradual intensification of trade frictions between countries, emergencies such as COVID-19 are unpredictable, short-cycle and of huge influence, which have led to frequent and dramatic fluctuations in the market environment, resulting in a global supply chain crisis. How to achieve coordination among enterprises at all levels of the supply chain, enhance their ability to cope with shocks and reduce losses of supply chain enterprises under the impact of emergencies has gradually become the focus of scholars at home and abroad. The port supply chain in shipping industry is gradually becoming a key link in the global industrial chain and international trade chain, providing transportation services for about 70% of global trade and having a major strategic position in global supply chain network. In the port supply chain, port enterprises play the role of integrating multiple information and building a trading platform. They play a vital role in connecting road carriers, ocean carriers and port companies as a whole, and are also responsible for distribution and coordination of internal revenue within the supply chain, while directly dealing with shippers externally.

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Therefore, under the impact of emergencies, how to coordinate the interest conflicts among the three-stage port supply chain consisting of road carriers, ocean carriers and port enterprises will become the key to whether the port supply chain can withstand risks, maintain efficient and stable operation.

Against the preceding background, this paper analyzes the response measures of risk and revenue sharing strategies of port supply chain under centralized and decentralized decision by using revenue sharing contract under the disturbance of emergencies, and explores what response measures of risk should be taken by the three-stage port supply chain under different market fluctuations, aiming to provide theoretical guarantee for port supply chain to cope with emergencies and port supply chain security.

2 LITERATURE REVIEW

First, the supply chain is a whole composed of multi-level enterprises. Due to different interests among enterprises at different levels, it is difficult to coordinate the interests of the whole supply chain. How to reasonably divide the interests of the supply chain so as to maximize the revenue of the supply chain has been the focus of academic research. For the distribution of interests within the supply chain, (Cachon, 2005) first proposed the role of revenue contribution contract in supply chain coordination,

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and concluded that revenue sharing contract can give the optimal revenue allocation proportion and optimal order quantity for each link in the supply chain system under a stable market environment, which proves the effectiveness of revenue sharing contract. And (Xu, 2010) improved the classical revenue sharing contract by considering price elasticity of demand, realized the coordination between traditional distribution channels and electronic distribution channels, explored the conditions for the existence of perfect win-win coordination between dual-channel supply chains, and gave a solution method for the contract parameters. (Niu, 2009) used Stackelberg game theory to study the game process between retailers and distributors and the equilibrium effect of revenue sharing contract on supply chain revenue under dominant supply chains. The above studies proved the role of supply chain contract in supply chain interest distribution, supply quantity optimization, etc., and proposed various paths to coordinate the supply chain.

It is worth noting that most of the above studies are based on normal market models and ignore the impact of unusual market fluctuations on the supply chain. Especially under the impact of the COVID-19, the instability of the supply chain has greatly increased. In order to cope with the impact of emergencies, many scholars have conducted research on the coordination of supply chain based on the background of abnormal perturbation of market fluctuations, in order to enhance the ability of supply chain to cope with risks and resist market fluctuations, so as to reduce the losses of supply chain enterprises under the market fluctuations. For example, (Liu, Liu, 2020). analyzed the coordination effect of quantity flexibility contract for supply chain under emergencies based on a two-stage closed loop supply chain model in the context of contingency disturbances. (Chen, Liu, 2014) studied the effect of revenue sharing contract on the coordination of emergency contingencies based on the perspective of a three-stage supply chain. (Liu, 2013) demonstrated that revenue sharing contract can still coordinate the revenue gap between supply chain links under complex market fluctuations from a four-stage supply chain consisting of suppliers, producers, distributors and retailers, and demonstrated the robustness of revenue contribution contract.

Due to the fundamental difference between the service supply chain represented by the port supply chain and the traditional product supply chain, the above-mentioned papers still focus on the traditional product supply chain and lack in-depth exploration of the service supply chain. At present, in the field of port supply chain, (Zhang, 2009) analyzed the profit distribution of port service supply chain by using the improved Shapley method and proposed a new profit distribution model from the perspective of cooperative game. (Wang, 2021) studied the optimal business strategy under two different decision scenarios: centralized decision and decentralized decision, for the port supply chain model under demand disturbance, and proposed different transportation strategies for goods with different characteristics, such as cost-sensitive and time-sensitive. (Zhao, 2007) studied the longitudinal alliance structure of the port supply chain and analyzed the potential benefits from the cooperation between upstream and downstream port enterprises. (Lv, 2020) considered the optimization effect of introducing fourth party logistics on the port supply chain, and analyzed the competition and coordination between port integrators and port and shipping enterprises. He found that the whole supply chain could achieve the highest yields under centralized decision, but the members of each link might need to sacrifice some of their own interests to achieve the goal of global optimum.

