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Revenue Allocation of Supply Chain in the Sharing Industry based on Cooperative Game

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Abstract

In the context of sharing economy, a three-level supply chain consisting of a single supplier, a manufacturer and a sharing platform was studied. A Stackelberg game was played among the members. The optimal pricing decisions and profits were calculated for various situations under the condition of restricted coalition. On the one hand, according to the master-slave relationship among the members of the supply chain, the Shapley value for directed graph in cooperative game theory was used to distribute the revenue. On the other hand, according to the different positions of members in the supply chain, the Position value reflecting the role of participants' position was used for allocation, and compared. The results show that the revenue distribution schemes obtained by both methods highlight the status of special roles in the supply chain. The overall benefit of the supply chain increases in the cooperative game, which helps to promote cooperation and improve the economic benefits of the whole society.

Keywords

Cooperative Game; Revenue Distribution; Directed Graph Shapley Value; Position Value.

1. Introduction

With the widespread application of "Internet +", the change of people's consumption concept and the improvement of consumption ability, the sharing economy model has emerged at the right moment, showing fresh vitality both at home and abroad [1]. Although some people still question the future development of the sharing economy, its overall development is good and is a progress for human beings. In 2020, the transaction volume of China's sharing economy market was about 3, 377.3 billion yuan, an increase of about 2.9 percent year-on-year.

The platform economy and sharing economy, as new models of business emerging in recent years, have played an important role in promoting innovation and increasing employment. The development of platform economy and sharing economy has also been written into relevant policy documents for many times. This indicates that the development of platform economy and sharing economy will have greater room for imagination in the next five years and for a longer period of time, and become an important force to enhance the resilience and vitality of the economy.

The sharing economy takes platform as the carrier to transfer idle resources from the supply end to the demand end, realizing the maximum utilization of resources.The rapid development of sharing economy in China has promoted the change and innovation of many traditional industries, and directly given birth to sharing economy modes such as shared cars, shared bikes and shared accommodation.The rapid development of economy and technology in the new century has brought significant changes to people's work and life patterns, and the concept of personalized consumption has gradually become the mainstream. As a result, the market competition environment becomes increasingly complex, which makes it difficult for individual enterprises to cope with it. Therefore, enterprises gradually participate in the market competition in the form of supply chain through collaboration and integration.

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Supply chain management has always been an important element in the strategic deployment of enterprises [2]. With the rapid development of the sharing industry, its supply chain management should also be paid sufficient attention to promote better development of the sharing industry. Numerous theoretical studies and practices have shown that cooperation is becoming more and more important in the field of supply chain management due to the highly complex structure of supply chain network. Cooperation helps to improve the benefits of supply chain, and enterprises form cooperation to reduce double marginalization and obtain greater benefits. Cooperation generates joint benefits, which is followed by the distribution of benefits. A reasonable distribution scheme can ensure the stability and fairness of cooperation. Scholars adopt the method of cooperative game to allocate supply chain profits, and the fairness and reasonableness of the benefit distribution is directly related to the sustainability of the supply chain, and the supply chain in the sharing industry is naturally no exception. Good cooperation among members can increase the profits of all parties, and fair and reasonable distribution of the profits generated can further motivate effective cooperation among members, which promotes good development of the industry.

Cooperative game theory studies all possible coalition outcomes, and most existing applications adopt an arbitrary coalition structure and assume equal power among members to solve the allocation problem [3]. However, in practical situations, the power status among members is usually not equal and some coalitions cannot be formed. Cooperative game theory provides many potential solutions for rational distribution of benefits generated by cooperation [4]. Scholars adopted the Shapley value for revenue distribution, and proposed modified calculation methods based on the deficiency of the Shapley value [5-11]. However, the Shapley value assumes that all participants can freely form coalitions, whereas in reality cooperation is usually restricted [12]. Therefore, it is unreasonable to use the Shapley value to distribute the benefits of coalitions. Although some scholars have used the modified Shapley value for revenue distribution, they all failed to reflect the importance of participants' position in the supply chain. In actual situations, the cooperation between two supply chain members is realized through “intermediaries”, that is, the participants playing the role of “intermediaries” have a special status in the supply chain. So in order to allocate the benefits of cooperation more fairly and reasonably, the importance of the position of the members in the chain should be taken into account.

