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O2O 資訊共享平台對於供應鏈成本分擔效果之分析

Allocation of Cost Savings in an O2O Information-sharing Supply Chain

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中文摘要

隨著互聯網時代的到來，透過網路串起的共享經濟日漸崛起，資源共享成了供應鏈裡減少成本相當重要的議題，尤其是透過資訊共享，從大數據分析以及顧客關係等方式中去掌握需求，得以從下游精準地行銷到上游正確預測銷量進而在備貨上減少倉儲或者缺貨成本。過去在供應鏈管理上，也有許多廠商亟思如何透過結盟、消費資訊的共享來減少成本，然而卻尚未有文獻結合今日創新商業模式-線上線下 O2O(Online-to-offline)模式的優勢去解決成本分擔的問題，因此本研究將利用虛擬平台準確掌握消費者資訊的特點，透過資訊共享使整個供應鏈合作，以達到使上中下游大大縮減成本且共同分擔成本的效果。本研究提出合作賽局(Cooperative game)模型並利用夏普利值(Shapley value)結合班佐夫指數(Banzahf index)進行成本分擔之分析。此模型中包含 O2O 商業模式中，串聯線上使用者以及線下實體商店的虛擬資訊平台，以及供應鏈中的製造商、物流商、和零售商。為達到整個供應鏈體系中，四位參賽者共享需求資訊進而減少最大成本的目的，本研究首先找出結合實務、可行的合作架構。進而在合作賽局模型中，進行資訊共享後之期望成本分析，並且透過特徵函數去衡量不同合作架構下節省成本之效果。模型中，本研究期望能找到節省最大成本且穩定的合作架構，以增進參賽者進入合作模式的動機，因此再利用夏普利值結合班佐夫加權指數去進行不同參賽者間的成本分擔後，結合合作賽局中重要的核心概念一一檢驗合作架構的穩定性。最後，本研究提出數值案例分析，以了解需求資訊的準確度及有效性，針對不同合作架構下節省成本、參賽者成本分擔的影響。本研究提供了一個資訊共享的決策系統給零售供應鏈，四位參賽者能透過此決策系統權衡結盟後的成本節省效果、以及所分擔到的成本，再進行是否參與合作的決策。此決策系統能協助供應鏈上下游透過分享需求資訊，省下因為需求預測落差所造成的缺貨和存貨成本，有效提升整個供應鏈的效率，進而最終提升獲利。

關鍵字:資訊共享、成本節省、O2O 線上線下商業模式

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Abstract

This paper investigates how information sharing in O2O (online-to-offline) business model, in which the platform is a website or mobile application that acts as a liaison between physical stores and Internet users, influences allocation of cost savings of a four-player supply chain with an upstream supplier, a downstream retailer, logistics service provider and platform. We aim to maximize cost saving through information sharing in different coalitions of O2O business models, which take advantage of information sharing among demand and product-inventory data collected by the platform for increasing in-store sales. We analyze the effect of cost savings in various feasible coalitions followed by the computation of the expected cost incurred in various coalitions. This paper adopts the Shapley value and Banzahf index to allocate cost savings to associated stakeholders in the chain. We present numerical analysis to examine the impacts of information sharing on cost savings in different allocation scheme.

***Keywords*: Information sharing, Cost saving, O2O business model**

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Contents

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List of Figures

doi:10.6342/NTU201601306

List of Tables

doi:10.6342/NTU201601306

Chapter 1 Introduction

Cost savings have consistently been the important issue in the supply chain management. By reducing expenses, the players in a chain can increase profits quickly. Instead of cutting price for competing market share with red ocean strategy, the players in creative and cultural industry should seek to cut down cost as well as increase additional value at the same time with blue ocean strategy to increase competitive advantage. To minimize waste cost which results from duplication of resources, sharing and using products and services on an as-needed basis instead of owning them helps to increase the operation efficiency in the whole supply chain. That's the reason why for perfect storm of sharing economy which response validly to social and environmental challenges dominated by internet.

Since internet, network infrastructure of information, plays the main role of promotor of sharing economy, it motivates development of information sharing, the key of innovative industries these days. Therefore, the Internet has contributed to both increasing needs and opportunities for improved supply chain management (Lee, 2015). Information sharing, a coordinated effort between manufactures (M), logistics service providers (L), retailers (R), and moreover, platform (P), in e-commerce edge, increases transparency as well as transaction integrity, and reduce risk in price competition as well as information searching cost for operation. Through exchange of information, it helps innovative business models to emerge, expand the industry boundary as well as realize economic scale.

In conventional Taiwan's cultural creative industry, people usually regard cultural products as high art whose target market segment is professional art collectors. To promote Taiwan's culture with cultural and creative products to the public and even the whole world, we hope that we can increase market penetration rate by applying O2O

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(online-to-offline), one of the most popular business models that intrigues lots of interests, to integrate the virtual and real channel for competition in the electronic commerce (EC) world.

The key of the innovative model, O2O platform, with a website or mobile app that acts as a middleman between physical stores and internet users to transmit funds or data over the Internet, is to attract online users and direct them to physical stores in the offline realm. It is a combination of payment model and foot traffic generator for merchants and also creates offline purchases (Kang et al., 2015). Instead of selling souvenir directly to customers through traditional channel in a supply chain which does not share demand information, we are in pursuit of an innovative supply chain, where the manufacture, retailers and logistics service provider can cooperate with a business, who serves as an O2O platform to take over the responsibility of point of sale (POS) data from end customers, who place orders through virtual channel, as well as inventory levels, and sell products to customers for increasing in-store sales. Hence, in order to achieve supply chain efficacy, each channel member is expected to pay attention to cost savings and profit enlarging by collaborating on supply chain integration.

In this paper, we aim to find out how O2O business models can influence supply chain in an efficient way by information sharing. As the core of information flow system, virtual platform plays the role of congregating demand data as well as liaison of upstream supplier, downstream retailers and logistics provider. Therefore, we would like to know that under the structure of O2O business model, where the platform is necessary, how platform interacts with other players to maximize the allocation of cost savings in the whole supply chain, how information sharing is conducted in different coalitions, which coalitions bring more profits and maximize cost savings and what mechanism could distribute allocation of cost savings brought by coalitional schemes in an unique and efficient way to motivate and stabilize participants in coalitions.

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We explored the implications of game theory as a context for providing useful insights into the cooperative strategic decisions in our model. Firstly, we tried to indicate all the possible coalitions in O2O model, inclusive of virtual platform, to define the feasible number of paths of information flow and calculate every player's cost savings in different situation. The analysis helped to discover the influence of participation of players. Secondly, we calculate characteristic functions to find out all conditions in coalitions to ensure feasibility of cooperative mechanism and stability of every coalition.

To take an in-depth look into what the best ways are to approach decisions when there are multiple decision makers, each of them with different information, motives, and goals, we applied Shapley value to a four-player game. A solution concept that applies the Shapley value to cooperative games can calibrate empirical estimates of demand among coalition structures of multi-players that have significant power in prediction most of the time. Yet, in the practice, some infeasible coalitions shouldn't be counted. Thus, we apply Banzhaf index to complete our analysis of distribution of cost allocation.

Finally, we discuss the boundary conditions of our results as well as the implications for managerial and policy issues to enhance the market share and sales revenue of products so that consumers actively make purchases rather than passive purchase behaviors.

This paper is organized as follows. In §3, we present a model of an O2O business model supply chain with four-level players. By analyzing the retailer's, the logistics service provider, and the manufacturer's ordering decisions based on demand data exchanged through platform, we develop different coalitions with different information-transmission pathway to simulate real situations of information flow for achieving the optimal order-up-to level stakeholders in the chain. Moreover, we analyze

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the benefits (cost savings) of information sharing in different coalitions, and we try to determine which coalitions or players have significant impacts on the benefits of information sharing in characteristic form. After we get characteristic values, in §4, we present some conditions for cooperation in the four-level system to ensure the stability and feasibility of coalitions. On the other hand, we use Shapley value and Banzahf index to distribute cost allocations to stakeholders in the system to get a unique balance and reach maximum efficiency. In §5, we use some numerical results to prove the efficacy of the model on the benefit of information sharing. Also, we present and examine the impact of the demand process on the benefits of information sharing. The paper ends with a discussion.

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Chapter 2 Literature Review

In this section, we review related literature, which can be categorized into four streams: cooperative game theory, cost allocation, O2O business model, and information sharing. There exists academics and practitioners paying considerable attention to applying cooperative game theory to supply chain management problems. One type of cooperative game concerns achievement of lower inventory under demand uncertainty. Joint replenishments for multiple companies can be regarded as one of the continuously reviewed strategies in lots of papers. In this setting, a set of players, who face random demands of a single product, place a joint order before observing the demands. After the predicted demands are realized, the inventory is optimally allocated to the retailers and retailers can place joint orders to reduce setup costs. This issue has been studied by Zhang (2009), Timmer et al. (2013) and Moshe et al. (2012). More general models about inventory management with cooperative procurement are studied by Drechsel (2010).

The second type of collaborative game considers allocation of cost savings problem, especially logistics cost. Joint costs provide an incentive for the companies to cooperate due to that any group of companies having lower costs than the individual companies become popular issue discussed in supply chain management. In this setting, Cooperative game theory studies the class of games in which selfish players form collaborations to obtain greater benefits and cost savings of transmission instead of operating their industries independently. The investigation of fair allocation can be found in Okamoto (2008) dealing minimizing the total cost for units under their conflict in real-world situations with cooperative games. Examples of practical problem in transmission cost and solution proposals can be found in Lima (2008) dealing with losses and demands to generators network. The procedures of allocation of cost savings

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based on pricing mechanism of multiple goods is mentioned by Kru's (2000). Moghaddam (2009) discuss the method considering time difference based on the marginal costs and the production elasticity of input factors to achieve a pattern of allocation of cost savings. Under the assumption, the distinguished feature of their approach requires less iterative computations. Jia (2003) studied the coalitional scheme deciding profit allocation in the electric power markets, and they prove that coalitions can help to obtain best solutions for retailers. In this paper, the authors develop a methodology based on formation of coalitions to sell electricity to the customers more efficiently and economically. Obviously, selecting good coalitional schemes to obtain a lower total transportation cost needed to satisfy customer demand over the planning horizon with information sharing has been more and more important thing these days, with the development of internet.

Our paper deals with the type of cost savings-allocation cooperative game, which concerns the cost savings-allocation problem for an infinite time horizon information sharing model. This paper is closely related to Lee et al. (2000) and Leng (2009). We discuss these works briefly, since it will be referred to in the paper. The authors analyze the problem of allocating cost savings through sharing demand information in a chain. To find unique allocation scheme, both researches put emphasis on coalitional schemes in cooperative games, and then analyze expected cost as well as distribute cost savings among different players.

Their models are essentially the same as ours, with two key differences. In their models, the practice of information sharing does not combine the situations in the real world. However, to really apply the coalitional scheme on today's e-commerce era, we try to combine these cooperative concepts with innovative O2O business models.

