Research on the Cooperative Operation Mechanism of Logistics Service Supply Chain Based on Fairness Preference Theory

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Abstract—In order to provide guidance for the incentive mechanism design and the efficiency improvement in logistics service supply chain management, the cooperative operation mechanism of double principal-agent mode of logistics service supply chain is investigated based on the fairness preference theory in the paper. The characteristics of double principal-agent mode of logistics services supply chain are analysed firstly, and then the double principal-agent model of logistics services supply chain is built considering the fairness preference between the integrator and the provider. The results of research show that the fairness preference will affect the effort level of both the integrator and the provider, even the performance in the logistics services supply chain. The existence of fairness preference will lead to efficiency loss, and reduce the expected utility of the customer and the integrator.

Keywords—Supply Chain Management; Logistics Service Supply Chain; Cooperative Operation Mechanism; Double Principal-agent; Fairness Preference

I. INTRODUCTION

As one of the modern management ideas and modes, the supply chain management has experienced rapid development not only in theory but also in practice in recent years. However, a substantial amount of researches have focused on manufacturing and retail industry, and service industries are just now recognizing the value of successfully implementation [1]. Service supply chain is a new research focus, which more and more scholars and practitioners have been directed towards nowadays[2]-[6]. The logistics industry is a classic example of the birth and development of a vital new service-based industry[7]; therefore, logistics service supply chain (LSSC) is one of the important forms in service supply chain and a focus in service supply chain research.

LSSC is a kind of socialized and industrialized logistics service operation mode, the structure of LSSC is generally considered as functional logistics providers-integrative logistics providers-logistics customers [8]-[11]. There are three main kinds of members in LSSC: integrative logistics providers (referred to as integrators), functional logistics providers (referred to as providers) and logistics customers. Generally, in a LSSC, there are just one integrator and not less than one provider, such as transport companies, warehousing companies, distribution centers, and logistics consulting firms, information technology firms etc. Customers refer to collective

customers compared to individuals. Every member affects and is affected by others in LSSC. According to the degree of synergy among customers, integrators and providers and their relationship, three collaborative operation modes are available: point-chain coordination, line-chain coordination mode, and chain-chain coordination mode[12][13]. Those three collaborative modes form a deepening process of collaborative operation.

In the paper, one kind of collaborative operation modes of LSSC, the double principal-agent mode which is the main form of the point-chain coordination mode, will be analyzed. As double principal-agent relationship is the initial driving mechanism for the formation and development of LSSC, it is worthy of a study. The author of the paper has conducted some researches on the double principal-agent mode of LSSC[13][14], yet they are just based on the assumptions that members are pure self-interest preference and psychological factors are ignored. In recent years, a lot of experimental study shows, agents also have fairness preference besides self-interest preference[15][16]. People will concern about the fairness of income distribution and behavior which will influence their behavior decision. Therefore, the paper tries to investigate the cooperative operation mechanism of double principal-agent mode of LSSC based on the fairness preference theory in order to provide a new idea for the incentive mechanism design and management in LSSC. Considering the fairness preference, there are two cases: one is that the agent compares with the principal, another is that one agent compares with other agents. In the paper, the former is conducted.

II. STRUCTURE AND CHARACTERISTICS OF DOUBLE PRINCIPAL-AGNET MODE OF LSSC

The basic structure of the double principal-agent mode of LSSC is showed in Fig. 1. In this mode, the customer commissions the integrator to complete logistics activities. Generally, it is difficult for the customer to control the logistics services process and get specific information about the efforts level of the integrator and providers. The asymmetry of information between the customer and the integrator will inevitably lead to moral hazard problems in the operation process of LSSC. It is clear that the principal-agent relationship is between the customer and the integrator. The integrator is mainly responsible for integrated design of logistics activities, and some professional operations are out-sourced to providers. The

asymmetry of information also exists between the integrator and providers, thus the integrator and providers also develop a principal-agent relationship.

