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Profit Allocation of Remanufacturing Virtual Enterprises

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ABSTRACT. *This paper discusses the profit distribution of remanufacturing virtual enterprises from two perspectives. Firstly, from the external point of view, the virtual remanufacturing enterprise is regarded as an oligopoly, and the maximum profit can be obtained when it plays the game with other oligopoly remanufacturing enterprises is analyzed, and the profit function is given. Secondly, from an internal perspective, the profit function is analyzed, and it is found that the factors affecting the overall profit of virtual enterprises are the production cost of unit remanufactured products. Then the profit distribution model is constructed according to the production cost of unit remanufactured product. Finally, the above profit distribution model is analyzed by examples, and the results are obtained. It is found that: when he profit of 30% is directly distributed to the core enterprise, and then 70% is distributed to the non-core enterprise, the profit distribution based on the production cost of unit remanufactured products is beneficial to the non-core enterprise.*

KEYWORDS: *virtual enterprises, remanufacturing, profit allocation*

1. Introduction

In order to better adapt to the diversification of the market, a single enterprise will choose to cooperate with other enterprises to form a virtual enterprise. In the supply chain, some remanufacturers choose to form virtual enterprises with upstream or downstream enterprises in the supply chain, so as to save production costs, obtain more technical information and improve their competitiveness. After the establishment of remanufacturing virtual enterprise, reasonable profit distribution should be adopted to ensure the stability of remanufacturing virtual enterprise.

The profit distribution after the establishment of virtual enterprises has been discussed by scholars. Chen et al. [1] established a virtual enterprise profit distribution model by analyzing the factors affecting profit distribution and combining with game theory; Chen et al. [2] analyzed the profit distribution of

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virtual enterprises based on fuzzy Shapley value method. Wang and Liu [3] used AHP method to assign the weight of influencing factors of profit distribution, and shapley value method of multi-player cooperative strategy to explore how to conduct profit distribution of virtual enterprises.Hu et al. [4] applied shapley method to analyze the profit distribution of virtual enterprises with four-level chain supply chain; Ye et al. [5] proposed two profit distribution mechanisms of virtual enterprise alliance based on supply chain. One is according to the strength of each enterprise in the virtual enterprise; the other is the contribution of each enterprise in the virtual enterprise; Chen [6] analyzed the basic constraints of the profit distribution of virtual enterprises, and studied the profit distribution of virtual enterprises by using the secondary distribution method and the performance difference benefit distribution method.

Literature [1-6] studies the profit distribution of virtual enterprises from multiple perspectives. However, no matter it is combined with various influencing factors, supply chain, or enterprise strength, the research object is the internal enterprise of virtual enterprise. At present, there is no literature that considers virtual enterprises as oligarchs and analyzes their profit models when they play games with other enterprises. Then the profit distribution within virtual enterprises is discussed with the profit model. At present, there is no literature on the profit distribution of virtual remanufacturing enterprises.

Firstly, this paper regards remanufacturing virtual enterprise as oligopoly and gives its profit function. Secondly, combining with the profit function, the paper tries to find out from which aspects each enterprise in the virtual enterprise influences the overall profit of the virtual enterprise. Then according to this influence factor, the profit distribution model is constructed. Finally, some suggestions for the construction and stability of remanufacturing virtual enterprise are put forward according to the results of the model.

2. Symbol and Assumptions

2.1 Symbol

θ: The willingness of consumers to pay for new products;

p_n: Prices of new products in the market;

p_r: Prices of remanufactured products in the market;

μ: The degree of consumer preference for remanufactured products;

q_{in}: New product output of i enterprise;

q_{ir}: Remanufactured product output of i enterprise;

q_n: The total number of new products in the market;

q_r: The total remanufactured products in the market;

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X_n: Consumer surplus of consumers buying new products;

X_r: Consumer surplus when consumers buy remanufactured products;

m_n: Market share of new products;

m_r: Market share of remanufactured products;

c_n: Unit production cost of new product;

c_{ir}: Production cost per unit of remanufactured product of i enterprise;

π_{in}: Profits from the sale of new products of i enterprise;

π_{ir}: Profits from the sale of remanufactured products of i enterprise;

π_i: Profits from the sale of new and remanufactured products of i enterprise;

k_{ix}: Contribution of x non-core enterprise in i enterprise to saving production cost of unit remanufactured products;

$\pi_{ix:}$The profit distributed by the non-core enterprise of x in the i enterprise.