On the other hand, through cooperation among different stakeholders, Cruijssen et al. (2007) discuss different coalitions correspond to identifying and exploiting win–win

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situations among companies at different levels of the supply chain in order to improve performance, platform economics would be the focus in our paper. Kang (2014) mentions that, since the core of our model, characterized by its information flow and cash flow on the line, as well as logistics and commerce flow off the line, greatly expanded the scope of business of e-commerce to store offline messages, we rely virtual platform, which plays the main role of reducing costs in the supply chain through sharing information to eliminate cost of information asymmetry among players and prevent forecast error of demand. Besides, to accurately practice the cooperative schemes in O2O business models, we eliminate some infeasible allocations to match platform economics, and we break the traditional rules about power of Shapley value. Instead, we adopt the Banzahf power index to cater to real conditions. K'oczy (2010) study the possibility to block formation of infeasible coalitions and discuss power of winning coalitions.

With an aim to realize cooperative models to discover truly effective coalitional schemes in the real world of internet era, we hope to develop methods of allocation of cost savings that obtain more cost savings through information sharing with virtual platform, which dominate the O2O business models with platform economics to coordinate virtual and real business fields.

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Chapter 3 Model Analysis

In this section, we first formally define the information shared by a coalition as the demand data obtained from the point of sale information system (POS) by the retailer and list our assumptions. Next, we identify all possible information-sharing coalitional structures for the supply chain and compute total cost savings for each possible coalition in which the participants share demand information faced by their downstream members.

3.1 Problem Description

To simplify the analysis, there is only a single product traded in the supply chain inclusive of four players. The upper stream of the supply chain is the manufacture, the logistics service provider stands for middle stream, the retailer is the downstream member and the platform plays the role of intermediary of information booth. The customers can reach the product information and place orders through the platform, then the platform retrieves demand information from end users and shares it with the upper stream manufacture, downstream retailer or logistics service providers to corporate for cost down and reach learning effects rapidly.

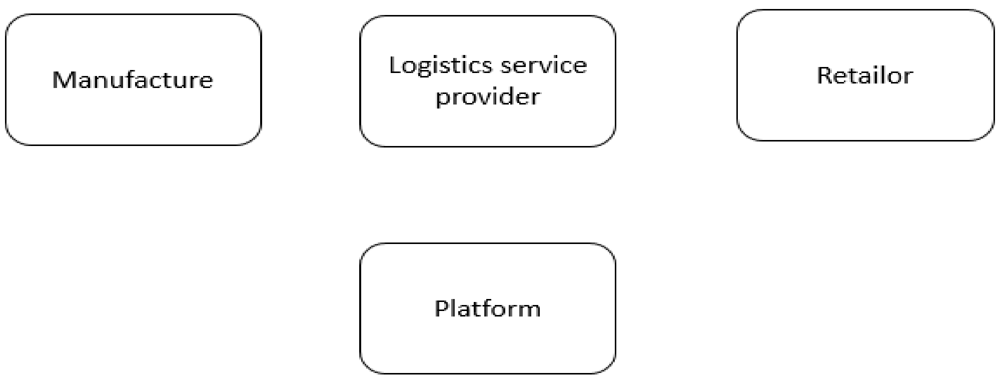

Figure 1. Four supply chain members P, M, L and R

doi:10.6342/NTU201601306

The demand data from ultimate customers is the most important piece of information worthy of sharing. We define the demand information shared in these coalitions as the demand data confronted with the platform and assume that the end demand is forecasted by the simple auto correlated AR(1) process:

$$D_t = d + \rho D_{t-1} + \varepsilon_t, \quad (1)$$

where D_t represents the consumption rate in period *t*, d is a positive contant, ρ is a autocorrelation parameter with $|\rho| \leq 1$ (*The value of information sharing in a two-level supply chain* (Lee et al. 2000) provided empirical evidence to show that for most products the autocorrelation coefficient ρ is positive.), and ε_t is the error term that is identically and independently distributed (i.i.d.) with a symmetric distribution (e.g., normal) having mean 0 and variance σ^2. After predicting the future demand, we treat the model as demand process for retailer's and manufacture's order quantity and compute cost savings generated by information sharing in this chapter. When $\rho = 0$, the end demand is reduced to $D_t = d + \varepsilon_t$, which is independent from the past demand information. In that way, end-demand information sharing of last term does not change the retailer's and the manufacture's ordering decisions.

We now derive the expression for the order-up-to-level C_t, that minimizes the total expected holding and shortage costs in period t. We assume the previous order is received in this term, and the retailer will make orders depend on demand of the last term. Therefore, the retailer's optimal order-up level C_t, at the end of period t is

$$C_t = d + \rho D_{t-1} + k\sigma, \quad (2)$$

doi:10.6342/NTU201601306

where $k = \emptyset^{-1}[s/(s+h)]$; h and s denote unit holding cost and the unit shortage cost respectively; $\emptyset^{-1}$ is the distribution function of the standard normal random variable (r.v.) (see Lee et al. 2000).

After considering the cost of demand data and clarifying the relationship between demand information and different players in the supply chain, we seek to find out the stable and effective coalitional structures for cost saving in the system. In the supply chain under study, platform is a mediator of O2O model, responsible for allocating sales information and consumer perception toward products, plays the leading role to control information flow and connect other players in the chain. As a result, in the whole possible coalitional structures, platform would never be absent in different feasible coalitions. In this case, we can find out seven feasible coalitions:

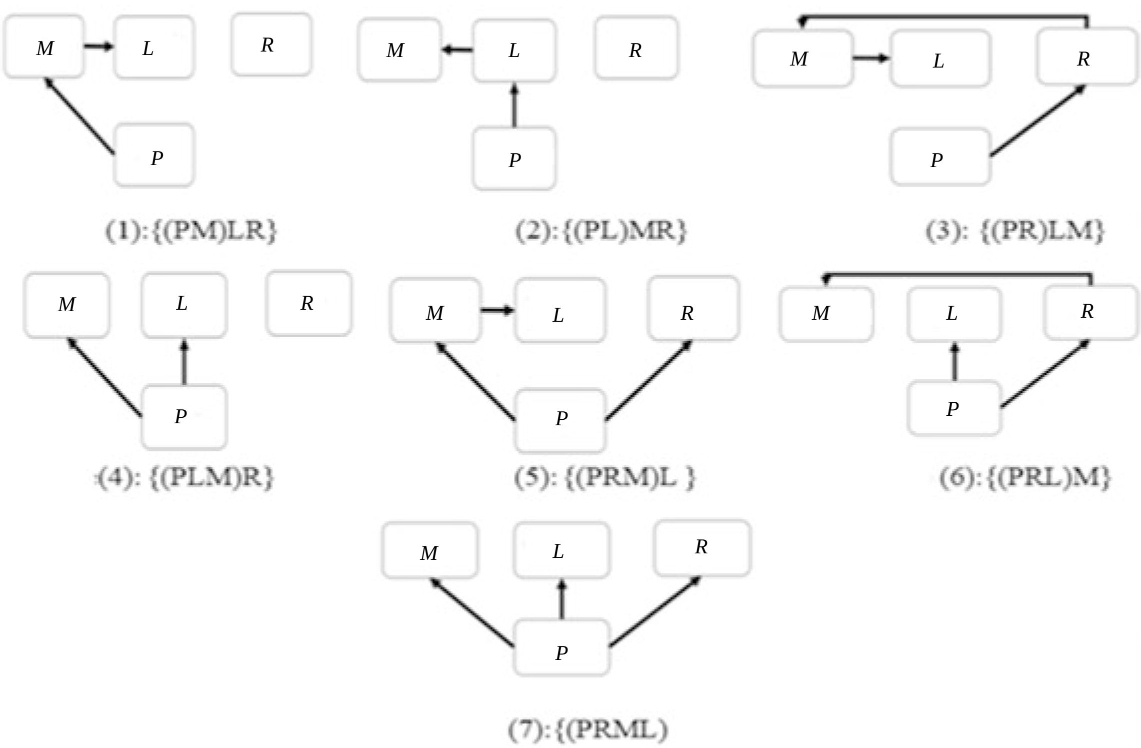

Figure 2. Feasible Information sharing structure for the four supply chain members P, M, L and R

doi:10.6342/NTU201601306

The paper examines the cases of specific allocation schemes to analyze the cost savings effects. Therefore, we still assume the original structure {P, M, L, R} as base to compare the difference of cost before cooperation with after cooperation which would be discussed later.

Figure 1 corresponds to the coalitional scheme {P, M, L, R}, prime condition before cooperation, that the supply chain members do not share end-demand information in original situation. For this case, the expected costs of the manufacturer, the logistics service provider, the retailer and the platform are $M_{P1},\ L_{P1},\ R_{p1},\ and$ PL_{p1} respectively.

To illustrate the examination, we refer to Figure 2 that depicts seven possible coalitional structures for information sharing among supply chain members. Figure 2 corresponds to the situation where platform and manufacture can form a two, three, or four-player coalitions. The manufacture can therefore receive end-demand information from the platform. In {(PM)LR} case, the expected costs of the manufacturer, the logistics service provider, the retailer and the platform are $M_{P2},\ L_{P2},\ R_{p2},\ and\ PL_{p2}$ respectively. The remaining parts Figure2 (2)-Figure2 (7) have similar interpretations.

To realize the goal of minimizing total cost in souvenir industry system where the players share demand information gained from platform which get orders and operate O2O service, we then compute the joint cost savings of each possible coalition which is equal to the sum of cost reductions incurred by all members in the coalition. Moreover, we aim to analyze cost savings for different allocation schemes and appropriately allocate expected cost savings in characteristic-function form in the next chapter.

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3.2 The Cost of Supply Chain Members in Different Coalitions

In the supply chain under study, as the innovative O2O business model is operated, the platform must be considered as the most important player in different coalition who leads the direction of information flow. Hence, after we identify all possible coalitional structures, we compute the unit cost of information sharing of the platform first.

Let $ic>0$ be the fixed operation cost of platform, which is spent on managing its customer relationship, search behavior and purchase intention and is larger than variable cost of other players; let the information transmission cost of platform without partners is 1, which stands for that the cost of coordinating information even there is no receiver. We also let r_{Pi} denote number of paths of information flow that the platform share with partners for coalition p_i. As constructing a database of customer relationship and maintaining a virtual platform would be an inevitable expenditure, the platform who expands its boundary to offer information service to more partners in the supply chain would realize economies of scale to decrease unit cost of operation of platform gradually. In this way, there would be inverse relationship between fixed information transmission cost of platform without partners plus number of paths of information flow for coalition p_i: $r_{Pi} + 1$, and fixed operation cost of platform, ic, then the unit cost of information sharing of the platform is

$$ic \cdot 1/(r_{Pi} + 1) \tag{3}$$

The reciprocity stands for economies of scale that can help the platform gain more profits and reduce average cost at the same time from sharing information with more partners (i.e. advertising income, commission from sale).

doi:10.6342/NTU201601306

While deciding the cost of manufacture, the set up cost in the lead time captures the effort involved in predicting future demand for retailers over time and based on users' characteristics as well as outcome measurements. However, since the manufacturer is the most upstream member, we assume that it can make decisions on production quantity at will without interference from other players. This helps us to compute the expected cost of manufacture more accurately.