Figure 1. Basic structure of double principal-agent mode of LSSC

The double principal-agent mode of LSSC is different from traditional principal-agent modes. The characteristics of double principal-agent mode of LSSC are as follows:

(1) The logistics service output is a kind of integrated service, which must be completed under the joint efforts of the integrator and providers. Therefore, although the first principal-agent interface is between the customer and the integrator, the integrator is not the only an agent but the representative of supplier (the integrator and providers).

(2) In LSSC, the integrator plays a “pivotal” role. From the view of funds flows, the integrator involves not only in the initial profits distribution with the customer, but also in the profits redistribution with providers. From the view of risk, the integrator not only takes risks from the customer, but also shares risks with providers. From the view of task, the integrator does not outsource logistics activities completely, and at least it needs to plan, organize and coordinate the logistics activities. Therefore, on the one hand, as an agent for the customer, the integrator is a designer and organizer of logistics activities; on the other hand, as a principal for providers, the integrator is also a supervisor.

(3) LSSC is essentially a collaborative operation system through sharing and optimal allocation of resources. Double principal-agent relationship of LSSC is different from pure market transaction relations or internal relations in an enterprise. Every member in LSSC is economically independent and affects and is affected by each other.

(4) The principal-agent relationship between the members in LSSC is a long-term, dynamic and multi-stage process. Compared with the traditional short time principal-agent relationship, the cooperation between the members in LSSC will be more stable, so the degree of information asymmetry and moral risk will decrease.

III. MODEL FOR DOUBLE PRINCIPAL-AGENT MODE OF LSSC BASED ON FAIRNESS PREFERENCE THEORY

A. Model Hypothesis

Hypothesis 1: For a simple analysis, there are just one integrator, one provider and one customer in a LSSC. The customer and the integrator are pure self-interest preference, while the provider also has fairness preference. Assume that the provider will be jealous when his income is lower than the integrator, and he will be proud when his income is higher than

the integrator. The jealousy is a kind of negative utility and the pride is a kind of positive one. g_1 describes the degree of jealousy; g_2 describes the degree of pride; $g_1, g_2 \geq 0$, $g_1 > g_2$, $0 < g_2 < 1$.

Hypothesis 2: As the logistics service output is a kind of integrated service, both the integrator and the provider input relative elements (including human, technology, and material, etc.). Then, logistics service output in a circle time can be expressed as follows:

$$\pi(\alpha, \beta) = p\alpha + q\beta + \varepsilon \quad (1)$$

where π is logistics service output; α is the integrator's effort level, $\alpha > 0$; β is the provider's effort level, $\beta > 0$, suppose no game relationship among providers. The effort is various behaviors to ensure the quality of logistics services, such as planning, implementation, management, coordination, information sharing and staff training, etc.

Assume 2-dimensional continuous variable $g = (\alpha, \beta)^T$ represents a specific behavior of logistics services supply, which decided by joint efforts of the integrator and providers. The greater the g the higher effort level and better logistics service is. p is the contributing coefficient of the integrator's efforts to logistics service output which is decided by the integrator's asset size, technical facilities and equipment, the degree of information, market reputation, etc., $p > 0$; q is the contributing coefficient of the provider's efforts to logistics service output, $q > 0$; ε is a random variable, decided by external uncertainties, $E(\varepsilon) = 0$, $Var(\varepsilon) = \sigma^2$.

Hypothesis 3: The linear mixed incentive contract is adopted. In the first principal-agent, suppose the linear mixed incentive contract is:

$$s(\pi) = w + \lambda\pi \quad (2)$$

In the second principal-agent, suppose the linear mixed incentive contract is:

$$f(s) = s + \theta\lambda\pi \quad (3)$$

where w and s are fixed reward, which have nothing to do with the output; λ represents the initial profit distribution coefficient; θ represent the second profit distribution coefficient, $0 \leq \lambda \leq 1$, $0 \leq \theta \leq 1$.