In the above studies on port supply chain, although they all propose corresponding coordination mechanisms for the port supply chain model to ensure the long-term stable operation of the port supply chain. However, most of the scholars in the current research are based on the simplified two-stage supply chain model for supply chain contract design, ignoring the three-stage supply chain consisting of road carriers, port enterprises and ocean carriers in the port supply chain. With the gradual development of port integration and the increasing flexibility of transportation services, the “door-to-door” transportation form represented by multimodal transport is gradually receiving more and more attention. Therefore, it is worthwhile to further study the three-stage port supply chain in the context of multimodal transport. Meanwhile, most scholars have focused on traditional product supply chain research in the study of supply chain coordination for emergencies, but not on the optimization and coordination of service supply chain such as logistics transportation. Currently, the occurrence of frequent disruptions such as COVID-19 and trade frictions, the study of service supply chain such as logistics services has become the focus of global attention.

To sum up, based on the three-stage port supply chain consisting of road carriers, ports and ocean carriers and considering both market random fluctuations and contingency disturbances, this paper constructs a revenue model for each party in the supply chain and the whole supply chain , and constructs a revenue sharing contract based on this model to explore the response strategies of the port supply chain under contingency disturbances and uses cases to demonstrate the general application of the contract.

3 PROBLEM DESCRIPTION AND CONDITION ASSUMPTIONS

In recent years, with the outbreak of the COVID-19 and the intensification of world trade frictions, outages and production shutdowns have occurred from time to time, leading to widespread market fluctuations, and these emergencies have posed challenges to the stable operation of the supply chain. Large fluctuations in market demand can lead to significant changes in demand for specific commodities. For example, after the outbreak of COVID-19, the market demand for medical supplies such as masks and vaccines increased significantly; after the China-Australia trade friction intensified, the volume of coal trade between China and Australia decreased greatly. At this time, the shipping industry, as the main carrier of world trade, needs to adjust to market fluctuations. In the event of demand expansion and capacity shortage caused by emergencies, enterprises at all levels of the supply chain need to improve transportation efficiency, expand transportation scale and bear the cost of exigently production increase. And in the case of sharp decline of market demand caused by emergencies, there will inevitably be a large amount of idle capacity in supply chain, resulting in waste and bringing losses to the supply chain enterprises.

To this end, this paper establishes a three-stage supply chain consisting of port operators, ocean carriers and road carriers in the context of sea-land combined transport. Compared with the traditional supply chain model, the port supply chain of sea-land combined transport has the following characteristics:

The information between road carrier and ocean carrier is symmetrical and independent. Logistics service as a intangible product without residual value. The ideal state of the whole supply chain is that the agreed volume of port operators is equal to the agreed volume of road carriers and ocean carriers. In view of the above problems and characteristics, the following assumptions are proposed in this paper:

Assumption 1: The cost of stocking and retail price of each service provider do not change, and the distribution function which market demand subject to in a stable environment is continuous, differentiable and derivable.

Assumption 2: The services provided by the port supply chain are multimodal transport of containers.

Assumption 3: Port service providers, road carriers, and ocean carriers are risk-neutral and entirely rational, i.e., each makes decisions according to the net benefit maximization principle.

Assumption 4: All parties in the supply chain can accurately predict the demand distribution function of customers.

The variables used in this paper are shown in Table 1:

Table 1: Definition of Parameters

π_t,π_p,π_o,π_r	Profit for the whole supply chain, port operators, ocean carriers and road carriers
Q_t,Q_p,Q_o,Q_r	Optimal transportation volume for the whole supply chain, port operators, ocean carriers, and road carriers
c_p,c_o,c_r	Unit cost for port operators, ocean carriers and road carriers
$F(x),G(x)$	Market demand distribution function after emergencies in a stable market
θ_o,θ_r	Unit price of ocean carriers and road carriers
k_o,k_r	Benefit coefficient of ocean carriers and road carriers
$\lambda_p,\lambda_o,\lambda_r$	Unit opportunity cost for port operators, ocean carriers and road carriers following a reduction in market demand due to emergencies
μ_p,μ_o,μ_r	Unit cost of exigent production increment for port operators, ocean carriers and road carriers following an increase in market demand due to emergencies
p_t,p_p	Shipper purchase price under centralized decision and decentralized decision

Based on the above assumptions, we first develop a benchmark revenue sharing contract model of three-stage service supply chain under a stable market, and further consider how the improved revenue sharing contract coordinates the entire system in the event of a sudden increase/decrease in market demand due to emergencies.