The production plan scheduled by manufacture relies on the actual demand at the end of the period t-1, so we make set up cost in the leading time in the coalition structure p_i be based on retailer's orders in the previous term. Let s_m be the shortage cost at manufacture's level per unit and h_m be the holding cost at manufacture's level per unit. The set up cost would be unit holding cost h_m or shortage cost s_m multiplied by retailer's order up level, the base stock level, in the previous term C_{t-1} and growth rate of order, $\frac{C_t - C_{t-1}}{C_{t-1}}$, since manufacture usually prepares stock for orders in current period, yet retailer sells current order in next term. In this case, the cost of manufacture without receiving and transmitting information is

$$s_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \text{ if } D_t \geq C_{t-1} \tag{4}$$

$$-h_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \text{ if } D_t < C_{t-1} \tag{5}$$

Practically, manufactures usually schedule their production plan according to retailer's orders in the previous term C_{t-1}, therefore, growth rate of order $\frac{C_t - C_{t-1}}{C_{t-1}}$, represents the rate of difference between current orders and production plan, equal to holding rate or shortage rate of manufacture.

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For the logistics service provider, let *tc* be the truck capacity and *Tr* be the transportation cost per path and per truck capacity. Let L_{pi} be the number of paths of logistics flow that a truck runs for in coalitional scheme pi. In this model, we fix L_{pi} at two due to consideration of receiving goods from the manufacture and delivering goods to the retailer. We assume that there would be only one truck in transit at one time, then the cost of logistic providers is

$$Tr \cdot L_{pi} \cdot tc. \tag{6}$$

On the other hand, if the retailor prepares stock up based on orders of last term, they would confront with holding cost and shortage cost in current period. We let $C_t = d + \rho D_{t-1} + k\sigma$ be retailer's order-up-to level in current period *t*. In this way, both kinds of cost are computed through multiplying order up level in the previous term, C_{t-1} , and growth rate of order, $\frac{C_t - C_{t-1}}{C_{t-1}}$, is equal to holding or shortage rate of retailor in current period, to obtain the quantity of holding or shortage. Let s_r be the shortage cost at retailer's level per unit, and let h_r be the holding cost at retailer's level per unit. As a result, total cost of retailor in the supply chain is

$$s_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \text{ if } D_t \geq C_{t-1}, \tag{7}$$

$$-h_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \text{ if } D_t < C_{t-1}, \tag{8}$$

where h_r stands for unit holding cost and s_r stands for shortage cost at retailer's level.

Therefore, the minimize cost function in different coalitional structure p_i is

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$$Min\ \ [(Tr \cdot L_{pi} \cdot tc) + (s_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}}) + (s_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}}) + (ic \cdot \frac{1}{r_{Pi}+1})]\ \text{ if }\ D_t \geq C_{t-1},$$

$$Min\ \ [(Tr \cdot L_{pi} \cdot tc) - (h_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}}) - (h_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}}) + (ic \cdot \frac{1}{r_{Pi}+1})]\ \text{ if }\ D_t < C_{t-1}.$$

However, since our model put emphasis on influence on cost of information sharing, therefore we let $|\delta|, |\alpha| \leq 1$ be a revise cost due to information sharing. Whenever a player (i.e. manufacture or retailer) receives information from others, it can prevent some error of prediction. Therefore, its unit cost can be (1-δ) times smaller than the original one; in this way the cost of manufacture with reception of information is

$$s_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot\ (1-\delta)\ \text{ if }\ D_t \geq C_{t-1}, \tag{9}$$

$$-h_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot\ (1-\delta)\ \text{ if }\ D_t < C_{t-1} \tag{10}$$

Similarly, total cost of retailor in the supply chain with reception of information is

$$s_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot\ (1-\delta)\ \text{ if }\ D_t \geq C_{t-1}, \tag{11}$$

$$-h_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot\ (1-\delta)\ \text{ if }\ D_t < C_{t-1}. \tag{12}$$

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Otherwise, if a player gives information to others, it might lose some advantages of private information. In this case, its cost would be (1+α) times larger than the original one due to constructing information network among different players in the supply chain; in this way the cost of manufacture with transmission of information is

$$s_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \ \text{ if } \ D_t \geq C_{t-1}, \tag{13}$$

$$-h_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \ \text{ if } \ D_t < C_{t-1}. \tag{14}$$

Similarly, total cost of retailor in the supply chain with transmission of information is

$$s_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \ \text{ if } \ D_t \geq C_{t-1}, \tag{15}$$

$$-h_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \ \text{ if } \ D_t < C_{t-1}. \tag{16}$$

Obviously, if a player gives information and receives information from others at the same time, then the cost of manufacture is

$$s_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \cdot (1-\delta) \ \text{ if } \ D_t \geq C_{t-1}, \tag{17}$$

$$-h_m \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \cdot (1-\delta) \ \text{ if } \ D_t < C_{t-1}. \tag{18}$$

Similarly, total cost of retailor is

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$$s_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \cdot (1-\delta) \ \text{ if } \ D_t \geq C_{t-1}, \tag{19}$$

$$-h_r \cdot C_{t-1} \cdot \frac{C_t - C_{t-1}}{C_{t-1}} \cdot \ (1+\alpha) \cdot (1-\delta) \ \text{ if } \ D_t < C_{t-1}. \tag{20}$$

Now we compute the cost of each participants in different coalitional schemes (i.e., $M_{P1}, \ldots, M_{P8}, L_{P1}, \ldots, L_{P8}, PL_{P1}, \ldots, PL_{P8}, R_{P1}, \ldots, R_{P8}$) for all eight coalitional structures shown in the Table 1.

Table 1. The expected cost of four players for each coalitional structure

Coalitional schemes	Cost of manufacture	Cost of platform	Cost of Logistics service provider	Cost of retailor
{P, M, L, R}	M_{P1}	PL_{P1}	L_{P1}	R_{P1},
{(PM)LR}	M_{P2}	PL_{P2}	L_{P2}	R_{P2}
{(PL)MR}	M_{P3}	PL_{P3}	L_{P3}	R_{P3}
{(PR)ML}	M_{P4}	PL_{P4}	L_{P4}	R_{P4}
{(PML)R}	M_{P5}	PL_{P5}	L_{P5}	R_{P5}
{(PMR)L}	M_{P6}	PL_{P6}	L_{P6}	R_{P6}
{(PLR)M}	M_{P7}	PL_{P7}	L_{P7}	R_{P7}
{(PMLR)}	M_{P8}	PL_{P8}	L_{P8}	R_{P8}

Coalition {P, M, L, R}:

The situation before cooperation, where every member in the supply chain does not save any cost, is unreasonable in practice due to the fact that the platform would not exist independently. However, we still assume it to be the prime state, where each player

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in the coalitions operates their own business with original cost, to compare allocation of cost savings with other coalitional schemes.

Total cost =

$$
\begin{cases}
(Tr \cdot 2 \cdot tc) + \left(s_m \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}\right) + \left(s_r \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}\right) \\
\qquad + \left(ic \cdot \dfrac{1}{r_{Pi} + 1}\right) \text{if } D_t \geq C_{t-1} \\
(Tr \cdot 2 \cdot tc) - (h_m \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}) - (h_r \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}) \\
\qquad + (ic \cdot \dfrac{1}{r_{Pi} + 1}) \text{ if } D_t < C_{t-1}
\end{cases}
$$

Coalition {(PM)LR}:

In the coalition {(PM)LR}, the platform only shares information with manufacture provider. Then the manufacture would transmit information of customer orders to the logistics provider, so that logistics provider can conduct transport management and schedule for the transport process to retailer. Thus, the information sharing also occur among *L* and *M*.

Total cost =

$$
\begin{cases}
[Tr \cdot (1 - \delta) \cdot 2 \cdot tc] + \left[s_m \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}} \cdot (1 - \delta) \cdot (1 + \alpha)\right] \\
\qquad + \left[s_r \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}\right] + \left[ic \cdot \dfrac{1}{2}\right] \text{ if } D_t \geq C_{t-1} \\
[Tr \cdot (1 - \delta) \cdot 2 \cdot tc] - [h_m \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}} \cdot (1 - \delta) \cdot (1 + \alpha)] \\
\qquad - [h_r \cdot C_{t-1} \cdot \dfrac{C_t - C_{t-1}}{C_{t-1}}] + [ic \cdot 1/2] \text{ if } D_t < C_{t-1}
\end{cases}
$$

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Coalition {(PL)MR }:

In the coalition {(PL)MR}, the platform only shares information with logistics provider. Then the logistics provider would transmit information of customer orders to the manufacture, so that manufacture would prepare stock accurately for retailer's orders. Thus, the information sharing also occurs among *L* and *M*.

Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot(1+\alpha)\cdot 2\cdot tc]+\left[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\right] \\ \quad +\left[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\right]+\left[ic\cdot\dfrac{1}{2}\right] \text{ if } D_t\geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot(1+\alpha)\cdot 2\cdot tc]-\{h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\} \\ \quad -\{h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\}+\{ic\cdot 1/2\} \text{ if } D_t< C_{t-1} \end{cases}$$

Coalition {(PR)ML}:

In the coalition {(PR)ML}, the platform only shares information with retailer. Since only the downstream firm get demand information, the retailer would give orders up to the manufacture in preparation for stock. Then the manufacture would transmit information of customer orders to the logistics provider. In this way, the logistic provider can conduct transport management and schedule for the transport process. Thus, the information sharing also occur among *R, L* and *M*.

doi:10.6342/NTU201601306

Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]+\left[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)\right] \\ +\left[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)(1+\alpha)\right]+\left\{ic\cdot\dfrac{1}{2}\right\} \text{ if } D_t\geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]-[h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)] \\ -[h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)(1+\alpha)]+\{ic\cdot 1/2\} \text{ if } D_t<C_{t-1} \end{cases}$$

Coalition {(PML)R}:

In the coalition {(PML)R}, the platform shares information with manufacture and logistic provider. Since they get enough information, the logistic provider can conduct transport management and schedule for the transport process right after receiving products from the manufacture. Besides, it could directly ship the orders to retailer, and the customer can just pick up their products faster. In this case, the retailer plays a passive role and does not have to make orders to the manufacture due to that the manufacture already has demand information.

Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]+\left[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\right] \\ +\left[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\right]+\left\{ic\cdot\dfrac{1}{3}\right\} \text{ if } D_t\geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]-[h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)] \\ -[h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}]+\{ic\cdot 1/3\} \text{ if } D_t<C_{t-1} \end{cases}$$

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Coalition {(PMR)L}:

In the coalition {(PMR)L}, the platform shares information with manufacture and retailor. After getting the demand information from platform, the manufacture would transmit information of customer orders to the logistics provider. In this way, the logistic provider can conduct transport management and schedule for the transport process to deliver goods on time to retailor. Thus, the information sharing occurs among *R*, *L* and *M*.

Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc] + \left[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)\right] \\ \quad + \left[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\right] + \left\{ic\cdot\dfrac{1}{3}\right\} \text{if } D_t \geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc] - \left[h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)\right] \\ \quad - \left[h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\right] + \{ic\cdot 1/3\}\; if\; D_t < C_{t-1} \end{cases}$$

Coalition {(PLR)M}:

In the coalition {(PLR)M}, the platform shares information with logistics provider and retailor. After getting the demand information from platform, the retailer would give orders up to the manufacture. Thus, the information sharing occur among *L*, *R* and *M*.