Since the Position value emphasizes the importance of the position of participants in the coalition, Shan et al. compared the benefit distribution schemes obtained by the Shapley value, Position value, and AT solution, and found that it is relatively more reasonable to use the Position value reflecting the special status of participants for revenue distribution [13]. Shan et al. considered the importance of the position of the members in the chain, the revenue distribution scheme obtained reflects the special status of position. In this paper,we will consider another situation that reflects the status of the participants: the master-slave relationships in the supply chain. The Shapley value for directed graph is used for revenue distribution, and the Position value is used for distribution at the same time, and comparative analysis is made.

The position of a participant in a supply chain network is crucial. The status is mainly reflected in two situations: the voice in the market and the position in the supply chain. The higher the status, the more voice it has. In the market, if one party has a dominant position in the cooperation, then it deserves to get the benefits corresponding to it, which is a reflection of its voice. In a supply chain network, the intermediaries connect all the members of the supply chain. Without the connection of the intermediate role, each enterprise is just an isolated point. The intermediaries play a particularly important role and should get the benefits in line with their status and roles, which helps the long-term survival of cooperation. Based on this, this

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paper mainly studies the allocation rules that reflect the status of the participants and applies them.

Inspired by Ren [14-19], this paper considers the special status of supply chain members in the supply chain and aims to study the benefit distribution in the supply chain of the sharing industry, with the purpose of getting a relatively reasonable distribution scheme to promote good cooperation of the supply chains, achieving better development of the sharing industry, maximizing the use of social idle resources, and improving the economic efficiency of the whole society.

2. Model Construction and Solution

2.1. Model Construction

The supply chain consists of a supplier, a manufacturer and a sharing platform. The supply chain structure is shown in Figure 1. In a perfectly competitive relationship, the decision-making goal of the supply chain is profit maximization. When cooperating, it is necessary to provide a fair and reasonable profit distribution scheme. Consider two decision situations: decentralized and centralized. In the case of decentralized supply chain, it is assumed that the production scale is large. The supplier is the dominant player in the chain, and the manufacturer and the sharing platform are followers, so there is Stackelberg competition within the supply chain. In the centralized supply chain, the members of the supply chain make decisions as a whole.

Figure 1. The structure of the supply chain

The members of the supply chain all satisfy the rational man hypothesis. The following assumptions are made for the supply chain formed by the supplier s, the manufacturer m and the sharing platform l:

(1) The cost of unit parts produced by the supplier s is c_s, which is supplied to the manufacturer at the unit price of p_s.

(2) The unit production cost of manufacturer m is c_m, and the unit cost of remanufacturing the recycled product is c_r, and $c_m > c_r$; Otherwise, the manufacturer have no incentive to remanufacture. $\Delta = c_m - c_r$ denotes the unit cost saved by producing the remanufactured products, assuming that all the recycled products are used for remanufacturing.

(3) As long as the leased products can be used normally, the customer does not distinguish between new products and remanufactured products. The manufacturer provides the products to the sharing platform at the unit price of p_m. The sharing platform recycles the waste products, and the manufacturer repurchases the waste products for remanufacturing at the price of p_r, and $p_r \leq \Delta$. As the research is based on the sharing industry, the recycling rate of this research is 100%. Because it is recycled from the platform, it is not so dispersed and difficult to collect.

(4) With consumers' increasing awareness of low carbon, Chitra points out that consumers' awareness of environmental protection has become an important factor influencing their willingness to pay [20]. Some scholars believe that the market demand function is the increasing function of the level of carbon emission reduction [21-22]. Considering the impact of low carbon level on demand, k denotes the level of carbon emission reduction. The larger k is, the more the manufacturer's effort to invest in carbon emission reduction. θ is the marketability coefficient of the level of carbon emission reduction of the product. C_h is the cost

of carbon emission reduction. The manufacturer's total cost will increase in order to improve the level of the emission reduction, so the total cost of carbon emission reduction is an increasing function of the level of carbon emission reduction. The carbon emission reduction cost of the manufacturer is quadratically related to the unit carbon emission reduction, i.e. $C_h = \frac{1}{2}ek^2$. e is the manufacturer's cost coefficient of emission reduction , $e > 0$.