4 THE BENCHMARK REVENUE SHARING CONTRACT MODEL OF THREE-STAGE SERVICE SUPPLY CHAIN

4.1 Model Overview

The port supply chain in the context of multimodal transport can provide customers with "door-to-door" entire transport services. Since the whole system has several independent subjects, the participants in the supply chain are usually set to make self-interested and rational decisions, and the goal of their decisions is often to maximize their own interests. Therefore, in general, the service volume when the individual achieves the optimum is often not the optimal service volume of the whole supply chain.

The supply chain contract model represented by revenue sharing contract can provide appropriate incentives for all parties in supply chain to optimize sales channels to ensure supply chain coordination. However, the occurrence of emergencies can lead to changes in contract parameters as well as market demand, which can result in lower overall revenue and further lead to supply chain incongruity. Therefore, we construct the supply chain revenue sharing contract models respectively under centralized and decentralized decision to coordinate the whole supply chain. Further, we consider the parameter optimization of the revenue sharing contract model to cope with such perturbations under the influence of emergencies, and finally, we verify the effectiveness of our model through case analysis.

The model in this paper considers a three-stage service supply chain consisting of port operators, road carriers, and ocean carriers, whose structure is shown in Figure1. Under the coordination of revenue sharing contract, port operators purchase transportation resources from road and ocean carriers respectively at below cost to provide multimodal transport services to customers, and sign carriage contracts with shippers outside the system as supply chain integrators, and finally share part of the revenue to road and ocean carriers through the earning yields agreed in advance.

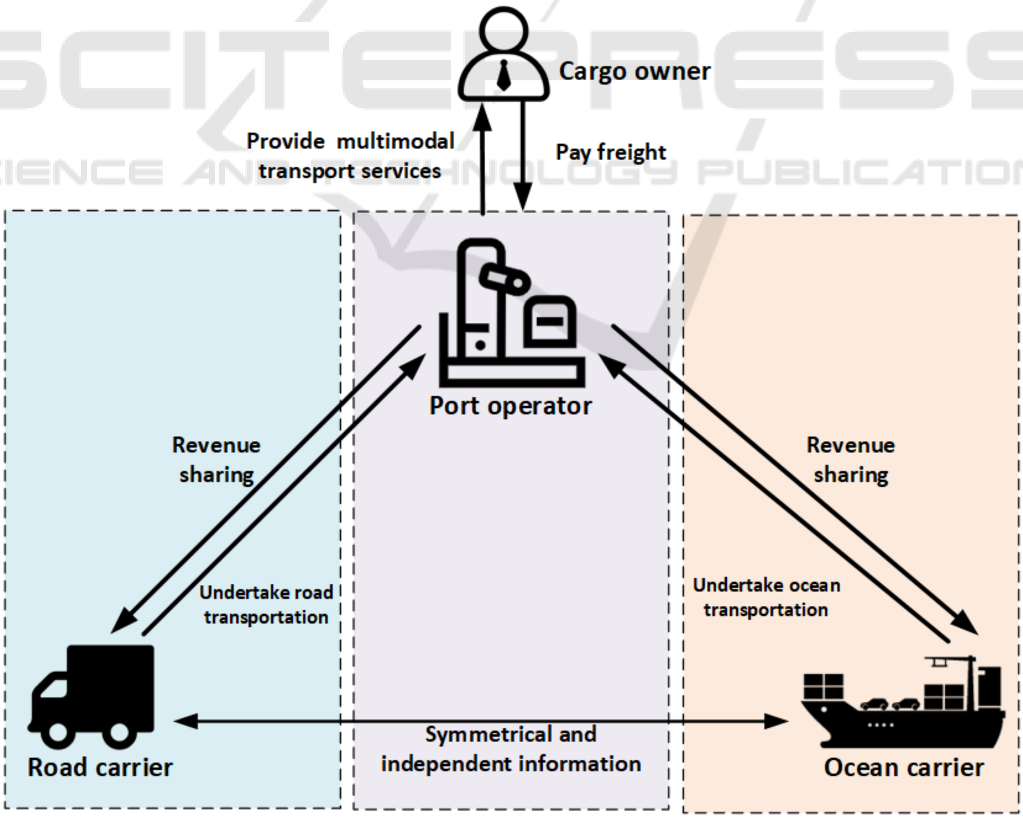

Figure 1: The framework of port three-level service supply chain.

To establish a benchmark three-stage service supply chain, we let the demand of shippers in the market D be an obeying random variable of F(x), and the unit stocking cost of the three parties, namely, port operators, road carriers and ocean carriers, be c_p, c_r, c_o.