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Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]+[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)] \\ +[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)]+\{ic\cdot 1/3\}\ \text{if}\ D_t\geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]-[h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)] \\ -[h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)\cdot(1+\alpha)]+\{ic\cdot 1/3\}\ \text{if}\ D_t< C_{t-1} \end{cases}$$

Coalition {(PMLR)}:

In the coalition {(PMLR)} which would fully exert its effect of information sharing, the platform would disseminate demand information to other three players. In the case, the other three players can save the cost of transmitting information to each other. At the same time, the platform can play the full role of information coordinator and realize economies of scale of information sharing.

Total cost=

$$\begin{cases} [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]+[s_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)] \\ +[s_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)]+\{ic\cdot 1/4\}\ \text{if}\ D_t\geq C_{t-1} \\ [\mathrm{Tr}\cdot(1-\delta)\cdot 2\cdot tc]-[h_m\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)] \\ -[h_r\cdot C_{t-1}\cdot\dfrac{C_t-C_{t-1}}{C_{t-1}}\cdot(1-\delta)]+\{ic\cdot 1/4\}\ \text{if}\ D_t< C_{t-1} \end{cases}$$

Proposition 1. *The unit cost of information sharing of the platform* PL_{Pi}, *i=1,...,8 have the characteristic of economic scale that* $PL_{P1} > PL_{P2} = PL_{P3} = PL_{P4} > PL_{P5} = PL_{P6} = PL_{P7} > PL_{P8}$.

doi:10.6342/NTU201601306

Proof.

In the four-player cooperative game, there are eight coalitions, i.e., {P, M, L, R} {(PL)MR},{(PM)LR},{(PR)LM},{(PML)R},{(PLR)M},{(PMR)L},{(PMLR)}. With the definition of the unit cost of information sharing of the platform, we can calculate PL_{Pi} with (3) and get that:

$$PL_{P1} = ic \cdot \frac{1}{1},$$

$$PL_{P2} = ic \cdot \frac{1}{2} = PL_{P3} = PL_{P4},$$

$$PL_{P5} = ic \cdot \frac{1}{3} = PL_{P6} = PL_{P7},$$

$$PL_{P8} = ic \cdot \frac{1}{4}.$$

From a straightforward comparison of PL_{Pi}, i=*1,...,8*, it is easy to see that as members of a coalition increase, the unit cost of information sharing of the platform would decrease. The unit cost of the platform of the grand coalition is smaller than that of three-player coalitional structures, which are smaller than two-player coalitional structures' unit cost of the platform. That is to say, it has the property of economic scale, the cost advantages that platform obtains due to size of coalitional structure, as fixed operation costs are spread out over more supply chain members.

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Chapter 4 Analysis and Discussion

4.1 Model and Analysis of the Cooperative Game

To find the characteristic-function values of various coalitions, we compute total cost savings for each possible coalition in which the participants share demand information faced by their downstream members in the last section. Then in this part, we develop a cooperative game in characteristic-function form as well as analyze models to find the appropriate allocation scheme which "fairly" allocating expected cost savings for stakeholders in the supply chain.

In our paper, we discuss the problem of O2O model, a business strategy that draws potential customers from online channels to physical stores. In our game model, we consider the e-commerce platform to be the virtual channel, which plays the most important intermediary in the business model. Therefore, we are not going to discuss the situations that a subset of players forms some coalitions exclusive of the platform. In that way, the allocation of cost savings among those players, exclusive of online platform, would deviate from our main goal of discussing with the influence of information sharing through virtual platform in cost allocation, one of the main competitive strengths of O2O business. As a result, in this paper, the definition of O2O coalition is given as follows:

Definition 1.

In the O2O business information-coordinated cooperative game, a scheme for allocating cost savings among all members in supply chain in a coalition is valid only if the platform, online channel, is inclusive in any multi-player coalitions and plays the coordinator of information sharing.

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4.2 An O2O Cooperative Game in Characteristic Function

A cooperative game is given by specifying a value for every coalition. Formally, the (coalitional game) consists of a finite set of players *N*, called the grand coalition. In our paper, the grand coalition is a four-person game. In practice, with the definition of O2O model which always includes online channel, we can obviously define some coalitions as infeasible coalitions and block them from all possible sets of players. Therefore, we still have seven feasible coalitions:

{(PL)MR}, {(PM)LR}, {(PR)LM}, {(PML)R}, {(PLR)M}, {(PMR)L}, {(PMLR)}.

In the theory of cooperative games, the characteristic value is the minimum collective payoff that the coalition can attain with a set of players. In our paper, the characteristic value of a coalition is the amount of cost saving and improvements in profits the coalitions could at least attain from its own effort when the coalitions is feasible in O2O model: v(PL), v(PM), v(PR), v(PMR), v(PML), v(PLR), v(PMLR).

A characteristic function $v\colon 2^N \to \mathbb{R}$ from the set of all possible coalitions of players to a set of cost allocations that satisfies $\mathrm{v}(\emptyset) = 0$. The function describes how much cost allocations a set of players can save by forming a coalition. Even more, after we get characteristic values, we will present some conditions for cooperation in the four- level system to ensure the stability and feasibility of coalitions. On the other hand, we use Shapley value and Banzahf index to distribute cost allocations to stakeholders in the system to get unique allocation scheme.

We now compute the characteristic values of all possible coalitions. First, the characteristic value of an empty coalition is naturally zero: $\mathrm{v}(\emptyset) = 0$.

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Next, we are going to discuss single-player coalitions. According to the definition of O2O business information-coordinated cooperative game, there is no possibility that the platform independently exists under the condition that other members but it make up coalitions. If other player in the supply chain can coordinate and getting better result of allocation of cost savings without involvement of platform, then the business model of O2O would not be efficient. In that case, the platform would be a meaningless dummy player, and there is no need for constructing the platform. Therefore, the value of v(P), the minimum amount the coalition with only platform can attain using its own efforts, would be zero.

On the other hand, when the retailer, manufacture, or logistics service provider does not share information with other members in the system, characteristics value of each member: v(M), v(L), v(R) depends on whether other members but itself share demand information. If they don't share information with each other, then the individuals will have no cost savings, and the characteristics value is zero. Otherwise, the cost savings they can at least get under the cooperation of other members will be presented as follows:

$$\mathrm{v(M)} = \min(M_{P1} - M_{P3}, M_{P1} - M_{P4}, M_{P1} - M_{P7}, 0),$$

$$\mathrm{v(L)} = \min(L_{P1} - L_{P2}, L_{P1} - L_{P4}, L_{P1} - L_{P6}, 0),$$

$$\mathrm{v(R)} = \min(R_{P1} - R_{P2}, R_{P1} - R_{P3}, R_{P1} - R_{P5}, 0).$$

As mentioned above, the characteristic function of p does not exist: $\mathrm{v(P)}=0$.

Next, we consider other feasible two-player coalitions in the O2O business model: the characteristic value v(PM) of the coalition {(PM)LR} is the minimum expected allocation of cost savings that the two players can create when only they cooperate.

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Therefore, the retailer and the logistics service provider don't share demand information with each other. Thus, we can get the value:

$$\mathrm{v(PM)} = \text{ Min }[(PL_{P1}-PL_{P2}),\left(PL_{p1}-PL_{p5}\right),\left(PL_{p1}-PL_{p6}\right)] + \text{Min }[(M_{P1}-M_{P2}),(M_{P1}-M_{P5}),(M_{P1}-M_{P6})].$$

Also, the characteristics functions of other feasible coalitions: $\mathrm{v(PR)}$, $\mathrm{v(PL)}$, are calculated as follows:

$$\mathrm{v(PR)} = \text{Min }[(PL_{P1}-PL_{P4}),\left(PL_{p1}-PL_{p6}\right),\left(PL_{p1}-PL_{p7}\right)] + \text{Min }[(R_{P1}-R_{P4}),(R_{P1}-R_{P6}),(R_{P1}-R_{P7})],$$

$$\mathrm{v(PL)} = \text{Min }[(PL_{P1}-PL_{P3}),\left(PL_{p1}-PL_{p5}\right),\left(PL_{p1}-PL_{p7}\right)] + \text{Min }[(L_{P1}-L_{P3}),(L_{P1}-L_{P5}),(L_{P1}-L_{P7})].$$

Now we consider the three-member coalitions and the grand four-player coalition. The characteristic value $\mathrm{v(PML)}$ of the coalition {(PML)R} is the minimum expected allocation of cost savings that the three players can create when only they cooperate. Therefore, we calculate the cost savings incurred at the manufacture, platform and logistics service provider level. In this case, the retailer does not share demand information with any other member. Then when the other three members share information with each other, they can gain the expected cost savings:

$$\mathrm{v(PML)}=\left(PL_{p1}-PL_{p5}\right) + (M_{P1}-M_{P5}) + (L_{P1}-L_{P5}).$$

Similarly, when calculating the coalitions v(PMR), v(PLR) & v(PMLR), we can get:

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$$v(\text{PMR}) = \left(PL_{p1} - PL_{p6}\right) + (M_{P1} - M_{P6}) + (R_{P1} - R_{P6}),$$

$$v(\text{PLR}) = \left(PL_{p1} - PL_{p7}\right) + (L_{P1} - L_{P7}) + (R_{P1} - R_{P7}),$$

$$v(\text{PMLR}) = \left(PL_{p1} - PL_{p8}\right) + (L_{P1} - L_{P8}) + (R_{P1} - R_{P8}) + (M_{P1} - M_{P8}).$$

4.3 Evaluation of Stability of O2O Coalition Scheme

We now analyze the cooperative game to realize the stability of possible coalitions. A coalition will be stable only if leaving the coalitions makes it worse off. In our game model, we consider the problem of fairly allocating cost savings among multi players under the condition of stability. Only if the coalition is stable, then the members in the coalition accept the allocation of cost savings and have no incentive to deviate. On the other hand, if the coalition is unstable, then the members might deviate to seek for more profits, or there would be no incentive for independent members to join coalitions due to uncertainty of that if others will stay in the collaborative scheme. We first find necessary conditions for stability of different coalitions.

