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Yanhong Zhang
Institute of system Engineering of Hydraulic and Hydroelectricity School, Wuhan University, Wuhan,430072, China, yh_zhang2004@126.com

Xianjia Wang
Institute of system Engineering of Hydraulic and Hydroelectricity School, Wuhan University, Wuhan,430072, China

Zhijie Chen
School of Management, Wuhan textile University, Wuhan,430073, China

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Yanhong Zhang[1,2*] *, Xianjia Wang*[1] *, Zhijie Chen*[1,3]
[1]Institute of system Engineering of Hydraulic and Hydroelectricity School, Wuhan University, Wuhan,430072, China
[2]College of Science, the Science and Technology of Wuhan University, Wuhan,430065, China
[3]School of Management, Wuhan textile University, Wuhan,430073, China

Abstract: This paper studies the behavior coordination of members in e-commerce supply chains with cooperative game theory. Under the environment of e-commerce, the retailers and the supplier can maximize their profits through the cooperation with the information provider. We study this cooperation by means of cooperative game theory and emphasize the importance of the information provider in the cooperation. We give a core allocation and a solution for these games.

Keywords: e-commerce supply chains, cooperative game, allocation

1. INTRODUCTION

With the development of electronic information technology, information network have a great impact on the traditional supply chain. The large potential impact of the Internet on supply chain management makes the study of supply chain models in e-commerce timely and important. Robert and Horance[1] argues that by upsetting the balance among the contextual forces, it will be the emergence of a new vision of supply chain in e-commerce. Wu and Li[2] construct a randomized pricing strategy for online retailers by borrowing long standing promotion methods from traditional retailing. Jayashankar et al.[3] present an overview of relevant analytical research models that have been developed in these areas, and conclude with a discussion on future modeling opportunities in this area. Studies on Supply Chain Operation Mode for Agricultural Products under Electronic Commerce have been carried out and discussed[4],[5]. E-commerce service platform has been designed and implemented for the supply chain management of agricultural products[5].

As we all known that the supply chain management emphasizes the behavior coordination between the enterprises in the supply chain by information sharing and resources optimization allocation[6] to reduce the transaction costs. There's a lot of talk in the e-commerce supply chain about integrating systems, collaborating with partners[7]-[10]. When used appropriately, the new e-commerce technologies allow firms to streamline their business processes to achieve lower operating costs and in crease sales revenue, as well as to improve flexibility in the e-commerce[11] . Sanjay G. et al.[11] explore the coordination for the flexibility in e-commerce supply chain.

In contrast, cooperative game theory emphasizes the cooperation between the companies. One of the main questions is whether the cooperation is stable, that is, whether there are allocations of the total profit among the companies such that no groups of companies would like to cooperate on its own[13],[14],[16]. Liang, Dong and Wilhelm study the e-commerce by the negotiation[10],[15]. Luis, Ana and Judith[16] analyze a traditional supply chain model by means of cooperative game theory, they show that the corresponding games are balanced and propose a stable solution concept(the mgpc-solution) for the game.

In this paper, we analyze the e-commerce supply chains by means of cooperative games. We consider one period e-commerce supply chains with a single product. In such a supply chain, the retailers know about the product through the information platform constructed by the information provider and place one-time orders for

* Corresponding author. Email:yh_zhang2004@126.com

the product at the supplier. The supplier receives the order in the information platform. After production, the supplier delivers the goods to the retailers. The information provider acts as an intermediary with revenues. Every retailer and supplier pays the same information cost to the information provider in a period. There are no competitions between retailers, and they sell the goods on their own market. The larger the quantity that is put on the market, the lower the price per unit is for retailers. Each retailer chooses its order quantity such that its profit is maximized.

The retailer pays the supplier a wholesale price per unit product ordered and delivered. This price is a decreasing function of the quantity ordered. The regular information cost is charged by the information provider according to the number of port clicked, and has nothing to do with the number of clicks on a port. Therefore, there exist incentives for cooperation among retailers. There are also the incentives for cooperation between the retailers and the supplier, and the retailers or supplier with the information provider. If the retailers combine their orders into one large order and place at the supplier, they enjoy a lower wholesale price. The supplier also hopes to receive a large order to earn more profits. The supplier may want to cooperate with the information provider to reduce the information cost. Besides, retailers may want to cooperate with the supplier and the information provider to reduce the wholesale prices and the information costs. Obviously, the total profit under full cooperation is larger than the sum of the individual profits. Because of the incentives for cooperation, we use cooperative game theory to study the supply chain. For this chain we define a corresponding cooperative game in which the supplier, the retailers and the information provider are players. We adapt some properties of the solution provided by Luis, Ana and Judith[15] to characterize our solution.