(5) The sharing platform shall pay p_m to obtain the unit of the product from the manufacturer and lease it to the customer at the unit price of p_l. The demand function of the product is $q = a - p_l + \theta k$. a is the basic market demand. k is the level of carbon emission reduction, that is, the extent of the manufacturer's effort to invest in carbon emission reduction. θ represents the marketability coefficient of the level of carbon emission reduction of the product, and $\theta > 0$. Its size measures the impact of the carbon emission reduction level of the product on the market demand. When other parameters being constant, increasing the level of carbon emission reduction by one unit will attract market demand of θ units.

(6) In previous studies, demand is the quantity of a product purchased by consumers. In the sharing industry, the consumers do not buy products when they need them, but rent them.

All relevant parameters of the model and their meanings are given in Table 1.

Table 1. Parameter Settings

Parameter	Meaning
c_s	the cost of the supplier
p_s	the price supplied to the manufacturer
c_m	the cost of producing new products of the manufacturer
c_r	the cost of remanufacturing recycled products of the manufacturer
Δ	the cost saved from producing the remanufactured products
p_m	The price provided to the sharing platform
p_r	manufacturer's cost of buying back used products
C_h	the cost of carbon emission reduction
k	the level of carbon emission reduction
θ	marketability coefficient of the level of carbon emission reduction of the product
e	the manufacturer's cost coefficient of emission reduction
p_l	the price of products that the platform rents to customers
a	The basic market demand
q	The demand function for the product

2.2. Model Solution

There are three possible alliance modes for supply chain members (enterprises only allied with neighboring enterprises), which are as follows: the supplier, the manufacturer and the sharing platform are all not allied, namely, the most common decentralized situation, denoted as $(\boldsymbol{s}, \boldsymbol{m}, \boldsymbol{l})$; The supplier and the manufacturer are allied, denoted as $([\boldsymbol{s}, \boldsymbol{m}], \boldsymbol{l})$; The manufacturer and the sharing platform are allied, denoted as $(\boldsymbol{s}, [\boldsymbol{m}, \boldsymbol{l}])$; The supplier, the manufacturer and the sharing platform are all allied, denoted as$([\boldsymbol{s}, \boldsymbol{m}, \boldsymbol{l}])$.

The profit expressions for each member or the member alliance of the supply chain in each case are given below. Using the backward induction method, which is most commonly used to solve the Stackelberg game, Maple is used to find the optimal solution in each case. And the optimal profit of each member or the member alliance of the supply chain is derived based on the optimal decision, so as to obtain the required characteristic function of the cooperative game.

(1) Non-alliance model (s, m, l)

ISSN: 2688-9323

$$\pi_s = (p_s - c_s)q$$
$$\pi_m = (p_m - p_s - c_m)q + (\Delta - p_r)q - \frac{1}{2}ek^2$$
$$\pi_l = (p_l - p_m + p_r)q$$

Solving the model, we can obtain the profit expression:

$$\pi_s = \frac{(\theta k + a - c_r - c_s)^2}{16}$$
$$\pi_m = \frac{(\theta k + a - c_r - c_s)^2}{32} - \frac{1}{2}ek^2$$
$$\pi_l = \frac{(\theta k + a - c_r - c_s)^2}{64}$$

(2) The supplier and the manufacturer are allied ($[s, m], l$)

$$\pi_{sm} = (p_m - c_s - c_r - p_r)q - \frac{1}{2}ek^2$$
$$\pi_l = (p_l - p_m + p_r)q$$