Proposition 2. *The necessary conditions for stability of each coalition in the cooperative game are given as follows:*

(1) The grand coalition {(PMLR)} is stable only if:

$$v(PMLR) \geq max\{v(P) + v(L) + v(M) + v(R),\ (M_{P1} - M_{P3}\ or\ M_{P1} - M_{P7}) + v(PLR),\ (L_{P1} - L_{P2}\ or\ L_{P1} - L_{P6}) + v(PMR), 0 + v(PML)\}\ and$$

$$v(PMLR) \geq \omega_P + \omega_L + \omega_R + \omega_m,$$

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where

$$\omega_m = \begin{cases} M_{P1}-M_{P3} \; or \; M_{P1}-M_{P7}, & If \; v(PLR) \geq v(L)+v(PR), v(R)+v(PL), v(L)+v(R)+v(P) \\ & and \; v(PR) \geq v(P)+v(R), v(PL) \geq v(P)+v(L) \\ 0, & o,w, \end{cases},$$

$$\omega_L = \begin{cases} L_{P1}-L_{P2} \; or \; L_{P1}-L_{P6}, & If \; v(PMR) \geq v(M)+v(PR), v(R)+v(MP), v(M)+v(R)+v(P) \\ & and \; v(PR) \geq v(P)+v(R), v(PM) \geq v(P)+v(M) \\ 0, & o,w, \end{cases},$$

$\omega_R = 0,$

$\omega_P = 0.$

(2) the coalition{(PML)R} is stable only if :

$$v(R)+v(PML) \geq v(PMLR), v(PML) \geq v(M)+v(PL), v(PL) \geq v(L),$$
$$v(PML) \geq v(L)+v(PM) \,\&\, v(PM) \geq v(M).$$

(3) the coalition{(PMR)L} is stable only if:

$$v(L)+v(PMR) \geq v(PMLR), v(PMR) \geq v(R)+v(PM), v(PM) \geq v(M),$$
$$v(PMR) \geq v(M)+v(PR) \,\&\, v(PR) \geq 0.$$

(4) the coalition{(PLR)M} is stable only if:

$$v(M)+v(PLR) \geq v(PMLR), v(PLR) \geq v(L)+v(PR), v(PR) \geq v(R), v(PLR) \geq$$
$$v(R)+v(PL) \,\&\, v(PL) \geq v(L).$$

(5) the coalition {(PM)RL} is stable only if:

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$$v(L)+v(PM) \ge v(PML),\ v(R)+v(PM) \ge v(PMR)\ \&\ v(PM) \ge v(M).$$

(6) the coalition {(PL) MR} is stable only if:

$$v(M)+v(PL) \ge v(PML),\ v(R)+v(PL) \ge v(PLR)\&\ v(PL) \ge v(L).$$

(7) the coalition {(PR) ML} is stable only if:

$$v(L)+v(PR) \ge v(PRL),\ v(M)+v(PR) \ge v(PMR)\ \&\ v(PR) \ge v(R).$$

(8) the coalition {P,M,R,L} is stable only if any other coalition is unstable

Proof.

In the O2O four-player information sharing game, there are eight possible coalitions:

{P, L, M, R}, {(PM)LR}, {(PL)MR}, {(PR)LM}, {(PML)R}, {(PMR)L}, {(PRL)M}, {(PRML)}.

A coalition will be stable only if leaving the coalition will makes a player worse off. Firstly, we are going to analyze the stability of the grand coalition:

1. the grand coalition would be stable only if the following criteria are satisfied:

   the allocation of cost savings incurred by the grand coalition are no less than those achieved in any other coalitions involved with platform. Therefore, the following conditions must be satisfied to cater to the quality of stability: $(M_{P1}-M_{P3}\ or\ M_{P1}-M_{P7})+$ v(PLR), $(L_{P1}-L_{P2}\ or\ L_{P1}-L_{P6})+$ v(PMR), 0+ v(PML); above all, the condition: v(PLMR) $\ge$ v(P)+v(L)+v(M)+v(R). The grand coalition would

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definitely be no less than sum of the characteristic value of the coalition with only one member, or the members in grand coalition would lose the motivation to compose grand coalition. That is, if a coalition existing generates higher cost savings, we cannot find an allocation scheme to make the grand coalition stable. However, the goal of stability conditions of grand coalition is to make none of the players in the grand coalition has an incentive to leave.

Next, we consider the rest conditions of grand coalition. When one of the players, i.e., the manufacture, does not join the coalition, there might be two situations:

If $\mathrm{v(PLR)} \geq \mathrm{v(L)} + \mathrm{v(PR)}$ and $\mathrm{v(PR)} \geq \mathrm{v(P)} + \mathrm{v(R)}$,

$\mathrm{v(PLR)} \geq \mathrm{v(R)} + \mathrm{v(PL)}$ and $\mathrm{v(PL)} \geq \mathrm{v(P)} + \mathrm{v(L)}$,

$\mathrm{v(PLR)} \geq \mathrm{v(L)} + \mathrm{v(R)} + \mathrm{v(P)}$, the retailer and logistics service provider would choose to stay in the three-player coalition {(PLR)M}, so the manufacture incurs cost saving of $M_{P1}-M_{P3}\ or\ M_{P1}-M_{P7}$; otherwise, the three-player coalition would be unstable and might change to three single-player games or two-player games, in this way, the manufacture's cost savings is zero.

As mentioned above, in the situation of manufacture leaving the grand coalition, then we can get its cost savings:

$$\omega_m = \begin{cases} M_{P1}-M_{P3}\ or\ M_{P1}-M_{P7}, & \text{If } \mathrm{v(PLR)} \geq \mathrm{v(L)} + \mathrm{v(PR)}, \mathrm{v(R)} + \mathrm{v(PL)}, \mathrm{v(L)} + \mathrm{v(R)} + \mathrm{v(P)} \\ & \text{and } \mathrm{v(PR)} \geq \mathrm{v(P)} + \mathrm{v(R)}, \mathrm{v(PL)} \geq \mathrm{v(P)} + \mathrm{v(L)} \\ 0, & \mathrm{o,w,} \end{cases}$$

Similarly, we can write ω_L as

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$$\omega_L = \begin{cases} L_{P1} - L_{P2} \ or\ L_{P1} - L_{P6}, & \text{If } v(PMR) \geq v(M) + v(PR), v(R) + v(MP), v(M) + v(R) + v(P) \\ & \text{and } v(PR) \geq v(P) + v(R), v(PM) \geq v(P) + v(M) \\ 0, & o, w, \end{cases}$$

However, since the original characteristic value of platform or retailer is zero in every situation; needless to say, $\omega_R\ and\ \omega_P$ would also be zero in the situation of that they leave the grand coalition. Thus, the second condition for the stability of the grand coalition is v(PMLR) ≥ $\omega_P + \omega_L + \omega_R + \omega_m$, which assures that no players would deviate from the coalition.

2. the stability of the three- player coalitions:

   the three-player coalitions would be stable only if the following two criteria are satisfied:

a. total cost savings incurred by all players in the coalition{(PML)R}, are no less than the cost savings of grand coalition, or the retailer won't deviate from grand coalition:

$$v(R) + v(PML) \geq v(PMLR).$$

b. each player in the three-player coalition{(PML)R} will be worse off if it leaves the coalition:

$$v(PML) \geq v(M) + v(PL)\ \&\ v(PL) \geq v(L),$$

$$v(PML) \geq v(L) + v(PM)\ \&\ v(PM) \geq v(M),$$

$$v(PML) \geq v(L) + v(M) + v(P).$$

The analysis of coalitions {(PMR)L}, {(PLR)M} is similar.

3. the stability of the two- player coalitions:

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the two-player coalition would be stable only if the following two criteria are satisfied:

a. total cost savings incurred by all players in the coalition{(PM)LR} are no less than the cost saving of three-player coalition, or the logistics or the retailer company won't deviate from the three-player coalitions:

$$v(L)+ v(PM) \geq v(PML),$$
$$v(R)+ v(PM) \geq v(PMR).$$

b. each player in the two-player coalition{(PM)LR} will be worse off if it leaves the coalition:

$$v(PM) \geq v(M).$$

The analysis of coalitions {(PR)ML}, {(PL)MR} is similar.

4. The coalition {P, L, M, R} would be stable only if any other coalition is unstable.

Thus, we can get whole necessary conditions for stability of each coalition in the O2O cooperative game.

Proposition 3. *Under the examination of exclusiveness of all the stable condition mentioned above,*

(1) *when any of the grand player coalitional schemes of O2O business model is stable, then the three-player coalitional schemes which include the same members must be unstable;*

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(2) *when any of the three-player coalitional schemes of O2O business model is stable, then the two-player and grand player coalitional schemes which include the same members must be unstable;*

(3) *when any of the two-player coalitional schemes of O2O business model is stable, then the one-player and three-player coalitional schemes which include the same members or the grand coalition must be unstable.*

Proof.

(1) When we take a look at the relationship between grand coalition and three-player coalition, we can find that the stable condition of grand coalition {(PMLR)} is

$$\text{v(PMLR)} \geq \max\{\text{v(P)+v(L)+v(M)+v(R)}, (M_{P1}-M_{P3}\ or\ \ M_{P1}-M_{P7}) + \text{v(PLR)}, (L_{P1}-L_{P2}\ or\ \ L_{P1}-L_{P6} + \text{v(PMR)}, 0+\text{v(PML)}\}.$$

Yet, the stable condition of three-player coalition{(PML)R} is v(R)+v(PML) ≥ v(PMLR), the stable condition of three-player coalition{(PMR)L} is v(L)+v(PMR) ≥ v(PMLR) and the stable condition of three-player coalition{(PLR)M} is v(M)+v(PLR) ≥ v(PMLR).

(2) When we take a look at the relationship between three-player and two-player coalitions, we can find that the stable condition of three-player coalition {(PML)R} is

$$\text{v(PML)} \geq \text{v(L)+ v(PM)}.$$

Yet, the stable condition of two-player coalition {(PM)LR} is v(L)+ v(PM) ≥ v(PML); the stable condition of two-player coalition{(PL)MR} is v(M)+ v(PL) ≥ v(PML).

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Similarly, the stable condition of three-player coalition {(PMR)L} is opposite against {(PM)LR} and {(PR)ML}'s conditions; the stable condition of three-coalition {(PLR)M} is opposite against {(PL)MR} and {(PR)ML}'s conditions.

(3) When we take a look at the relationship between two-player coalitions and one-player coalitions, which are uncooperative games, we can find that the stable condition of two-player coalition {(PM)LR} is

$$v(PM) \geq v(P) + v(M),$$

Yet, the condition of deviation from coalitions is :

$$v(PM) \leq v(P) + v(M).$$

Similarly, the condition of deviation from coalitions for {(PR)ML} is

$$v(PR) \leq v(P) + v(R),$$

and {(PL)MR}'s conditions of deviation is

$$v(PL) \leq v(P) + v(L).$$

4.4 Solution concepts

In this chapter, we discuss the commonly used solution concepts for multi-player cooperative games. When the necessary conditions for stability of a multi-player coalition are satisfied, the coalition would be stable if the allocation is fair to each player in the system. To find fairly allocating cost savings which all members in the coalition accept the allocation scheme and are willing to stay in the coalition (Leng 2009), we

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adopt major solution concepts in the theory of cooperative games to assure fairness in allocation of extra cost savings defined as the difference between cost savings of coalitions and the sum of cost savings of individual members.

4.4.1 Essential game

Because our final goal is to discuss the relationship between the O2O information sharing model and cost saving effects, we must seek for a game in coalitional form realizing maximum efficiency, Pareto optimality, achieved when specific criterion is maximized and no allocation of resources could yield a higher value according to that criterion. In the theory of cooperative game, to create more efficiency; moreover, to make the grand coalition stable and the members have more incentive to form a grand coalition, we have to apply the concept of essential game, where $\sum_{i\in T} \mathrm{v}_i > \mathrm{v}(T)\ \ for\ coalition\ T,$ to find an allocation scheme. In our model, we can find that, under the stable condition:

$$\sum_{i\in T} \mathrm{v}_i = \mathrm{v(P)} + \mathrm{v(L)} + \mathrm{v(M)} + \mathrm{v(R)} < \mathrm{v(PLMR)}.$$

Therefore, the allocation scheme also qualifies as an essential game.