Hypothesis 4: Suppose fixed cost of the effort is zero. The effort cost function of the integrator is CI , and the effort cost function of the provider is CF . No consider the impact of the random variable. CI , CF could be described as follows:

$$C_I(\alpha) = \frac{1}{2}k_1\alpha^2 \quad (4)$$

$$C_F(\beta) = \frac{1}{2}k_2\beta^2 \quad (5)$$

where k_1 and k_2 represent the cost coefficient, $k_1 > 0$, $k_2 > 0$. It is easy to get $C_I(\alpha) > 0$, $C_I'(\alpha) > 0$, $C_I''(\alpha) > 0$, that is the higher lever of effort the greater cost of effort, which is reasonable. The same explanation is for $C_F(\beta)$.

Hypothesis 5: Assume the customer is risk neutral; the integrator and the provider are risk averse. Define the degree of risk aversion based on Arrow-Pratt absolute risk

aversion. ρ_1 represents the amount of risk aversion of the integrator; ρ_2 represents the amount of risk aversion of the provider.

B. Modeling

According to the above model assumptions, the expected utility of the customer is equal to the expected income. The expected income of the customer is:

$$E(U_c) = \pi_c = -w + (1 - \lambda)(p\alpha + q\beta) \quad (6)$$

The expected utility of the integrator and the provider are equal to the maximum certainty equivalent income. The certainty equivalent income of the integrator can be expressed as:

$$E(\pi_I) - \frac{1}{2} \rho_1 (1 - \theta)^2 \lambda^2 \sigma^2 = w - s + (1 - \theta) \lambda (p\alpha + q\beta) - \frac{1}{2} k_1 \alpha^2 - \frac{1}{2} \rho_1 (1 - \theta)^2 \lambda^2 \sigma^2 \quad (7)$$

The actual income of the provider who has fairness preference is:

$$\pi_F = s + \theta \lambda (p\alpha + q\beta + \varepsilon) - \frac{1}{2} k_2 \beta^2 - g_1 \max[(\pi_I - \pi_F), 0] + g_2 \max[(\pi_F - \pi_I), 0] \quad (8)$$

For a simple analysis, assume $g_1 = g_2 = g$. g refers to the fairness preference coefficient. When $\pi_I > \pi_F$, g represents jealousy preference; otherwise, g represents pride preference.

Where, Equation (8) could be expressed as:

$$\begin{aligned} \pi_F &= s + \theta \lambda (p\alpha + q\beta + \varepsilon) - \frac{1}{2} k_2 \beta^2 - g(\pi_I - \pi_F) \\ &= (1 + 2g)s - gw + [(2\theta - 1)g + \theta] \lambda (p\alpha + q\beta + \varepsilon) \\ &\quad + \frac{1}{2} k_1 g \alpha^2 - (1 + g) \frac{1}{2} k_2 \beta^2 \end{aligned} \quad (9)$$

The certainty equivalent income of the provider can be expressed as:

$$\begin{aligned} E(\pi_F) - \frac{1}{2} \rho_2 [(2\theta - 1)g + \theta]^2 \lambda^2 \sigma^2 &= (1 + 2g)s - gw \\ &\quad + [(2\theta - 1)g + \theta] \lambda (p\alpha + q\beta) + \frac{1}{2} k_1 g \alpha^2 \\ &\quad - (1 + g) \frac{1}{2} k_2 \beta^2 - \frac{1}{2} \rho_2 [(2\theta - 1)g + \theta]^2 \lambda^2 \sigma^2 \end{aligned} \quad (10)$$

Then, the double principal-agent mode of LSSC can be modeled as follows:

$$\begin{aligned} \max_{\lambda} E(U_c) &= \max_{\lambda} [-w + (1 - \lambda)(p\alpha + q\beta)] \\ \text{s.t. (IR)} \end{aligned} \quad (11)$$

$$w - s + (1 - \theta) \lambda (p\alpha + q\beta) - \frac{1}{2} k_1 \alpha^2 - \frac{1}{2} \rho_1 (1 - \theta)^2 \lambda^2 \sigma^2 \geq \pi_{I0} \quad (12)$$