The paper makes two contributions to the e-commerce supply chain. First, we use the cooperative game theory in e-commerce supply chain; Second, we emphasize the importance of the information provider in the cooperation in e-commerce supply chain.

The contents of the paper are organized as follows. Section2 we briefly introduce the necessary concepts of cooperative game theory. Section3 gives the model of a single period e-commerce supply chain and study the related cooperative game and give an allocation for the game. Section4 concludes.

2. PRELIMINIARIES COOPERATIVE GAME THEORY

A cooperative game with transferable utility (TU game) is a pair (N,v), where $N=\{1,2,\ldots,n\}$ is a finite set of players and v, the characteristic function, is a real valued function on $2^N=\{S:S\subseteq N\}$ satisfying $v(\phi)=0$. In this paper, the cardinality of a finite set is denoted by the operator $|\cdot|$,i.e., $|S|$ is the number of players in S, for any $S\subseteq N$. Sometimes we use lowercase letters to denote cardinalities, and thus $s=|S|$ for any $S\subseteq N$. A benefit vector, or allocation, is denoted by $x\in R^n$. The core of the game (N,v) consists of those allocations $v(N)$ of in which each coalition receives at least its benefits:

$$\mathrm{Core}(N,v)=\{x\in \mathrm{R}^n \mid \sum_{i\in N} x_i = v(N)\ and\ \sum_{i\in S} x_i \geq v(S)\ \ for\ all\ S\subset N\}$$

A core allocation $x\in \mathrm{Core}(N,v)$ is both efficient, that is $\sum_{i\in N} x_i = x(N)$, and it satisfies the coalitional stability property, that is $\sum_{i\in S} x_i \geq v(s)$ for all $S\subset N$. A game is called balanced if its core is nonempty.

A game (N,v) is called monotone if for every $S,T \subseteq N$ with $S \subseteq T$, it holds that $v(S) \le v(T)$ .We denote by G the set of all monotone games.

Given $(N,v) \in G$, a player $i \in N$ is a dummy if $v(S) = v(S \setminus i) + v(i)$ for all $S \subseteq N \setminus i$, that is, if all her marginal contributions are equal to $v(i)$. A player is called a null player if she is a dummy and $v(i) = 0$. Two players $i, j \in N$ are symmetric if $v(S \cup i) = v(S \cup j)$ for all $S \subseteq N \setminus \{i, j\}$, that is, if their marginal contributions to each coalition coincide.

A single-valued solution φ for TU game (N,v) is a map $\varphi : \Gamma^N \to R^N$ where Γ^N is the class of TU-games with player set N. The payoff to player $i \in N$ in game $v \in \Gamma^N$ according to this solution is denoted by $\varphi_i(v)$ and $\varphi(v) = (\varphi_i(v))_{i \in N}$.

3. THE MODEL OF THE E-COMMERCE SUPPLY CHAIN AND RELATED COOPERATIVE GAME

In this section, we study single period models of e-commerce supply chain involving a single product. The retailers and the supplier must use the information platform from different ports and make transaction in the information platform, while the retailers can make alliance to use the information platform from a port and make transaction with the supplier. Every retailer and supplier pays a regular information cost to the information provider in a period.

3.1 The retailer –supplier-information provider problem(RSI-problem)

We first concentrate on a chain with a single retailer. The retailer places a one-time order that the size is q units through the information platform. The ordered goods are produced by the supplier at a cost c ($c \ge 0$)of per unit. The cost of this order is the wholesale price $w(q)$. The more the retailer orders, the lower the price per units he has to pay. So the wholesale price function $w(q)$ is a decreasing and continuous function with $w(q) \ge c$, $q \ge 0$. The expected price function $p : R_+ \to R$ is decreasing and continuous in q.

The retailer determines his order quantity q such that his profit is maximized:

$$\text{Max} \quad (p(q) - w(q))q - t$$

$$\text{s.t.} \quad q \in Q$$

where $Q = \{q \in R_+ \mid p(q) \ge w(q)\}$ is the set of feasible order size, that is, those order sizes that result in a nonnegative profit margin for the retailer from the commodities.

Given the retailer's order size q, the supplier's profit equals

$$\text{Max} \quad (w(q) - c)q - t$$

The information provider's profit equals $2t$.