Solving the model, we can obtain the profit expression:

$$\pi_{sm} = \frac{(\theta k + a - c_r - c_s)^2}{8} - \frac{1}{2}ek^2$$

(3) The manufacturer and the sharing platform are allied ($s, [m, l]$)

$$\pi_s = (p_s - c_s)q$$
$$\pi_{ml} = (p_l - p_s - c_r)q - \frac{1}{2}ek^2$$

Solving the model, we can obtain the profit expression:

$$\pi_{ml} = \frac{(\theta k + a - c_r - c_s)^2}{16} - \frac{1}{2}ek^2$$

(4) The supplier, the manufacturer and the sharing platform are all allied ($[s, m, l]$)

$$\pi_{sml} = (p_l - c_s - c_r)q - \frac{1}{2}ek^2$$

Solving the model, we can obtain the profit expression:

$$\pi_{sml} = \frac{(\theta k + a - c_r - c_s)^2}{4} - \frac{1}{2}ek^2$$

ISSN: 2688-9323

2.3. Directed Graph Shapley Value and Position Value

The transferable utility game (TU-game) is denoted by(N,v). $N=\{1,\dots,n\}$ represents a finite set of participants. v is the characteristic function that is the mapping defined on $2^N\to R$ and $v(\emptyset)=0$. For any non-empty union $S\subseteq N$, the $v(S)$ denotes the utility generated by the cooperation of the participants in the coalition S. The set of all TU-games is denoted as G^N. There are various permutations of the set of participants. Ψ is the set of all permutations on N. ψ represents one permutation, and $\psi(i)$ is the position of participant i in the permutation ψ.

Anna et al. assume that finite cooperation is determined by an arbitrary directed graph D. The directed links determine the subordination relationship between the players of the game [23]. The structure of a directed graph describes a subordination relationship between the players of the game, while embodying finite cooperation. Based on this, the Shapley value of the directed graph is defined as the average of the vectors of marginal contributions corresponding to all permutations that do not violate the participants' affiliation. It is calculated as follows.

$$Sh_i(v,D)=\frac{1}{|\Psi^D|}\sum_{\psi\subseteq\Psi^D}\bar{w}_i^{\psi}(v)$$

Where Ψ^D denotes the set of all permutations that do not violate the participants' affiliation in the directed graph D. For each eligible permutation ψ, for any$i\in N$, the corresponding marginal vector $\bar{w}_i^{\psi}(v)$ is $w_i^{\psi}(v)=v(\{j\in N|\psi(j)\le\psi(i)\})-v(\{j\in N|\psi(j)<\psi(i)\})$.

Among the many allocation rules for cooperative game on graphs, another allocation rule that has received a lot of attention is the Position value proposed by Meessen [15] in 1988. The Position value treat links as participants and first find the Shapley value of each link and then assign the Shapley value of each link equally to its two endpoints. The feature of the Position value is its ability to highlight the importance of a participant's position in the coalition, which corresponds to many practical problems.

The Position value is an allocation rule that focuses on the contribution of "links" in a cooperative game with a network structure [24]. L_i denotes the set of links to which a participant i belongs. A point that is not associated with any link is called an isolated point. For $A\subseteq L$, the$(N(A),A)$ is called the subgraph derived from the subset of links A. Here $N(A)$ is the set of points associated with the links in A. The Position value focuses on the role or contribution that each communicating link makes in the cooperation. First, each link is considered as a participant. A characteristic function r^v on the set of links L is derived from the characteristic function v, and then the Shapley value of each link is found. The Position value is defined as:

$$P_i=\begin{cases}\sum_{l\in L_i}\frac{1}{2}sh_l(L,r^v) & \text{The participant } i \text{ is not an isolated point in } (N,L)\\ v(i) & \text{The participant } i \text{ is an isolated point in } (N,L)\end{cases}$$

where for any$A\subseteq L$, the $r^v(A)=\sum_{R\in N(A)/A}v(R)$ is called the link game. The Position value indicates that when a participant i is an isolated point, i.e., not connected to any other participant by a communication link, the payment given to it is exactly his utility $v(i)$; otherwise, the participant i gets the payment that is the sum of half of the Shapley value of each of the links associated with it.

ISSN: 2688-9323

2.4. Revenue Allocation

For the purpose of the analysis, the following assumptions are made about the parameters.