4.4.2 Shapley value with Banzhaf power index

In the cooperative game theory, Shapley value is a solution concept assigning a unique distribution of a total surplus generated by the coalition among all players. That is to say, The Shapley value distribute the total gains and provides unique imputations in assumption that all members collaborate fairly by an arbitrator. The unique Shapley values $\emptyset = (\emptyset_1, \ldots, \emptyset_n)$ are determined by $\emptyset_i = \sum_{i\in T}(|T-1|)!\,(n-|T|)\,!\,[\mathrm{v}(T) -$

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$\mathrm{v}(T-i)]/n!$, where T denotes an information sharing coalition, $|T|$ is the size of T, n is the total number of players and the sum extends over all coalitions T not containing player i, The formula can be interpreted as follows: imagine the coalition being formed one player at a time, with each player demanding their contribution $[\mathrm{v}(T)-\mathrm{v}(T-i)]$as a fair compensation, and then for each player take the average of this contribution over the possible permutations in which the coalition can be formed.

However, for the situations associated with practical applications, the amounts of feasible input coalitions can often be reduced. In some cases, subtraction of a member from a coalition may also result an infeasible coalition. In our paper, since the online channel is indispensable in the practice of O2O business models, removing platform that dominates information sharing of coalitions in supply chain would then be infeasible. The coalition among other players, exclusive of platform, though has the power to make decisions, betray the definition of O2O, coordination of virtual and physical channel. Therefore, we are going to block these infeasible coalitions in O2O business model from our coalition sets.

To truly combine the real world with theorem, we adopt the concept of Shapley value, yet with Banzhaf power index. Our paper is not the first to disallow certain coalitions in values or power indices. Aumann and Dr`eze (1975) assume that property rights may make it impossible to form every coalition. Though the application of such restrictions to power indices are more recent, to obtain an index a further normalization is required. The Banzhaf measure (Penrose 1946; Banzhaf 1965), originally designed for changing an outcome of a vote where voting rights are not necessarily equally divided among the voters, is the probability that a party is critical for a coalition, that its desertion can turn winning coalitions into losing ones. That is, in real world, some

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strategic behaviors could influence the formation of some coalitions; therefore, through the concept we can block some infeasible coalitions in the business models.

In our paper, we are going to adopt the concept of the Banzhaf measure as power index to weight winning coalitions, defined by enough quota to win. To properly distribute allocation of cost savings among members in different feasible coalitions, we follow the procedures below:

Step 1: According to the definition of O2O business models, platform would always play the role of one of critical players. We try to block some infeasible coalitions where the platform does not involve in. Then there are seven feasible coalitions:

{(PL)MR}, {(PM)LR}, {(PR)ML}, {(PML)R}, {(PLR)M}, {(PMR)L}, {(PMLR)}.

Step 2: After blocking some infeasible coalitions, we need to determine quota, the minimum number to become winning coalitions. We assume min{v(PM), v(PL), v(PR)} the minimum allocation of cost savings as quota, which stands for entry barrier of O2O model. That is, with the involvement of platform in a supply chain, we can at least gain these cost savings. If the characteristic function is larger than min{v(PM), v(PL), v(PR)}, we regard it as winning solution. Then we can find that all the feasible coalitions are winning coalitions:

$$v(PL) \geq \min\{v(PM),v(PL),v(PR)\},$$

$$v(PM) \geq \min\{v(PM),v(PL),v(PR)\},$$

$$v(PR) \geq \min\{v(PM),v(PL),v(PR)\},$$

$$v(PML) = (P_{P1}-P_{p5}) + (M_{P1}-M_{P5}) + (L_{P1}-L_{P5}) \geq \min\{v(PM),v(PL),v(PR)\},$$

$$v(PLR) = (P_{p1}-P_{p7}) + (L_{P1}-L_{P7}) + (R_{P1}-R_{P7}) \geq \min\{v(PM),v(PL),v(PR)\},$$

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$$v(PMR) = (P_{P1} - P_{P6}) + (M_{P1} - M_{P6}) + (R_{P1} - R_{P6}) \geq \min \{v(PM), v(PL), v(PR)\},$$

$$v(PLMR) = \left(P_{p1} - P_{p8}\right) + (L_{P1} - L_{P8}) + (R_{P1} - R_{P8}) + (M_{P1} - M_{P8}) \geq \min \{v(PM), v(PL), v(PR)\}.$$

Table 2. The feasible, infeasible coalitions and winning coalitions of O2O model

Infeasible coalitions	Feasible coalitions	Winning coalitions
{(ML)PR}	{(PM)LR}	{(PM)LR}
{(MR)PL}	{(PL)MR}	{(PL)MR}
{(LR)PM}	{(PR)ML}	{(PR)ML}
{(MLR)P}	{(PML)R}	{(PML)R}
{P, M, L, R}	{(PMR)L}	{(PMR)L}
	{(PLR)M}	{(PLR)M}
	{(PMLR)}	{(PMLR)}

Since some of infeasible coalitions in O2O business model would be considered in the calculation of marginal contribution of the platform in the next step, we also list these coalitions in the table.

Step 3: We now can start to identify the critical players in whole winning coalitions. In each of the winning coalitions, there would be critical members, which provide the required allocation of cost savings for the coalition, and unnecessary members. Now we can find out critical players (underlined) below. The set winning coalitions with critical players underlined is

$$\{\{\underline{(PL)}MR\}, \{\underline{(PM)}LR\}, \{\underline{(PR)}LM\}, \{(\underline{P}ML)R\}, \{(\underline{P}LR)M\}, \{(\underline{P}MR)L\}, \{(\underline{P}LMR)\}\}$$

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Obviously, the coalition is able to provide the required production, even when one of these unnecessary members goes out of the winning coalition. However, when one necessary member leaves, the winning coalition becomes insufficient. Since the Banzhaf index is derived by simply counting, we can find that there are 10 total swing players, the coalitions in which participate would win, or would lose, and the power is divided as:

$$P = 7/10,\ L = 1/10,\ M = 1/10,\ R = 1/10.$$

The player *P* is necessary for whole seven winning coalitions, *L* is necessary for one winning coalitions, *M* also for one winning coalitions, *R* for one winning coalitions. Therefore, *P* is necessary in 0.7 of the total cases (10 = 7+1+1+1, so 7/10= 0.7), *L* in 0.1, *M* in 0.1, and *R* in 0.1. Obviously, platform dominates the weight of distribution of cost allocation. As the main source of cost allocation, *P* is definitely the critical player of the game, or it would be meaningless to construct a platform as well as adopt O2O model. The importance of platform also corresponds to that, in our O2O model, platform is the coordinator of information flow, and the cost of *P* would definitely decrease by a wider margin than other players' cost due to its larger base of fixed cost.

After calculating the Banzahf power index, next, we will compute one of the most important part of Shapley value, marginal contributions of individual players (*M*C) to coalitional scheme. The following table displays the marginal contributions of players:

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Table 3. The marginal cost allocations of different players

Player	MC
P	$[v(P)-v(\emptyset)]+[v(PL)-v(L)]+[v(PM)-v(M)]+[v(PR)-v(R)]+[v(PML)-v(ML)]+[v(PLR)-v(LR)]+[v(PMR)-v(MR)]+[v(PMLR)-v(MLR)]$
L	$[v(L)-v(\emptyset)]+[v(PL)-v(P)]+[v(PML)-v(PM)]+[v(PLR)-v(PR)]+[v(PMLR)-v(PMR)]$
M	$[v(M)-v(\emptyset)]+[v(PM)-v(P)]+[v(PML)-v(PL)]+[v(PMR)-v(PR)]+[v(PMLR)-v(PLR)]$
R	$[v(R)-v(\emptyset)]+[v(PR)-v(P)]+[v(PLR)-v(PL)]+[v(PMR)-v(PM)]+[v(PMLR)-v(PML)]$

Now, we can use the results from Banzhaf measure to calculate the allocated cost saving to the supply chain member *i*: *P*, *L*, *M*, *R* completely.

$$\emptyset_p = 7/10\{[v(P)-v(\emptyset)]+[v(PL)-v(L)]+[v(PM)-v(M)]+[v(PR)-v(R)]+[v(PML)-v(ML)]+[v(PLR)-v(LR)]+[v(PMR)-v(MR)]+[v(PMLR)-v(MLR)]\}$$

$$\emptyset_l = 1/10\{[v(L)-v(\emptyset)]+[v(PL)-v(P)]+[v(PML)-v(PM)]+[v(PLR)-v(PR)]+[v(PMLR)-v(PMR)]\}$$

$$\emptyset_m = 1/10\{[v(M)-v(\emptyset)]+[v(PM)-v(P)]+[v(PML)-v(PL)]+[v(PMR)-v(PR)]+[v(PMLR)-v(PLR)]\}$$

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$$\emptyset_r = 1/10\{[v(R) - v(\emptyset)] + [v(PR) - v(P)] + [v(PLR) - v(PL)]$$
$$+ [v(PMR) - v(PM)] + [v(PMLR) - v(PML)]\}$$

4.4.3 Core

From the Shapley value with Banzahf power index above, we now can continually discuss commonly used solution concepts in cooperative game theory to analyze and find fair unique allocation scheme for our cooperative game. We use the concept of core to assure the stability of coalitions. Before that, we first analyze the imputations, defined as an acceptable distributions of the payoff of the grand coalition. the imputations distributions must satisfy two properties: efficiency and are individually rational. To make the grand coalition stable, we define x_i as the allocated cost savings to the supply chain member *i* = *P*, *L*, *M*, & *R*. To meet the condition of imputations, the allocation of cost savings($x_p,\ x_l,\ x_m,\ x_r$) must be (1) individual rational:

$$x_p > v(P),\ x_M > v(M),\ x_L > v(L),\ x_R > v(R)$$

Obviously, in our paper, we satisfy the condition due to that the characteristics value of *P*, *L*, *M*, & *R* all equals zero, and is smaller than ($x_p,\ x_l,\ x_m,\ x_r$).

The other property (2) collective rationality, i.e., $x_p + x_M + x_L + x_R = v(PLMR)$, is not satisfied in our model with the unique allocation scheme suggested by Shapley value with Banzhaf power index method. However, we use linear programming (LP) method to get the constrained solution, which makes the grand coalition stable, and the result will be presented in the next section.

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After we get the imputations, then we can apply the concept of core to assure the stability of allocation scheme. In game theory, the core is the set of imputations under which no coalition has a value greater than the sum of member s' payoffs in grand coalition to block it. Therefore, no coalition has incentive to leave the grand coalition and receive a larger payoff. The core of multi-player cooperative game is defined as the set of imputations (x_p ; x_L ; x_m ; x_r) such that for all coalitions, we have $\sum_{i\in T} x_i \geq v(T)$ (Shapley 1967). In our model, we can easily find that our allocation scheme is suggested by the core:

$$x_p+x_M+x_L+x_R \geq v(PLMR)$$

$$x_p+x_M+x_L \geq v(PLM)$$

$$x_p+x_M+x_R \geq v(PMR)$$

$$x_p+x_L+x_R \geq v(PLR)$$

$$x_p+x_M \geq v(PM)$$

$$x_p+x_L \geq v(PL)$$

$$x_p+x_R \geq v(PR)$$

Even if the core exists, we face the problem of which allocation scheme would be best to be divided cost savings among whole stakeholders.