3.2 The retailer –supplier-information provider games(RSI-games)

Now we consider single period cooperative models of e-commerce supply chains with a supplier, an information provider and multiple retailers. Each of the retailers places its order at the information platform provided by the information provider. The retailers have the possibility to cooperate among each other and place a joint order, which results in a lower wholesale price per unit. The retailers and the supplier also have the incentives to cooperate with the information provider with the absence of the information costs.

Let $N=\{1,\ldots,n\}$ be the set of retailers and denote the supplier by 0, the information provider by I. Then $N_0 = N \cup \{0\}$ is the set of all retailers and the supplier and $N_1 = N_0 \cup \{\mathrm{I}\}$ is the set of all players in the chain. Similarly, we define $S_0 = S \cup \{0\}$ and $S_1 = S_0 \cup \{\mathrm{I}\}$, for all $S \subseteq N$. If $q_s = \sum_{i \in S} q_i$ denotes the total order size by a coalition $S \subseteq N$ of retailers, then the joint benefit of this coalition equals

$$\text{Max} \ \sum_{i \in S} (p_i(q_i) - w(q_S))q_i - t$$

$$q \in Q^S := \{q \in R_+^S \mid p_i(q_i) \geq w(q_S) \text{ for all } i \in S\}$$

The cooperation among the group of retailers S and the supplier is described just as the joint benefit:

$$\text{Max} \ \sum_{i \in S} (p_i(q_i) - c)q_i - 2t$$

The worth of the grand coalition formed by retailers, supplier and the information provider equals

$$\text{Max} \ \sum_{i \in S} (p_i(q_i) - c)q_i$$

Luis, Ana and Judith[15] prove that cooperation with the supplier is attractive for retailers. While the cooperation with the information provider is also attractive for retailers and supplier since the information cost will disappear as long as the information provider is in the cooperation and the profit is positive. When the information provider is in the cooperation or the information cost is asked zero, the RSI-games is the RS-games that discussed by Luis, Ana and Judith[15]. So the profit function arising from cooperation in e-commerce have the similarly properties discussed in traditional supply chain.

Lemma3.1. Let

$$\mathrm{P}_i^{ret}(q_i, w(q_i)) = (p(q_i) - w(q_i))q_i - t\,, \quad \mathrm{P}_i^{\sup}(q_i, w(q_i)) = (w(q_i) - c)q_i - t$$

$i \in S \subseteq N$, and $\mathrm{P}_i^{\mathrm{I}}(q_i) = t$. Then

(1) $\mathrm{P}_i^{ret}(q_i^S; c) = \mathrm{P}_i^{ret}(q_i^S; w(q_S^S)) + \mathrm{P}_i^{\sup}(q_i^S; w(q_S^S)) + \mathrm{P}_i^{\mathrm{I}}$;

(2) $\mathrm{P}_i^{ret}(q_i^c; c) \geq \mathrm{P}_i^{ret}(q_i^S; c)$;

(3) $\mathrm{P}_i^{ret}(q_i^c; c) \geq \mathrm{P}_i^{ret}(q_i^S; w(q_S^S))$ and $\mathrm{P}_i^{ret}(q_i^c; c) \geq \mathrm{P}_i^{ret}(q_i^S; w(q_S^S))$.

Proof. (1) –(3)follows immediately from the definitions of P_i^{ret}, $\mathrm{P}_i^{\sup}$, $\mathrm{P}_i^{\mathrm{I}}$.

Next we define the cooperative game corresponding to the supply chain in e-commerce described in our situation that is RSI-game.

Definition3.2 The cooperative game in e-commerce(RSI-game) (N_1, v) is defined by

$$v(S) = \sum_{i \in S} (p_i(q_i^S) - w(q_i^S))q_i^S - t \,,$$

$$v(S_0) = \sum_{i \in S} (p_i(q_i^c) - c)q_i - 2t \,,$$

and $$v(S_1) = \sum_{i \in S} (p_i(q_i^c) - c)q_i$$

for all coalitions $S \subseteq N$, and $v(\phi) = 0$.

The definition above shows that a coalition of retailers benefit from a lower wholesale price per unit and a lower information costs, while a coalition including the supplier and information provider increases its profit due to the absence of the wholesale prices and the information costs. It is more attractive to cooperative with the information provider for the retailers and the supplier since $v(S_1) > v(S_0)$, $v(S_1) > v(S)$, $S \subseteq N$. This provides the companies in the chain with sufficient incentives for cooperation and that the information provider also has reasons to share the gain from cooperation with the retailers just as the supplier.