The basic market demand for the product in the supply chain is $a = 500$. The cost of unit parts produced by the supplier s is $c_s = 40$. The unit production cost of manufacturer m is $c_m = 90$. The unit cost of remanufacturing the recycled product is $c_r = 40$. The level of carbon emission reduction is $k = 0.2$. The marketability coefficient of the level of carbon emission reduction of the product is $\theta = 0.4$. The cost coefficient of emission reduction of the manufacturer is $e = 0.3$.

Based on the above parameter assumptions, the benefits for all parties in all scenarios are calculated to derive the values of all feasible coalitions: $\pi_s = 11029.20$, $\pi_m = 5514.59$, $\pi_l = 2757.30$, $\pi_{sm} = 22058.39$, $\pi_{ml} = 11029.19$, $\pi_{sml} = 44116.80$. Cooperation will double the revenue and generate significant income. Cooperation is necessary, and the benefits generated are in urgent need of a reasonable distribution scheme.

Based on the above calculations, the utility values of different coalitions were derived as shown in Table 2.

Table 2. Utility values of coalitions (a)

Coalition	Utility value	Coalition	Utility value
$v(s)$	11029.20	$v(sm)$	22058.39
$v(m)$	5514.59	$v(ml)$	11029.19
$v(l)$	2757.30	$v(sml)$	44116.80

According to the master-slave relationship of the participants in the model, the corresponding directed graph is shown in Figure 2. The directed graph specifies the subordination relationship among the participants and limits the feasibility of the coalition.

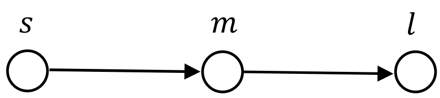

Figure 2. The structure of directed graph

From the above figure, it can be seen that there is only one permutation that matches the master-slave relationship between the participants, namely (l, m, s). Based on the definition and the characteristic function of the Shapley value of the directed graph, the gain obtained from each participant's allocation is calculated as: $v(s) = 33{,}087.61$, $v(m) = 8{,}271.89$, $v(l) = 2757.30$.

The proportion of profit distribution is shown in Figure 3.

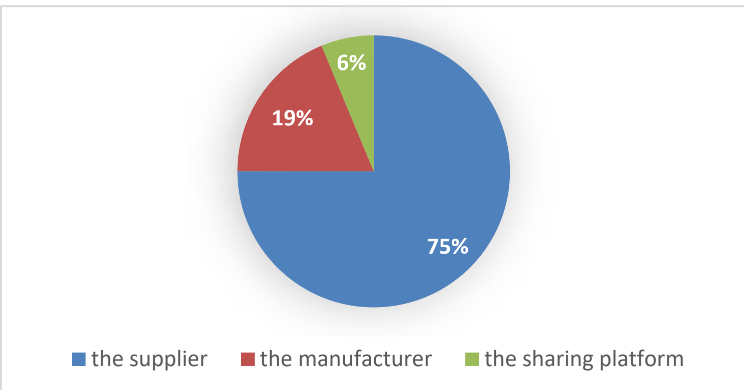

Figure 3. Revenue distribution scheme with Shapley value of directed graph

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According to the data, it is obvious that almost all the revenue generated from the cooperation is distributed to the supplier and the manufacturer. And the supplier as the dominant player gets most of the benefits of the cooperation. The sharing platform, due to its lower status, does not increase its revenue even if it participates in the cooperation of the supply chain. As a dominated player in the supply chain, its voice is weak, and this situation can have an incentive effect on the sharing platform.

Next the gain is allocated with the Positions value. The structure of the undirected graph is shown in Figure 3.

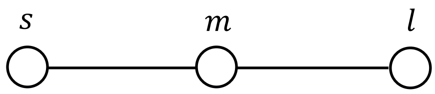

Figure 4. The structure of the undirected graph

Suppose $a = \{s, m\}$, $b = \{m, l\}$, then the characteristic function is:

$$v^L = 24815.69u_a + 22058.39u_b - 2757.28u_{a,b}$$

According to the definition of the Position value, the benefits of each party are calculated as follows:

$$v(s) = 11718.53, \text{and} v(m) = 22058.40, v(l) = 10339.88.$$

The proportion of profit distribution is shown in Figure 5.