(IC)

$$\max_{\alpha, \theta} [w - s + (1 - \theta) \lambda (p\alpha + q\beta) - \frac{1}{2} k_1 \alpha^2 - \frac{1}{2} \rho_1 (1 - \theta)^2 \lambda^2 \sigma^2]$$

(13)

s.t.(IR)

$$\begin{aligned} (1 + 2g)s - gw + [(2\theta - 1)g + \theta] \lambda (p\alpha + q\beta) + \frac{1}{2} k_1 g \alpha^2 \\ - (1 + g) \frac{1}{2} k_2 \beta^2 - \frac{1}{2} \rho_2 [(2\theta - 1)g + \theta]^2 \lambda^2 \sigma^2 \geq \pi_{F0} \end{aligned} \quad (14)$$

(IC)

$$\begin{aligned} \max_{\beta} \{ (1 + 2g)s - gw + [(2\theta - 1)g + \theta] \lambda (p\alpha + q\beta) + \frac{1}{2} k_1 g \alpha^2 \\ - (1 + g) \frac{1}{2} k_2 \beta^2 - \frac{1}{2} \rho_2 [(2\theta - 1)g + \theta]^2 \lambda^2 \sigma^2 \} \end{aligned}$$

(15)

π_{I0} is the retained profit of the integrator, π_{F0} is the retained profit of the provider.

C. Solution

According to the principle of profit maximization, the first-order and the second-order partial derivative for β of Equation (15) are

$$\frac{\partial \pi_F}{\partial \beta} = [(2\theta - 1)g + \theta] \lambda q - (1 + g) k_2 \beta \quad (16)$$

$$\frac{\partial^2 \pi_F}{\partial \beta^2} = -(1 + g) k_2 \quad (17)$$

As the second-order partial derivative is less than zero, set Equation (16) equal to zero, researchers get

$$\beta^* = \frac{[(2\theta - 1)g + \theta] \lambda q}{(1 + g) k_2} \quad (18)$$

As $\beta > 0$, then $(2\theta - 1)g + \theta > 0$.

According to the individual rationality constraint (IR, or participation constraint), when the expected utility of the agent is no less than its retained profit, it is willing to accept the commission. From the view of the principal, the better the smaller the payment is to the agent. Therefore, the actual participation constraint (14) is

$$\begin{aligned} (1 + 2g)s - gw + [(2\theta - 1)g + \theta] \lambda (p\alpha + q\beta) + \frac{1}{2} k_1 g \alpha^2 \\ - (1 + g) \frac{1}{2} k_2 \beta^2 - \frac{1}{2} \rho_2 [(2\theta - 1)g + \theta]^2 \lambda^2 \sigma^2 = \pi_{F0} \end{aligned} \quad (19)$$

According to equations (13), (18) and (19), researchers can calculate the derivative for α and θ . Then, researchers get

$$\alpha^* = \frac{\lambda p}{k_1} \quad (20)$$

$$\theta^* = \frac{\rho_1 (1 + g) k_2 \sigma^2 + (1 + 2g) q^2 + \rho_2 g (1 + g) k_2 \sigma^2}{\rho_1 (1 + g) k_2 \sigma^2 + (1 + 2g) q^2 + \rho_2 (1 + g) (1 + 2g) k_2 \sigma^2}$$

(21)

Similarly, according to equations (11), (12), (18) and (20), researchers can calculate the derivative for λ . Then, researchers get

$$\lambda^* = \frac{\frac{p^2}{k_1} + \frac{[(2\theta-1)g+\theta]q^2}{(1+g)k_2}}{\frac{(1+2g)(1-\theta)^2}{1+g}\rho_1\sigma^2 + \frac{[(2\theta-1)g+\theta]^2}{1+g}\rho_2\sigma^2 + \frac{p^2}{k_1} + \frac{[(2\theta-1)g+\theta]^2 q^2}{(1+g)^2 k_2}}$$

(22)