2.2 Assumptions

Assumption 1: Assume that the game between two remanufacturing virtual enterprises is a general oligopoly game.

Assumption 2: Consumers have no difference in cognition of similar products of different oligarchs, but there are differences in cognition of new products and remanufactured products, that is, consumers have different willingness to pay for new products and remanufactured products. Assume that consumers' willingness to pay for new products are all θ, and θ follows the uniform distribution on [0, 1].

Assumption 3: The sales price of the two enterprises' new products is the same, and the sales price of the remanufactured products is the same, and the sales price of the new products is greater than the sales price of the remanufactured products, $0 < p_r < p_n \leq 1$.

Assumption 4: Assuming that consumers' preference for remanufactured products is $\mu(0 < \mu < 1)$, then consumers' willingness to pay for remanufactured products is $\mu\theta$.

Assumption 5: Assuming that the cost of manufacturing new products is c_n, but the cost of manufacturing remanufactured products is c_{ir} due to different internal members of different virtual enterprises.

Assumption 6: The total number of new products in the market is $q_n = q_{1n} + q_{2n}$; The total amount of remanufactured products is $q_r = q_{1r} + q_{2r}$.

Assumption 7: The virtual enterprise consists of a core enterprise and n non-core enterprises. Because the remanufacturer masters the core technology of remanufacturing, it is the core enterprise of remanufacturing virtual enterprise.

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Assumption 8: The increase of non-core enterprises in virtual enterprises can improve the competitiveness of virtual enterprises, for example, it can reduce the production cost of unit remanufactured products.

3. Remanufacturing the virtual enterprise profit model

The consumer surplus of consumers buying new products and remanufactured products is respectively

$$X_n = \theta - p_n \ , \ X_r = \theta - p_r .$$

According to Ferrer and Swaminathan[7, 8], when the corporate game involves new products and remanufactured products, if $\mu \in (-\infty, \frac{p_r}{p_n}) \cup (1-(p_n - p_r), \infty)$, there will be a negative demand for new products or remanufactured products in the market. As the enterprise only considers the new product price and remanufactured products price when the market demand is not negative, so $\frac{p_r}{p_n} \le \mu \le 1-(p_n - p_r)$.

In the game between remanufacturers, the market share of the new product is

$$m_n = \int_{\Theta_n} f(x)dx = \int_{\Theta_n \cap [0,1]} \frac{1}{1-0} dx = \int_{[\frac{p_n - p_r}{1-\mu}, \infty) \cap [0,1]} dx$$

The total production of new products on the market is

$$q_n = m_n = 1 - \frac{p_n - p_r}{1-\mu} \tag{1}$$

The market share of remanufactured products is

$$m_r = \int_{\Theta_r} f(x)dx = \int_{\Theta_r \cap [0,1]} \frac{1}{1-0} dx = \int_{[\frac{p_r}{\mu}, \frac{p_n - p_r}{1-\mu}) \cap [0,1]} dx$$

The total remanufactured product output in the market is

$$q_r = m_r = \frac{p_n - p_r}{1-\mu} - \frac{p_r}{\mu} \tag{2}$$

Combining (1) and (2), we can get

$$\begin{cases} 1 - \frac{p_n - p_r}{1-\mu} = q_n \\ \frac{p_n - p_r}{1-\mu} - \frac{p_r}{\mu} = q_r \end{cases}$$

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Take p_n and p_r as unknowns, solve the above linear equations of binary order, and get

$$p_n = 1-q_n-\mu q_r,\ p_r = \mu(1-q_n-q_r)$$

For the game between two remanufacturing virtual enterprises, the profit function of the ith enterprise selling new products is

$$\pi_{in} = (p_n-c_n)q_{in}, i = 1,2$$

The profit function of selling remanufactured products is

$$\pi_{ir} = (p_r-c_{ir})q_{ir}, i = 1,2 \tag{3}$$

The total profit function of remanufacturing virtual enterprise is

$$\pi_i = (p_n-c_n)q_{in} + (p_r-c_{ir})q_{ir}, i = 1,2$$

According to the assumption, the above equation can be expressed as

$$\pi_i = (1-q_n-\mu q_r-c_n)q_{in} + (\mu(1-q_n-q_r)-c_{ia})q_{ir}, i = 1,2 \tag{4}$$