4.2 The Revenue Sharing Contract Model under Centralized Decision

Under centralized decision, the supply chain parties jointly aim at maximizing the profit of the system, and let the overall profit of the supply chain be π_t, the agreed volume jointly decided by supply chain participants under the centralized decision be Q_t and the unit charge to shippers be p_t. When the market volume is D, the final actual volume of the port supply chain is $\min\{D,Q_t\}$.

The unit cost of the port supply chain consists of the unit cost of each party together, i.e. $c_t = c_p + c_r + c_o$ .After the supply chain participants reach an agreed volume, each participant prepares resources for stocking according to the determined agreed volume, and the overall stocking cost is $(c_p + c_r + c_o)Q_t$. Thus, the profit of the port supply chain under centralized decision is shown as follows:

$$\pi_t = p_t \min\{D,Q_t\} - (c_p + c_r + c_o)Q_t \quad (1)$$

The expected profit function is:

$$E(\pi_t) = p_t\left[\int_0^{Q_t} xf(x)dx + \int_{Q_t}^{\infty} Q_t f(x)dx\right] - (c_p + c_r + c_o)Q_t \quad (2)$$

$$s.t.Q_t > 0$$

The first derivative of the expected profit for the whole supply chain with respect to the agreed volume Q_t is:

$$\frac{\partial E(\pi_t)}{\partial Q_t} = p_t[1 - F(Q_t)] - (c_p + c_r + c_o)$$

The second derivative of the expected profit $E(\pi_t)$ with respect to the agreed volume Q_t is:

$$\frac{\partial^2 E(\pi_t)}{\partial Q_t^2} = -p_t f(Q_t)$$

Because of $\frac{\partial^2 E(\pi_t)}{\partial Q_t^2} < 0$, $E(\pi_t)$ is convex function, and the agreed volume of the whole port supply chain is determined by $\frac{\partial E(\pi_t)}{\partial Q_t}$.

Let $\frac{\partial E(\pi_t)}{\partial Q_t} = 0$,then $F(Q_t^*) = 1 - \frac{c_p + c_r + c_o}{p_t}$, i.e.:

$$Q_t^* = F^{-1}\left(1 - \frac{c_p + c_r + c_o}{p_t}\right)$$

Therefore, under the centralized decision, the optimal agreed volume of the whole supply chain is shown in the above equation.

4.3 The Revenue Sharing Contract Model under Decentralized Decision

Since port operators, as the integrators of the supply chain, dominate the game process in the port supply chain, in order to match the agreed volumes of each party under the decentralized decision with the agreed volumes under the centralized decision, i.e., to achieve supply chain coordination, we adopt a revenue sharing contract to allocate the revenue of each party in the supply chain. The road carrier and ocean carrier determine the respective optimal agreed volumes Q_r^*, Q_o^* under a given revenue sharing contract $(\theta_r, k_r), (\theta_o, k_o)$, θ_r, θ_o are the unit prices of transport services purchased by the port from the road carrier and ocean carrier, and k_r, k_o are the proportion of revenue allocated by the port to two parties. Further, the port operator determines his own optimal agreed volume Q_p^* based on his expected revenue function and $(\theta_r, k_r), (\theta_o, k_o)$.

Under the revenue sharing contract, the revenue functions of the road and ocean carriers are as follows:

$$\begin{cases} \pi_r = (\theta_r - c_r)Q_r + k_r p_p \min\{D,Q_r\} \\ \pi_o = (\theta_o - c_o)Q_o + k_o p_p \min\{D,Q_o\} \end{cases} \quad (3)$$

Expected profit function is:

$$\begin{cases} E(\pi_r) = (\theta_r - c_r)Q_r + k_r p_p\left[\int_0^{Q_r} xf(x)dx + \int_{Q_r}^{\infty} Q_r f(x)dx\right] \\ E(\pi_o) = (\theta_o - c_o)Q_o + k_o p_p\left[\int_0^{Q_o} xf(x)dx + \int_{Q_o}^{\infty} Q_o f(x)dx\right] \end{cases} \quad (4)$$

$$s.t.Q_r, Q_o > 0$$

Calculate the first derivative and the second derivative of $E(\pi_r)$, and results are as follows:

$$\begin{cases} \dfrac{\partial E(\pi_r)}{\partial Q_r} = (\theta_r - c_r) + k_r p_p [1 - F(Q_r)] \\ \dfrac{\partial^2 E(\pi_r)}{\partial Q_r^{\ 2}} = -k_r p_p f(Q_r) \end{cases}$$

Because of $\dfrac{\partial^2 E(\pi_r)}{\partial Q_r^{\ 2}} < 0$, and $E(\pi_r)$ is convex function, its optimal agreed volume Q_r^* can be determined by $\dfrac{\partial E(\pi_r)}{\partial Q_r}$.