If $g=0$, that is the provider has not the fairness preference, then

$$\alpha_0^* = \alpha^* = \frac{\lambda p}{k_1} \quad (23)$$

$$\beta_0^* = \frac{\theta \lambda q}{k_2} \quad (24)$$

$$\theta_0^* = \frac{\rho_1 k_2 \sigma^2 + q^2}{\rho_1 k_2 \sigma^2 + q^2 + \rho_2 k_2 \sigma^2} \quad (25)$$

$$\lambda_0^* = \frac{\frac{p^2}{k_1} + \frac{\theta q^2}{k_2}}{\rho_1 (1-\theta)^2 \sigma^2 + \rho_2 \theta^2 \sigma^2 + \frac{p^2}{k_1} + \frac{\theta^2 q^2}{k_2}} \quad (26)$$

IV. ANALYSIS FOR MODEL

According to the above calculation results, some conclusions can be drawn.

A. Result 1

According to Equation (18), $\frac{\partial \beta}{\partial \lambda} > 0$, $\frac{\partial \beta}{\partial \theta} > 0$, it means the provider will improve its efforts level with the increase of the initial profit distribution coefficient and the second profit distribution coefficient. $\frac{\partial \beta}{\partial k_2} < 0$, it means the provider will reduce its efforts level with the increase

of the cost coefficient. $\frac{\partial \beta}{\partial q} > 0$, it means the provider will improve its efforts level with the increase of the contributing coefficient of the provider's efforts to logistics service output.

$\frac{\partial \beta}{\partial g} = \frac{[(2\theta-1)g+\theta]\lambda q}{(1+g)k_2} = \frac{(\theta-1)\lambda q}{(1+g)^2 k_2} < 0$, it means the provider will reduce its efforts level with the increase of its fairness preference. The provider's effort level has nothing to do with the degree of risk aversion and the external uncertainties on logistics service output.

B. Result 2

According to (20), $\frac{\partial \alpha}{\partial \lambda} > 0$, it means the integrator will improve its efforts level with the increase of the initial

profit distribution coefficient. $\frac{\partial \alpha}{\partial k_1} < 0$, it means the integrator will reduce its efforts level with the increase of

the cost coefficient. $\frac{\partial \alpha}{\partial p} > 0$, it means the integrator will improve its efforts level if it possesses the bigger asset size, the higher integrated technical capacity, and the higher degree of information. Compared (20) and (23), researchers can see that the integrator's effort level has nothing to do with the provider's fairness preference, and some traditional factors, including the degree of risk aversion and the external uncertainties on logistics service output.

In order to get further conclusion, a numerical experiment is designed (see Fig. 2 and Fig. 3). Then, researchers can get the following conclusions.

C. Result 3

The initial profit distribution coefficient and the second profit distribution coefficient will decrease with the increase of degree of fairness preference.

D. Result 4

The expected utility of the customer and the integrator will decrease with the increase of degree of fairness preference. On the contrary, the expected utility of the provider will increase with the degree of fairness preference.

Figure 2. Variation of θ, λ with g

Figure 3. Variation of π_c, π_I, π_F with g

V. CONCLUSIONS

The agent has the fairness preference is an important problem which has to be considered when making

incentive policy. In ISSC, the fairness preference between the integrator and the provider will affect the effort level of both the integrator and the provider, even the performance in the ISSC. The existence of fairness preference will lead to efficiency loss, and reduce the expected utility of the principal. The greater the degree of fairness preference is, the less the expected utility of the customer and the integrator is, and the integrator needs to pay more for the provider to compensate the negative utility caused by fairness preference.

Fairness preference has extensive influence on social and economic activities. The relationship between the integrator and the provider in LSSC is different from simple transactions, so it is important to consider both fairness preference and efficiency which is very useful for operation and management of LSSC. It is an attempt to introduce the fairness preference theory into the LSSC research, and there still exist a lot of problems to be solved. It should be noted that this paper analyzed on one agent and a single task principal-agent problem. In practice, it is common that there is more than one provider in a LSSC, and then it is a multi-agent and multi-task principal-agent problem. Therefore, the fairness preference exists not only between the integrator and the provider but also among providers, which are the future research.

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