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4.4.4 Nucleolus

Another interesting value function for multi-person cooperative games may be found in the nucleolus, a concept introduced by Schmeidler (1969). Instead of applying a general method of fairness to the set of all characteristic functions, we try to find an imputation $x = (x_1,..., x_n)$ that minimizes worst inequity, the maximum dissatisfaction among members in the information sharing coalition. The nucleolus is defined as a measure of the inequity of an imputation x for a coalition T, excess, $\mathrm{e}(x,T) = \mathrm{v}(T) - \sum_{i\in T} x_i$. Since we have discussed the core above: $\sum_{i\in T} x_i \geq \mathrm{v}(T)$, we immediately have that an imputation x is in the core if and only if all its excesses are negative or zero. Then we can find the nucleolus by looking first at the largest excess of those coalitions. Then we try to adjust x, to make the largest excess smaller. When the largest excess has been made as small as possible, we concentrate on the next largest excess, and adjust x to make it as small as possible, and so on. In our model, we use LP to solve the nucleolus solution.

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Chapter 5 Numerical Analysis

We first present two numerical examples and try to analyze effects of allocation of cost savings among four-player coalition in an O2O model with cooperative game theory.

Example 1

In this example, we assume the following values for the parameters: For the demand information AR (1), we let d = 100, ρ= 0.5 and ∂ = 20. We also assume the original values of unit shortage costs and unit holding costs are (P_M; P_R) = (2; 5) and (h_M; h_R) = (1; 2); the cost of transportation per route and per unit of truck capacity Tr=3, $t$he capacity per truck: tc=1 and the fixed operation cost of platform: ic=20, respectively. To compute the manufacturer's, retailer, logistics service provider's and platform's expected costs, we simulate the system for 100 runs for a run length of N = 50 periods, take the average of the results obtained in all runs in each coalition, then we can show the result in Table 4.

Table 4. Simulation results for Example1

{P, M, L, R}	{(PM)LR}	{(PL)MR}	{(PR)ML}	{(PML)R}	{(PMR)L}	{(PLR)M}	{(PMLR)}
M_{P1}	M_{P2}	M_{P3}	M_{P4}	M_{P5}	M_{P6}	M_{P7}	M_{P8}
1.601313	1.200984	0.800656	1.200984	0.800656	1.200984	0.800656	0.800656
L_{P1}	L_{P2}	L_{P3}	L_{P4}	L_{P5}	L_{P6}	L_{P7}	L_{P8}
6	3	4.5	4.5	3	3	3	3
R_{P1}	R_{P2}	R_{P3}	R_{P4}	R_{P5}	R_{P6}	R_{P7}	R_{P8}
4.003281	4.003281	4.003281	3.002461	4.003281	2.0016407	3.002461	2.001641
PL_{P1}	PL_{P2}	PL_{P3}	PL_{P4}	PL_{P5}	PL_{P6}	PL_{P7}	PL_{P8}
20	10	10	10	6.666667	6.666667	6.666667	5
Total cost							
31.60459	18.20427	19.30394	18.70345	14.4706	12.869292	13.46978	10.8023

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Using the results in Section 4.1 to 4.3, and those in Table 3 the characteristic value of a cooperative game would be presenter in Table 5:

Table 5. Characteristic value of the cooperative game of O2O business model

v(P)	v(M)	v(L)	v(R)	v(PM)	v(PR)	v(PL)	v(PMR)	v(PML)	v(PLR)	v(PMLR)
0	0	0	0	10.40033	11.00082	11.5	15.7353	17.13399	17.33415	20.8023

With the stable conditions mentioned in 4.2, we can find that we that these feasible coalitions are stable. Moreover, the three-player coalitions would allocate more cost than two-player coalitions, and the grand coalition {(PMLR)} would save the most cost. That is to say, with the information spread more extensively in the supply chain, the system can be operated in a more efficient way. They might react to the capricious market demand more quickly with the help of platform coordinating information. When considering the three-player and two-player coalitions, we can find that sharing information with logistics service provider would be more effective and beneficial due to that the logistics service provider plays the mediator of upper stream and downstream firms. In this way, if the demand information is shared with logistics service provider, it can be spread in a more efficient way and does more help to the supply chain.

To find a unique allocation scheme, we use the Shapley value with Banzhaf power index to compute Shapley value as Table 6:

Table 6. Shapley value with Banzhaf power index method

	Allocating cost savings to player i
$\emptyset_{\boldsymbol{p}}$	72.734823
$\emptyset_{\boldsymbol{l}}$	2.9633989
$\emptyset_{\boldsymbol{m}}$	2.4236944
$\emptyset_{\boldsymbol{r}}$	2.58382536

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However, since one of the property, collective rationality, of imputations: $x_p + x_M + x_L + x_R = \text{v(PLMR)}$ is not satisfied due to $\emptyset_p + \emptyset_l + \emptyset_m + \emptyset_r$= 80.7059 > 20.8023, the unique allocation scheme suggested by Shapley value with Banzhaf power index method makes the grand coalition unstable. Hence, we use LP to compute the constrained nucleolus solution as (γ_P; γ_L; γ_M; γ_R) = (20; 6; 1.6013; 53.1046), which results in the stability of {(PMLR)}. The solution can satisfy the both properties of imputations, besides, the nucleolus solution is also in the core. Then we can regard the unique allocation scheme of the grand coalition as stable.

Example 2

To realize the importance of sensitivity of demand process in the cooperative game with demand information sharing in four-player supply chain, we change the value of ρ from 0.5 to 0.3 but use the same values for the other parameters as in Example 1 to investigate the change in prediction of demand. Similar to Example 1, we compute the manufacturer's, retailer's, logistics service provider's and platform's expected costs, and simulate the system for 100 runs for a run length of N = 50 periods. The result is presented in Table 7.

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Table 7. Simulation results for Example 2

{P, M, L, R}	{(PM)LR}	{(PL)MR}	{(PR)ML}	{(PML)R}	{(PMR)L}	{(PLR)M}	{(PMLR)}
M_{P1}	M_{P2}	M_{P3}	M_{P4}	M_{P5}	M_{P6}	M_{P7}	M_{P8}
0.34342	0.25756	0.17171	0.25756	0.17171	0.25756	0.17171	0.17171
L_{P1}	L_{P2}	L_{P3}	L_{P4}	L_{P5}	L_{P6}	L_{P7}	L_{P8}
6	3	4.5	4.5	3	3	3	3
R_{P1}	R_{P2}	R_{P3}	R_{P4}	R_{P5}	R_{P6}	R_{P7}	R_{P8}
0.85855	0.85855	0.85855	0.6439	0.85855	0.42927	0.64391	0.42927
PL_{P1}	PL_{P2}	PL_{P3}	PL_{P4}	PL_{P5}	PL_{P6}	PL_{P7}	PL_{P8}
20	10	10	10	6.6666	6.6666	6.6666	5
Total cost							
27.20197	14.11611	15.53026	15.40146	10.69686	10.35343	10.48222	8.60098

For this example, Using the results in Section 4.1 to 4.3, and those in Table 7, the characteristic value of a cooperative game would be presented in Table 8.

Table 8. Characteristic value of the cooperative game of O2O business model

v(P)	v(M)	v(L)	v(R)	v(PM)	v(PL)	v(PR)	v(PMR)	v(PML)	v(PLR)	v(PMLR)
0	0	0	0	10.08586	10.21464	11.5	13.84854	16.50511	16.54804	18.60099

With the result in the table above, obviously, we can find that the cost savings of allocation scheme {(PR)ML} decreases dramatically than other two-player coalitions and the cost savings of coalition {(PM)LR} decreases in smaller scale; the cost savings of coalition {(PL)MR}is not influenced. Similarly, in the three-player coalition, the allocation scheme {(PLR)M} with participant of retailer, also decreases more dramatically than other three-player coalition. Therefore, we can infer from the

doi:10.6342/NTU201601306

situation about that sensitivity of demand based on last term consumption would influence more on retailer's cost savings.

To find a unique allocation scheme, we use the Shapley value with Banzhaf power index to compute Shapley value as Table 9.

Table 9. Shapley value with Banzhaf power index method

	Allocating cost savings to player i
$\emptyset_p$	68.112226
$\emptyset_l$	2.90051
$\emptyset_m$	2.077782
$\emptyset_r$	2.112124

For this example, we can still find that the unique allocation scheme suggested by Shapley value with Banzhaf power index method makes the grand coalition unstable. Hence, we use LP to compute the constrained nucleolus solution as (γ_P; γ_L; γ_M; γ_R) = (20; 6; 0.3434; 28.8592), which results in the stability of {(PMLR)}. The solution can satisfy the both properties of imputations, besides, the nucleolus solution is also in the core. Then we can regard the unique allocation scheme of the grand coalition as stable.

5.1 The impact of ρ on the coalition stability, cost savings of different allocation schemes

We perform a sensitivity analysis to examine the effect of the autocorrelation coefficient on the coalitional stability, total cost savings for the supply chain members and allocations. In the sensitivity analysis, we first increase the value of ρ from 0.01 to 0.1 in increments of 0.01, and then increase from 0.1 to 1.0 in increments of 0.1. Then we

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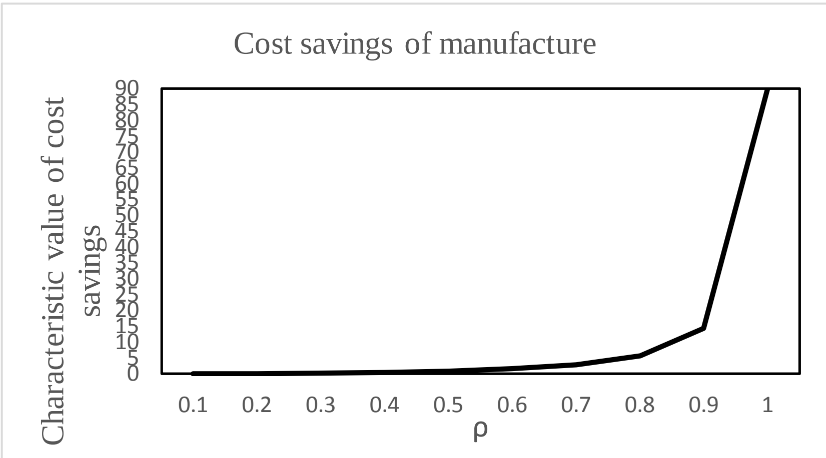
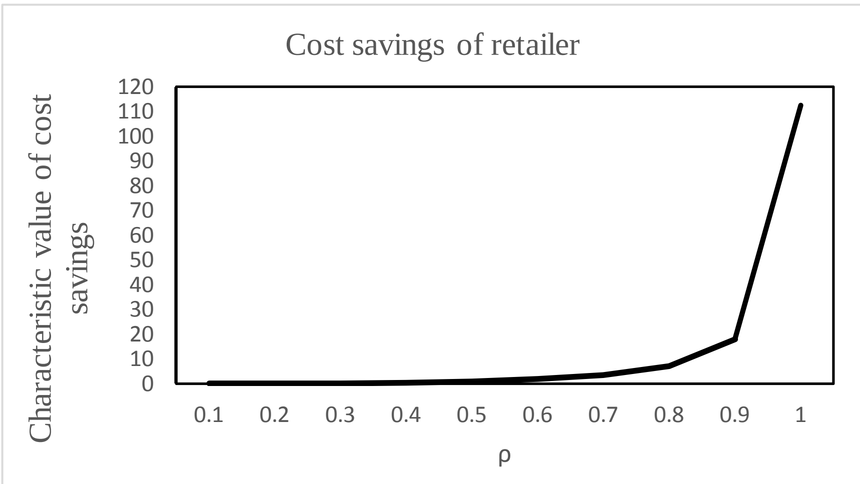
can easily find that during the process of increasing the value of ρ from 0.01 to 0.1, especially when 0.09 to 0.1, the cost savings of manufactures and retailers soon turn from negative values to positive ones. The results are presented in Table 10. In this way, when ρ < 0.0997, we find that the value of information is not substantial so that the two members, the manufacturer and retailer, don't have the motivation to join coalitions, and would be unwilling to cooperate and share information with platform. We can use the data in Table 10 to plot the allocations in Figure 3 (a) and (b).