When the game between two virtual remanufacturing enterprises is stable, the enterprise will no longer adjust the output of new products and the output of remanufacturing, i.e

$$\begin{cases} \dfrac{\partial \pi_i}{\partial q_{in}} = 1-q_n-\mu q_r-c_n-q_{in}-\mu q_{ir} = 0 \\ \dfrac{\partial \pi_i}{\partial q_{ir}} = -\mu q_{in} + \mu(1-q_n-q_r)-c_{ia}-\mu q_{ir} = 0 \end{cases} \tag{5}$$

The above equation can be regarded as a binary first-order equation of q_{in} and q_{ir}, and can be solved

$$q_{in}^* = \frac{1-\mu+c_n+c_{ia}}{3-3\mu},\ q_{ir}^* = \frac{\mu c_n + c_{ia}}{3\mu-3\mu^2} \tag{6}$$

When the game between two remanufacturing virtual enterprises reaches a stable level, the profit obtained by the remanufacturing virtual enterprise selling the remanufactured products is

$$\pi_{ir} = \frac{\mu^2 c_n - \mu c_{ia} - \mu c_n c_{ia} + c_{ia}^{\ 2}}{9\mu-9\mu^2} \tag{7}$$

Corollary 1: When choosing cooperative enterprises, remanufacturers should try their best to control the production cost per unit of remanufactured products within

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the minimum range, and the maximum production cost per unit of remanufactured products should not exceed μc_n.

Proof: Consider (7) as a quadratic equation of one variable concerning the production cost per unit of remanufactured product. It is easy to know $\Delta = (\mu - \mu c_n)^2$. If π_{ir} =0, this quadratic equation has a solution. Solve for π_{ir} =0 to get

$$c_{ia} = \mu,\ c_{ia} = \mu c_n.$$

According to the assumption, it has $\mu c_n < \mu$. So if $c_{ia} \in (0, \mu c_n) \bigcup (\mu, 1)$, The profit of remanufact-uring virtual enterprise selling remanufactured products is greater than 0; if $c_{ia} \in (\mu, 1)$, The profit of remanufacturing virtual enterprise selling remanufactured product π_{ir} increases with the increase of production cost per unit of remanufactured product c_{ia}, which is inconsistent with reality. Therefore, the production cost per unit of the remanufactured product is $c_{ia} \in (0, \mu c_n)$, and the smaller the produ-ction cost per unit of the remanufactured product is, the greater the profit the remanufactured virtual enterprise can obtain from selling the remanufactured product.

4. Profit distribution of remanufacturing virtual enterprise

According to corollary 1, when two remanufacturing virtual enterprises are engaged in the game, the production cost per unit of remanufactured products has a significant impact on the profit of remanufacturing virtual enterprises. Therefore, the profit distribution model of remanufacturing virtual enterprises can be constructed from the perspective of production cost per unit of remanufactured products.

For remanufacturing virtual enterprise, remanufacturer is the core enterprise. If there is no remanufacturer, the remanufacturing virtual enterprise cannot be established According to a certain proportion of λ, λ times the remanufactured product profit can be allocated to the remanufacturer. λ is determined by the enterprise in the remanufacturing virtual enterprise. Then we only need to consider how to allocate the remanufactured product profit of 1- λ to non-core enterprises.