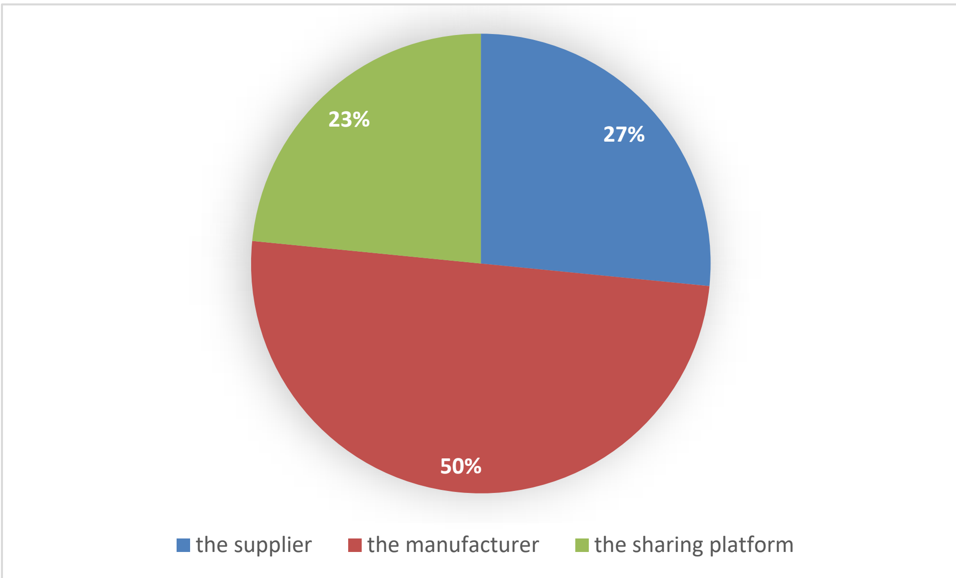

Figure 5. Revenue distribution scheme with Position value

As can be seen from the above data, the manufacturer playing the role of "intermediaries" is distributed the most revenue, followed by the suppliers with only a slight increase in revenue compared to non-cooperation. In contrast, there is also a significant increase in revenue for the sharing platform. Using the Position value to allocate the benefits of cooperation highlights the intermediary role of the manufacturer.

ISSN: 2688-9323

Table 3. Utility values of coalitions (b)

The member of the supply chain	Benefits in case of non-cooperation	Distribution scheme with Shapley value of directed graph	Distribution scheme with Position value
$v(s)$	11029.20	33,087.61	11718.53
$v(m)$	5514.59	8,271.89	22058.40
$v(l)$	2757.30	2757.30	10339.88

There is no doubt that the overall benefits of the supply chain increase through cooperation The benefits of the members also increase compared to the situation where the members of the supply chain do not cooperate with each other. This is a consistent conclusion in all the articles on the distribution of benefits with the cooperative game theory. From the results of the above two methods, it can be seen that there are advantages with the Shapley value of the directed graph and the Position value to allocate the benefits of cooperation. The allocation scheme reflects the status of "special players". The manufacturer, as the “intermediary” connecting the supplier and the sharing platform, clearly reflects its position as a connector when using the Position value for revenue allocation. The use of the directed graph Shapley value, on the other hand, highlights the dominant position of the supplier. For the sharing platform, it is relatively disadvantaged, which can help to motivate the platform to move up and become dominant.

3. Conclusion

Based on the context of the sharing economy, this paper studies a three-level supply chain consisting of a single supplier, a manufacturer and a sharing platform, where the members of the chain play Stackelberg game. Considering various possible scenarios of cooperation among the members of the supply chain, construct a model and solve it. Based on the optimal solution of the model, a characteristic function is established. The gains are distributed with the Shapley value of the directed graph, which reflects the dominance of the participants, and the Position value, which reflects the importance of the position of the participants, then compared and analyzed. Both allocation schemes highlight the position of different participants and each has its own advantage. If the revenue generated by the cooperation of supply chain members in the sharing industry can be reasonably distributed, the cooperation will be sustainable in the long run and contribute to the good development of the sharing industry.

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