Let $\dfrac{\partial E(\pi_r)}{\partial Q_r} = 0$, then $F(Q_r) = 1 + \dfrac{\theta_r - c_r}{k_r p_p}$, i.e.:

$$Q_r^* = F^{-1}(1 + \frac{\theta_r - c_r}{k_r p_p})$$

Calculate the first derivative and the second derivative of $E(\pi_o)$, and results are as follows:

$$\begin{cases} \dfrac{\partial E(\pi_o)}{\partial Q_o} = (\theta_o - c_o) + k_o p_p [1 - F(Q_o)] \\ \dfrac{\partial^2 E(\pi_o)}{\partial Q_o^{\ 2}} = -k_o p_p f(Q_o) \end{cases}$$

Because of $\dfrac{\partial^2 E(\pi_o)}{\partial Q_o^{\ 2}} < 0$, and $E(\pi_r)$ is convex function, its optimal agreed volume Q_r^* can be determined by $\dfrac{\partial E(\pi_o)}{\partial Q_o}$.

Let $\dfrac{\partial E(\pi_o)}{\partial Q_o} = 0$, then $F(Q_o) = 1 + \dfrac{\theta_o - c_o}{k_o p_p}$, i.e.:

$$Q_o^* = F^{-1}(1 + \frac{\theta_o - c_o}{k_o p_p})$$

The port operator, as the supply chain integrator, is the actual leader of this service supply chain. The port operator purchases transportation services from road carriers and ocean carriers respectively and then allocates the profits received from the customer to the carriers for supply chain coordination, so its profit function can be expressed as:

$$\pi_p = (1 - k_r - k_o) p_p \min\{D, Q_p\} - (c_p + \theta_r + \theta_o) Q_p \quad (5)$$

Its expected profit function is:

$$E(\pi_p) = (1 - k_r - k_o) p_p \left[\int_0^{Q_p} x f(x) dx + \int_{Q_p}^{\infty} Q_p f(x) dx \right] - (c_p + \theta_r + \theta_o) Q_p$$
$$s.t. Q_p > 0 \quad (6)$$

Calculate the first derivative and the second derivative of Q_p with respect to $E(\pi_p)$, and the results are as follows:

$$\begin{cases} \dfrac{\partial E(\pi_p)}{\partial Q_p} = (1 - k_r - k_o) p_p [1 - F(Q_p)] - (c_p + \theta_r + \theta_o) \\ \dfrac{\partial^2 E(\pi_p)}{\partial Q_p^{\ 2}} = -(1 - k_r - k_o) p_p f(Q_p) \end{cases}$$

Because of $\dfrac{\partial^2 E(\pi_p)}{\partial Q_p^{\ 2}} < 0$, and $E(\pi_p)$ is convex function, its optimal agreed volume Q_p^* can be determined by $\dfrac{\partial E(\pi_p)}{\partial Q_p}$.

Let $\dfrac{\partial E(\pi_p)}{\partial Q_p} = 0$, then $F(Q_p) = 1 - \dfrac{c_p + \theta_r + \theta_o}{(1 - k_r - k_o) p_p}$, i.e.:

$$Q_p^* = F^{-1}\left[1 - \frac{c_p + \theta_r + \theta_o}{(1 - k_r - k_o) p_p}\right]$$

In summary, the respective optimal agreed volumes for road carriers, ocean carriers and port operators under decentralized decision are shown above.

4.4 Coordination of Centralized Decision and Decentralized Decision

For the three-level port supply chain who provides the service of transport, the key to achieve overall coordinating is that the decided volume of each party should be equal, the same as the optimal volume of the centralized decision.

Proposition 1. When the market remains stable, the revenue sharing contract enables the supply chain to be coordinated, which means that the optimal volume of each party of the decentralized decision should equal with that of the centralized decision. The proof as follows:

let $Q_p^* = Q_t^*$, then $\frac{c_p+\theta_r+\theta_o}{(1-k_r-k_o)p_p} = \frac{c_p+c_r+c_o}{p_t}$ .Considering that the port, as an integrator, receives the quotation of the cargo owner in our model, so $p_p = p_t$, the constraints on the port in our overall coordination are as follows:

$$1-k_r-k_o = \frac{c_p+\theta_r+\theta_o}{c_p+c_r+c_o} \tag{7}$$

let $Q_r^* = Q_t^*, Q_o^* = Q_t^*$,then

$$\theta_r = c_r - k_r\left(c_r+c_o+c_p\right) \tag{8}$$

$$\theta_o = c_o - k_o\left(c_r+c_o+c_p\right) \tag{9}$$

put the above three equations into the profit function of port operator, road carrier and marine carrier respectively:

$$\pi_p = (1-k_r-k_o)\,p_t \min\{D,Q_t\} - (1-k_r-k_o)\left(c_p+c_r+c_o\right)Q_t \tag{10}$$

$$\pi_r = k_r p_t \min\{D,Q_t\} - k_r\left(c_p+c_r+c_o\right)Q_t \tag{11}$$

$$\pi_o = k_o p_t \min\{D,Q_t\} - k_o\left(c_p+c_r+c_o\right)Q_t \tag{12}$$

Compare the result with the overall profit function of the supply chain of centralized decision π_p , and we can find:

$$\pi_p = \left(1-k_r-k_o\right)\pi_t \tag{13}$$

$$\pi_r = k_r\pi_t \tag{14}$$

$$\pi_o = k_o\pi_t \tag{15}$$

In this case, we can figure out that the profit function of each part of decentralized decision and the overall profit function of centralized decision are affine. Therefore, when the market reaches a plateau, the revenue sharing coefficient can maintain its coordination by adjusting the supply chain.

Proposition 2. The road carriers and ocean carriers are the independent information-sharing carriers in the supply chain, and their revenue contract coefficients satisfy the following relationship when the supply chain is coordinated:

$$k_o\left(\theta_r - c_r\right) = k_r\left(\theta_o - c_o\right) \tag{16}$$

Let $Q_r^* = Q_o^*$, then $1+\frac{\theta_r-c_r}{k_r p_p} = 1+\frac{\theta_o-c_o}{k_o p_p}$. The above equation can be obtained after simplification. At this time, the optimal volume of the three parties in the three-stage chain of the port is equal to the optimal volume of the system, from which it can be obtained that under the coordination of the revenue sharing contract, the optimal volume of the participating parties are the same, and their profit functions are affine to the overall income function of the supply chain, and the supply chain reaches coordination.

Proposition 3. The pricing of ocean carriers and road carriers are negatively correlated with their revenue sharing coefficients respectively when the decentralized decision parties adopt the optimal volume under a centralized agreement, as evidenced by the following：

According to Proposition 1, if supply chain coordination is to be achieved under the revenue sharing contract, the optimal agreed volume for road carriers and ocean carriers is:

$$Q_p^* = F^{-1}\left[1-\frac{c_p+\theta_r+\theta_o}{\left(1-k_r-k_o\right)p_p}\right] \tag{17}$$

As can be seen from the equation, under the decentralized decision, if the supply chain is required to achieve coordination, both road carriers and ocean carriers should use this optimal agreed volume, at this time, $Q_p^* = Q_o^* = Q_r^*$, the optimal supply of transportation services for the road carrier under decentralized decision is:

$$Q_r^* = F^{-1}(1+\frac{\theta_r-c_r}{k_r p_p}) \tag{18}$$

If the road carrier is still required to maintain the original optimal volume at this time, i.e. $Q_r^* = Q_p^*$. The relationship between its revenue sharing coefficient k_r and the price of transport services provided to the port operator θ_r can be obtained as:

$$k_r = \frac{k_o-1}{\theta_o+c_r+c_p}\theta_r + \frac{c_r-c_r k_o}{c_p+\theta_o+c_r} \tag{19}$$

$$s.t.\, k_o < 1$$

It can be obtained from the above formula, there is a negative correlation between k_r and θ_r , which demonstrates that when the port operator increases the revenue-sharing coefficient, the carrier will correspondingly reduce the unit price of its transport services in order to increase the freight volume to gain more revenue. As a result, when supply chain reaches equilibrium, the revenue-sharing contract can regulate the overall pricing of the supply chain. Integrators can adjust the overall price by adjusting the revenue-sharing coefficient in order to adapt to the normal fluctuations and changes of the market.

5 OPTIMIZATION OF REVENUE SHARING CONTRACT COORDINATION FOR THE THREE-STAGE PORT SUPPLY CHAIN UNDER THE DISTURBANCE OF EMERGENCIES

5.1 The Effect of Emergencies to Three-stage Port Supply Chain

Now considering the effect of benchmark revenue sharing contract on supply chain coordination when emergencies lead to drastic fluctuations in market demand, causing the distribution function of market demand subject to change from $F(x)$ to $G(x)$.