When two remanufacturing virtual enterprises play a game, for the i remanufacturing virtual enterprise, firstly, calculate the profit distributed by its core enterprise

$$\pi_{core} = \lambda \pi_{ir},\ i = 1, 2.$$

Secondly, for any of its non-core enterprises x, when x is in the i remanufacturing virtual enterprise, the production cost per unit of remanufactured

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products is c_{ia} ; When x is not in the i remanufacturing virtual enterprise, the production cost per unit of remanufactured products is c_{-ix} Then, the production cost of unit remanufactured products saved by the non-core enterprise x in the i remanufacturing virtual enterprise is $c_{ia} - c_{-ix}$. If the non-core enterprise x is added into the i remanufacturing virtual enterprise, the contribution rate of production cost saving per unit of remanufactured products is k_{ix} , which is

$$k_{ix} = \frac{c_{ia} - c_{-ix}}{\sum_{j=1}^{n} (c_{ia} - c_{-ij})}, x \in n. \tag{8}$$

Thus, the profit distributed by non-core enterprise x is

$$\pi_{ix} = k_{ix}(1-\lambda)\pi_{ir} \tag{9}$$

5. Analysis of examples

Assume that the remanufacturing virtual enterprise y can be composed of four enterprises, denoted by subscript A to represent the remanufacturer, subscript B, C and D to represent the other three cooperative enterprises respectively. The degree of consumers' preference to remanufactured products is $\mu = 0.8$, The cost per unit of production of a new product by a remanufacturer $c_n = 0.85$. When all the four enterprises are in the virtual enterprise of remanufacturing, the production cost of unit remanufactured products in the virtual enterprise of remanufacturing $c_{ya} = 0.4$; When B does not exist in the remanufacturing virtual enterprise, the production cost of unit remanufactured products of the remanufacturing virtual enterprise is $c_{-yB} = 0.55$; When C does not exist in the remanufacturing virtual enterprise, the production cost of unit remanufactured products of the remanufacturing virtual enterprise is $c_{-yC} = 0.6$; When D does not exist in the remanufacturing virtual enterprise, the production cost per unit of remanufactured products in the remanufacturing virtual enterprise is $c_{-yD} = 0.65$. After the negotiation of 4 enterprises, the remanufacturer's distributable profit is 30% of the total profit, $\lambda = 0.3$. Then the profit distributed by the remanufacturer is

$$\pi_{core} = 0.3\pi_{yr}$$

So next, just allocate the remaining $0.7\pi_{yr}$ to enterprise B, C and D.

According to (8), when profit is distributed according to the production cost per unit of remanufactured products, the contribution of enterprise B, C and D is

$$k_{yB} = 0.25, k_{yC} = 0.33, k_{yD} = 0.42$$

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Furthermore, according to (9), the profit distributed by non-core enterprises B, C and D can be written as

$$\pi_{yB} = k_{yB}(1-\lambda)\pi_{yr} = 0.175\pi_{yr},$$
$$\pi_{yC} = k_{yC}(1-\lambda)\pi_{yr} = 0.231\pi_{yr},$$
$$\pi_{yD} = k_{yD}(1-\lambda)\pi_{yr} = 0.294\pi_{yr}.$$

According to (7), π_{yr} =0.078 is calculated when 4 enterprises are all in the virtual enterprise, so

$$\pi_{core} = 0.0234,\ \pi_{yB} = 0.01365,\ \pi_{yC} = 0.01802,\ \pi_{yD} = 0.02293$$

According to the above calculation results, when the remanufacturer and cooperative enterprise negotiate the distribution ratio of λ = 0.3, the remanufacturer A gains 0.0234, and the non-core enterprise B, C and D respectively distribute 0.01365, 0.01802 and 0.02293.

6. Summary

This paper analyzes the remanufacturing virtual enterprise from both internal and external perspectives. The profit distribution model of remanufacturing virtual enterprise is constructed. According to the calculation example analysis results of the model, it is found that: the profit obtained by remanufacturers is higher than that of other cooperative enterprises.

Corresponding to the assumption that remanufacturers are the core enterprises, the profit distribution results are obtained according to the contribution of each enterprise. This method is also relatively fair and beneficial to maintain the stability of virtual enterprises. When choosing partners, virtual enterprises should try their best to choose the enterprises, which make the production cost per unit of remanufactured products lower. In the distribution of profits, more profits can be distributed to the enterprise that can save the most unit remanufactured products production cost, so as to maintain the stability of the virtual enterprise, maintain the loyalty of the cooperative enterprise, and make the long-term development of the virtual enterprise.

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