Lemma3.3 Let (N_1, v) be a game in e-commerce. Then

(i) $v(T \cup \{\mathrm{I}\}) \ge 0$ for all coalitions;

(ii) v is super-additive;

(iii) $v(T \cup \{\mathrm{I}\}) \ge v(T)$ for all $T \subseteq N$;

(iv) $v(S_1) = \sum_{i \in S} v(\{0, \mathrm{I}, i\})$ and $v(S_1) - v(S_1 \setminus \{i\}) = v(\{0, \mathrm{I}, i\})$ for all $S \subseteq N$ and $i \in S$.

Proof. (i)If $T = \{0\}$, then $v(T \cup \{\mathrm{I}\}) = v(\{0, \mathrm{I}\}) = 0$;

If $T \subseteq S$, then $v(T \cup \{\mathrm{I}\}) = \sum_{i \in S} (p_i(q_i^S) - w(q_S))q_i^S \ge 0$;

If $T \subseteq S_0$ and $T \subseteq S_1$, then $v(T \cup \{\mathrm{I}\}) = \sum_{i \in S} (p_i(q_i^c) - c)q_i^c \ge 0$;

(ii)Let $S, T \subseteq N$ be two disjoint coalitions of retailers, then

$$\begin{aligned} v(S) + v(T) &= \sum_{i \in S} (p_i\,(q_i^S) - w(q_S))q_i^S - t + \sum_{i \in T} (p_i\,(q_i^T) - w(q_T))q_i^T - t \\ &\le \sum_{i \in S} (p_i\,(q_i^{S \cup T}) - w(q_{S \cup T}))q_i^{S \cup T} + \sum_{i \in T} (p_i\,(q_i^{S \cup T}) - w(q_{S \cup T}))q_i^{S \cup T} - t \\ &= \sum_{i \in S \cup T} (p_i\,(q_i^{S \cup T}) - w(q_{S \cup T}))q_i^{S \cup T} - t = v(S \cup T) \end{aligned}$$

Furthermore

$$v(S_0) + v(T) = \sum_{i \in S_0} (p_i\,(q_i^c) - c)q_i^c - 2t + \sum_{i \in T} (p_i\,(q_i^T) - w(q_T))q_i^T - t$$

$$\leq \sum_{i\in S_0}(p_i\,(q_i^c)-c)q_i^c+\sum_{i\in T}(p_i\,(q_i^c)-c)q_i^T-t$$
$$=\sum_{i\in S_0\cup T}(p_i\,(q_i^c)-c)q_i^c-t=v(S_0\cup T)$$

and

$$v(S_1)+v(T)=\sum_{i\in S_0}(p_i\,(q_i^c)-c)q_i^c+\sum_{i\in T}(p_i\,(q_i^T)-w(q_T))q_i^T-t$$
$$\leq \sum_{i\in S_0}(p_i\,(q_i^c)-c)q_i^c+\sum_{i\in T}(p_i\,(q_i^c)-c)q_i^T$$
$$=\sum_{i\in S_0\cup T}(p_i\,(q_i^c)-c)q_i^c=v(S_1\cup T)$$

(iii)This follows from (ii) and the definition of the game.

(iv)These results follow from the definition of the game.

Obviously the game is not monotonic and does not satisfy the null property and symmetry. The first and third property in this lemma shows the important role of the information provider in the cooperation.

3.3 The core of the game

Recalling the properties of the characteristics v, the core of the game (N_1,v) can be described as follows:

Theorem 3.4 Let be the RSI-game. The core of this game equals

$$\mathrm{Core}(N_1,v)$$
$$=\{x\in \mathrm{R}^{n_1}\mid \sum_{i\in N_1}x_i=v(N_1);x_i\leq v(\{0,\mathrm{I},i\}),i\in N;\sum_{i\in S}x_i\geq v(S),S\subseteq N\}$$

Proof. Let $x\in \mathrm{Core}(N_1,v)$, $i\in N_1$. Then $\sum_{i\in N_1}x_i=v(N_1)$ and $\sum_{j\in N_1\setminus\{i\}}x_j\geq v(N_1\setminus\{i\})$.

Thus $x_i=v(N_1)-\sum_{j\in N_1\setminus\{i\}}x_j\leq v(N_1)-v(N_1\setminus\{i\})=v(\{0,\mathrm{I},i\})$.