Proposition 4. Supply chain coordination cannot be achieved if the benchmark revenue sharing contract is still adopted in the presence of large fluctuations in market demand under emergencies, as evidenced by the following:

When $Q > Q^*$, due to emergencies resulting in a sharp increase in demand for cargo transportation of the shipper, the supply chain parties need to provide the exigent transportation capacity, the amount is $\left(Q - Q^*\right)$,the unit incremental cost of exigent production increment of port operators, road carriers and ocean carriers are μ_p, μ_r, μ_o. At this time the profit function of three parties becomes as:

$$\pi_p = (1 - k_r - k_o) p_p Q - (c_p + \theta_r + \theta_o) Q^* - \mu_p \left(Q - Q^*\right) \quad (20)$$

$$\pi_r = (\theta_r - c_r) Q^* + k_r p_p Q - \mu_r \left(Q - Q^*\right) \quad (21)$$

$$\pi_o = (\theta_o - c_o) Q^* + k_o p_p Q - \mu_o \left(Q - Q^*\right) \quad (22)$$

Taking the road carrier as an example, at this point, substituting the revenue sharing ratio of the road carrier in a stable market state into its profit function, we can get $\pi_r \frac{1}{k_r} = \frac{\theta_r - c_r}{k_r} Q^* + p_t Q - \frac{\mu_r}{k_r}\left(Q - Q^*\right)$. Now the profit function of the road carrier is not affine to the whole supply chain's profit function π_t, so the supply chain cannot be coordinated according to the original revenue sharing coefficient.

When $Q < Q^*$, as a result of emergencies that lead to a sharp drop in the transportation demand for the cargo of the shipper, all parties in the supply chain still prepare their goods in accordance with the optimal volume Q^* in a stable market, therefore there will be surplus capacity $\left(Q^* - Q\right)$ cannot be sold, the respective increased unit opportunity cost for port operators, road carriers and ocean carriers are $\lambda_p, \lambda_r, \lambda_o$. At this point the profit functions of the three parties become as:

$$\pi_p = (1 - k_r - k_o) p_p Q - (c_p + \theta_r + \theta_o) Q^* - \lambda_p \left(Q^* - Q\right) \quad (23)$$

$$\pi_r = (\theta_r - c_r) Q^* + k_r p_p Q - \lambda_r \left(Q^* - Q\right) \quad (24)$$

$$\pi_o = (\theta_o - c_o) Q^* + k_o p_p Q - \lambda_o \left(Q^* - Q\right) \quad (25)$$

By the same token, the profit function of each party in the supply chain is not affine to the profit function of the whole supply chain, and the supply chain cannot be coordinated as well.

5.2 Optimizing Revenue Sharing Contract Coordination

In order to enable the three-stage port service supply chain to coordinate by using the revenue sharing contract even under the disturbance of emergencies, we improve the original revenue sharing contract, i.e., the cost of exigent production increment borne by each supply chain entity is allocated according to its benefit coefficient in the whole.

Proposition 5. In the case of emergencies perturbation resulting in an increase in market size, the cost of exigent production increment is allocated according to the benchmark revenue sharing coefficient, at which point the adjusted revenue sharing contract still can make supply chain back to the coordinated situation, as evidenced by the following:

Assuming that the emergencies make the market demand expectations increased to Q, let the optimal volume obtained by adopting revenue sharing contract coordination under the stable operation of the market is Q^*, then the revenue functions for each of the decision parties are shown as:

$$\pi_p' = (1 - k_r - k_o) p_p Q - (c_p + \theta_r + \theta_o) Q^* - (1 - k_r - k_o)(\mu_p + \mu_r + \mu_o)\left(Q - Q^*\right) \quad (26)$$

$$\pi_r^{'} = (\theta_r - c_r)Q^* + k_r p_p Q - k_r(\mu_p + \mu_r + \mu_o)(Q - Q^*) \tag{27}$$

$$\pi_o^{'} = (\theta_o - c_o)Q^* + k_o p_p Q - k_o(\mu_p + \mu_r + \mu_o)(Q - Q^*) \tag{28}$$

Now respectively substitute the revenue sharing ratio between each subject and the whole $(1-k_r-k_o), k_r, k_o$ into $\pi_p^{'}, \pi_r^{'}, \pi_o^{'}$, we can find that the profit functions of road carriers, ocean carriers and port operators are still affine to the revenue function of the whole supply chain, i.e. the port supply chain is re-coordinated. In the three-stage port service supply chain, the company that receives more shared revenue also needs to bear greater costs accordingly to achieve the overall coordination of supply chain.

Similarly, when the market demand is reduced by emergencies, the newly increased opportunity costs of all parties in the supply chain are distributed according to the benchmark revenue sharing coefficient. The adjusted revenue sharing contract can also make the income function of all parties involved in decision-making form an affine relationship with the overall income function, that is, the supply chain can achieve coordination again.