(a): Allocation of cost savings when ρ is increased from 0.01 to 0.1



(b): Allocation of cost savings when ρ is increased from 0.1 to 1.00

Figure 3. The impact of ρ on the allocation schemes in the four level supply chain

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Table 10.The impacts of the parameter ρ on the allocation schemes

(a). Sensitivity analysis when the value of ρ is increased from 0.01 to 0.1 in increments of 0.01

ρ	Stable coalition	Total cost saving	Cost saving for *M*	Cost saving for *R*	Cost saving for *L*
0.01	{(PL)RM}	11.5	-	-	1.5
0.02	{(PL)RM}	11.5	-	-	1.5
0.03	{(PL)RM}	11.5	-	-	1.5
0.04	{(PL)RM}	11.5	-	-	1.5
0.05	{(PL)RM}	11.5	-	-	1.5
0.06	{(PL)RM}	11.5	-	-	1.5
0.07	{(PL)RM}	11.5	-	-	1.5
0.08	{(PL)RM}	11.5	-	-	1.5
0.09	{(PL)RM}	11.5	-	-	1.5
0.0996	{(PL)RM}	11.5	-0.0000159	-0.00003974	1.5
0.0997	{(PMLR)}	18.0002	0.000006233	0.00001558	1.5
0.1	{(PMLR)}	18.0002	0.0000729	0.00018	1.5

(b). Sensitivity analysis when the value of ρ is increased from 0.1 to 1.0 in increments of 0.1.

ρ	Stable coalition	Total cost saving	Cost saving for *M*	Cost saving for *R*	Cost saving for *L*
0.1	{(PMLR)}	18.0002	0.0000729	0.00018	1.5
0.2	{(PMLR)}	18.1756	0.0502	0.1254	1.5
0.3	{(PMLR)}	18.601	0.1717	0.4293	1.5
0.4	{(PMLR)}	19.4015	0.4004	1.0011	1.5
0.5	{(PMLR)}	20.8023	0.8007	2.001641	1.5
0.6	{(PMLR)}	23.2534	1.501	3.7525	1.5
0.7	{(PMLR)}	27.8054	2.8015	7.0038	1.5
0.8	{(PMLR)}	37.6089	5.6025	14.0064	1.5
0.9	{(PMLR)}	68.1608	14.3317	35.8292	1.5
1	{(PMLR)}	333.1148	90.0328	225.082	1.5

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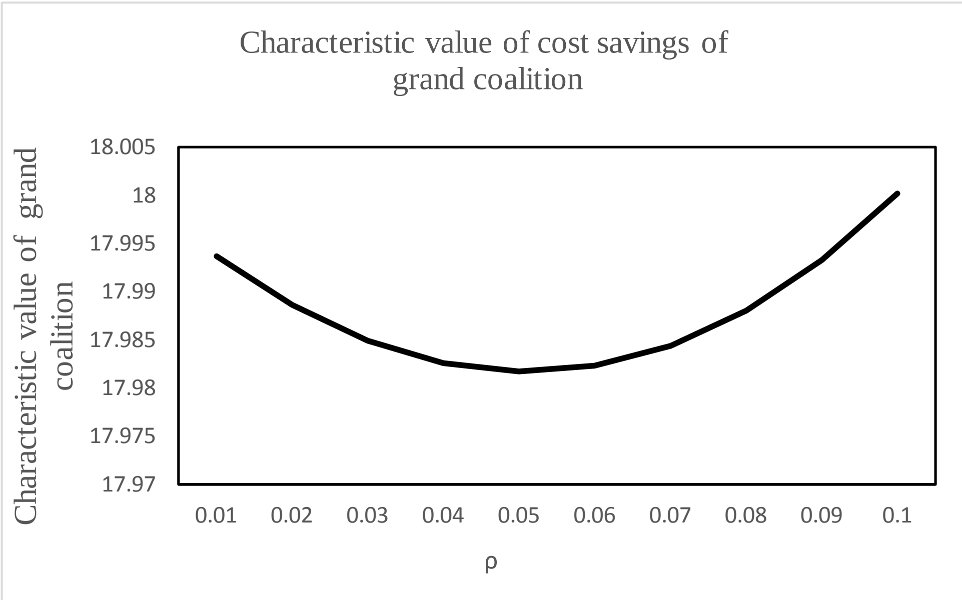
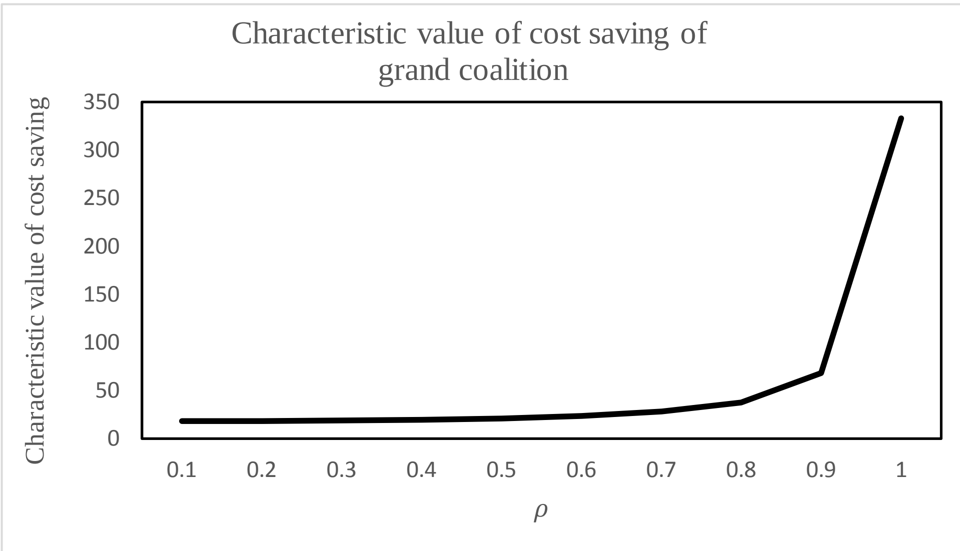
When ρ > 0.0997, the cost savings of retailer and manufacture become larger than zero and grow positively. Therefore, the retailer and manufacture would definitely join coalitions with platform due to positive cost savings; on the other hand, since the cost saving of logistic service provider would always be positive whenever logistic service provider cooperates with platform, it remains in the allocation scheme.



(a): Allocation of cost savings in grand coalition when ρ is increased from 0.01 to 0.1



(b): Allocation of cost savings in grand coalition when ρ is increased from 0.1 to 1.0

Figure 4. The impact of ρ on the allocation schemes in the grand coalition

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As Figure 4 indicates, we find that, for a constant $\sigma = 20$, higher values of the parameter ρ generate higher total cost savings enjoyed by the entire supply chain when $\rho > 0.0997$. Before ρ reaches 0.0997, the manufacture and retailer are not willing to join O2O model due to negative cost savings, so {(PL)MR} becomes the only stable coalition. This result is expected since increasing ρ raises the value of historical data according to the end-demand AR model (1). The cost saving effect would become obvious gradually due to stable demand process. However, the end-demand information is still worth sharing between the logistics service provider and the platform in a stable {(PL)MR} allocation scheme when ρ assumes very small values. We believe that from the consequence of the model, dominating the logistics service knowhow and demand information would be the most important thing when in an unpredictable market.

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Chapter 6 Conclusion

Our paper tries to develop an information sharing cooperative game of O2O business model in characteristic form and propose allocation scheme for allocation of cost savings among members in the supply chain. Through comparing the results of cost saving among different coalitional schemes in the O2O system, we considered a four-level supply chain involving a manufacturer, a retailer, a logistics service provides and the most important platform, which dominates the information flow in the supply chain. These supply chain members cooperate with each other in sharing the demand information to improve profits in the whole system. When we discuss feasible and infeasible coalitions, we can find that some coalitional schemes are impractical in the O2O business model, which coordinates the virtual and real channel, due to lack of participant of the virtual platform. Therefore, after we consider the possible coalitions in the real lives, we investigated and compared the cost savings among different members with characteristic form. Then, obviously, through comparing the results of cost savings of different coalitions, we can find that the allocation of cost savings of grand coalition in characteristic form would be the largest. Also, the three-player coalitions inclusive of logistics service provider will be more effective rather than repetitive share demand information with manufacture and retailer, both of which are responsible for stock preparation. The calculated result gives these coalitions clear and definite answer that it can obtain more profits when collaboration with others than join market by itself.

The importance of platform in the innovative business model influences our decisions on power index of different players when distributing cost allocations. We apply different strategies on distributing allocation of cost savings since traditional Shapley value can't be applied totally in our model. Therefore, we use Banzahf power

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index to revise power index of cost distribution, and the possibility of the cooperation of players in the supply chain is discussed as an approach to calculate the allocation of cost savings based on game theory in this paper. We try to consider really feasible coalitions with innovative business model for improving benefits in real world. We show empirically that our proposed method of distributing cost and coalitional scheme better than the original state of supply chain and the traditional method used in practice, as these typically used method ignore the synergy and benefits of information sharing among players. The proposed methods are computationally efficient in cost savings.

We have computed analytically the expected cost savings incurred at the different player's level as well as different scheme, and used simulation to confirm the cost saving effects with fluctuating demand; next, we derived the necessary conditions for stability of every coalition to ensure that no player would deviate from their coalitions, which is unique allocation scheme. First, we conduct the analysis of efficiency through taking into account constraints that would keep the coalition stable, and properties of efficiency have been proved. We also analyze properties of the solution by calculating core, nucleolus to verify the stability of coalitions. When considering Shapley value to determine unique distribution of allocation of cost savings, we found that this allocation scheme could result in an unstable grand coalition since one of two conditions required for imputation is not satisfied. Therefore, we use LP method to find out the constrained nucleolus solution. An analytic description of empty core was derived for solving the game to find the constrained nucleolus solution. After we utilize the implemented LP methods to prove the exemplary problem, we showed that the constrained core of the game could be non-empty provided that the properties of imputation and a condition of core are satisfied when the grand coalition is stable. In our numerical study, calculations of different impacts of the autocorrelation coefficient ρ in AR model (1) has been described and implemented in two examples to illustrate the effects of demand

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sensitiveness on the coalition stability and allocation schemes. In our paper, multi-criteria decision making problem has been formulated and a procedure for multi-criteria analysis has been proposed to prevent myopia when solving problem and applications in supply chain analysis. We believe future research direction could be far sighted solution concepts.

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