Conversely, we only need to prove the following inequalities:

$x_0+\sum_{i\in S}x_i\geq v(S_0)$, $S\subseteq N$ and $x_1+\sum_{i\in S_0}x_i\geq v(S_1)$, $S\subseteq N_1$

The second inequality is obvious. We now prove the first inequality.

$$x_0+\sum_{i\in S}x_i=\sum_{i\in N_1}x_i-\sum_{j\in N_1\setminus S}x_j+x_0\geq v(N_1)-\sum_{j\in N_1\setminus S}v(\{0,\mathrm{I},j\})$$
$$=\sum_{i\in S}v(\{0,\mathrm{I},i\})\geq \sum_{i\in S}v(\{0,\mathrm{I},i\})-2t=v(S_0)\qquad \text{QED.}$$

Define the allocation $x^0(v)$ by $x_\mathrm{I}{}^0(v)=0$, $x_0{}^0(v)=0$, $x_\mathrm{i}{}^0(v)=v(\{0,\mathrm{I},i\})$, $i\in N$. It is easy to see that the allocation $x^0(v)\in \mathrm{Core}(N_1,\mathrm{v})$. We have the result:

Theorem 3.5 Let be the RSI-game. Then the game is balanced.

Since the supplier and the information provider get nothing, the allocation $x^0(v)$ is the worst possible core-allocation for the supplier and the information provider.

3.4 The solution of the game

In this section we adjust some properties of the solution for the RS-game to get a solution for the RSI-game.

The solution assigns a payoff for the supplier and the information provider and is an allocation. In addition to the properties (a)-(d) similar to that described by Luis, Ana and Judith[15], a single-value solution for RSI-game has the property(e).

(a)Efficiency: $\sum_{i\in N_1}\varphi_i(v)=v(N_1)$.

(b)Stability: $\sum_{i\in S}\varphi_i(v)\geq v(S)$ for all coalition $S\subseteq N$.

(c)Retailer reduction: $\varphi_i(v)=v(\{0,\mathrm{I},i\})-\dfrac{v(S_1^i)-v(S^i)}{s^i}$ for some coalitions $S^i\subseteq N$ and $i\in N$.

(d) Preservation of differences for retailers:

$\varphi_i(v)-\varphi_j(v)=v(\{0,\mathrm{I},i\})-v(\{0,\mathrm{I},j\})$ for all $i,j\in N$ with $i\neq j$.

(e) Share the reduction: $\varphi_{\mathrm{I}}(v)+\varphi_0(v)=\sum_{i\in N}\dfrac{v(S_1^i)-v(S^i)}{s^i}$.

Then we have the main result in the following theorem3.6:

Theorem3.6 Let (N_1,v) be an RSI-game. The unique solution $\varphi(v)$ on the class of RSI-game, satisfying(a)-(e) defined by

$$\varphi_i(v)=\begin{cases} n\alpha, & i=\mathrm{I},\\ n(\beta-\alpha), & i=0,\\ v(\{0,\mathrm{I},i\})-\beta, & i\in N,\end{cases}$$

where $\alpha=\max_{S\subseteq N,S\neq\phi}\dfrac{t}{s}$, $\beta=\min_{S\subseteq N,S\neq\phi}\dfrac{v(S_1)-v(S)}{s}$.

Corollary3.7 Let (N_1,v) be an RSI-game, $\varphi(v)$ is the solution of the game (N_1,v). Then $\varphi(v)\in\mathrm{Core}(N_1,v)$.

Corollary3.8 Let $\varphi(v)$ is the solution of the RSI-game. If $t=0$, then $\varphi(v)$ is the solution of the RS-game.

Example3.9 Let $N_1=\{\mathrm{I},0,1,2\}$, $t=2$, $c=4$, $p_1(q)=12-q$, $p_2(q)=20-q$ and

$$w(q)=\begin{cases} 10, & 1\leq q\leq 2\\ 4+\dfrac{8}{q}, & q>2\end{cases}$$

(N_1,v) is the corresponding game. Then

$$\varphi_{\mathrm{I}}(v)=4,\ \varphi_0(v)=14,\ \varphi_1(v)=7,\ \varphi_2(v)=55$$

4. CONCLUSIONS

The central problem that we have introduced is the behavior coordination between the members in the e-commerce supply chain with several retailers, one supplier and an information provider. All players have incentives to cooperate with each to reduce costs and increase profits. We analyze theses chains by means of cooperative game theory. The information provider plays an important role of in the cooperation. We show that the RSI-game has a nonempty core. A solution that recognizes the importance of the information provider in cooperation is given. These results imply that the companies in an e-commerce supply chain are willing to cooperate because there exists stable distributions of the joint profit.

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