In that case, the current market demand is the optimal transportation service provision for the whole supply chain. Thus, through revenue sharing contract, it is possible to optimize and adapt to specific volumes. This enables enterprises in the supply chain to have a strong risk response capability, which greatly enhances the overall earnings of the supply chain and realizes the risk sharing of the supply chain.

6 CASE ANALYSIS

Assuming that the market demand D satisfies the uniform distribution of $[30, 60]$,

$$c_p = 5, c_r = 6, c_o = 4, \theta_r = 5$$

$$\theta_o = 2, k_r = 0.2, k_o = 0.3, p_p = 48$$

Under the above conditions, coordination between carriers is achieved when satisfying $Q_r^* = Q_o^*$, the relationship between the revenue sharing contract coefficients (θ, k) for road and ocean carriers is shown in Figure 2:

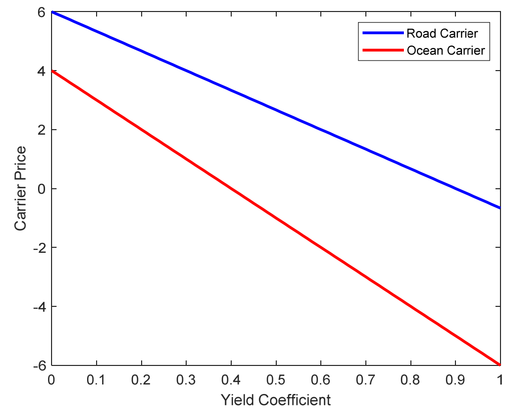

Figure 2: Relationship between carrier yield sharing coefficient θ and price k.

It can also be seen from the figure that there is a negative correlation between the price of each carrier and its yield coefficient.

Under decentralized decision, when the revenue sharing coefficient, unit cost and unit price of each carrier and port operator are respectively unknown, the relationship between the optimal agreed volume of carriers and each coefficient is shown as:

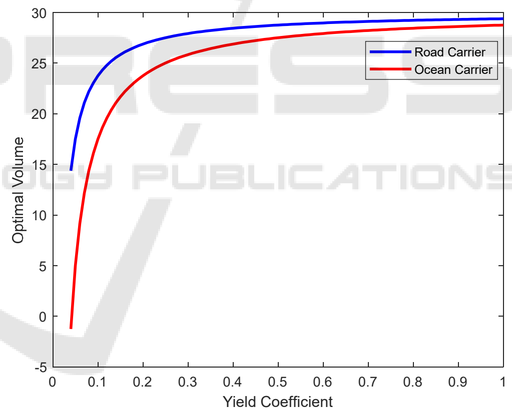

Figure 3: Relationship between carrier yield sharing coefficient θ and optimal volume.

The figure shows that the optimal agreed volume of road carriers and ocean carriers are positively related to their respective yield sharing coefficient.

Through the case analysis, we compare the yield sharing coefficient of road carriers and ocean carriers separately with the optimal agreed volumes and their own selling prices, and visualize how the revenue sharing coefficient coordinate the whole supply chain.

7 CONCLUSION

In this paper, we only considered the contingency response of the three-stage port service supply chain when the market price is stable. We first propose the use of revenue sharing contract for the stable market to achieve coordination among the participants of the three-stage port supply chain so as to maximize the overall revenue of the supply chain. Further, we consider the impact of emergencies on the transportation demand of cargo owners in the market, where the disturbance of such emergencies can make the originally coordinated supply chain no longer coordinated. For this reason, we adjust the existing revenue sharing contract model so that each entity shares the cost of the whole supply chain in proportion to the revenue coefficient, and in this case, the improved revenue sharing contract can restore the system to coordination after the perturbation.

The study concludes that when the disturbance of transportation cost and market demand caused by emergencies is small, the transportation plan does not need to be adjusted and the supply chain system has the ability to recover itself; however, when the disturbance of emergencies is large enough to influence the transportation cost, the original revenue sharing contract cannot achieve the purpose of risk sharing and the revenue sharing coefficient of each entity need to be adjusted in time. The improved revenue sharing contract can enable the supply chain companies to share the risk to cope with emergencies and maximize the overall revenue.

In this paper, we only consider the applying and improving of revenue sharing contract and enable it to effectively coordinate the supply chain system under emergencies under the situation where the the information is complete, the data such as cost structure and profit function of each supply chain node enterprise is available, and the demand distribution faced by retailers can be predicted, and the risk is neutral.

Further in-depth research is needed to address the complex situation of incomplete information of the supply chain system and different risk attitudes of the node companies.

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