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Research Article

Profit Distribution of Agricultural Supply Chain Based on Shapley Value

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Abstract: The paper builds an agricultural supply chain and profit model between single farmer and single supermarket by following the game theory. On the basis of the economic purchasing quantity, it compares the profit difference between the cooperation and non-cooperation of the two parties. Study results demonstrate the profits for the whole supply chain are much bigger than that under non-cooperative circumstances when the two parties cooperate with the condition of negotiated purchasing quantity. An investment example using Shapley Value method is given to distribute the profit of each party under cooperation and prove the effectiveness of this method.

Keywords: Agricultural supply chain, profit distribution, shapley value

INTRODUCTION

In recent years, research on agricultural supply chain seems particularly important for the increasingly prominent fluctuations in price of the agricultural products, farmers have more difficulties in selling vegetables and consumers have more problems in buying vegetables. Agricultural supply chain is a net chain, so the products have a movement along with farmers, processing enterprises, distribution centers, wholesalers, retailers and consumers. Each participant maximizes their own interests during the trading process. However, the common interest maximization forces supply chain enterprises to build cooperative and effective consultation mechanism so that they can reach the binding agreement of mutual recognition and share cooperative benefits eventually. While due to the different goals, their own interests of supply chain participants may have conflicts, which may lead to the supply chain fracture. Therefore, reasonable profit distribution is the key for long-term cooperation of supply chain participants.

Profit distribution is always a hot-spot issue for scholars. Scientific and reasonable distribution mechanism is not only beneficial to maintain the stability of the supply chain system, but also can realize the effective allocation of enterprise resources and improve the resources utilization efficiency of service supply chain system (Daa and Teng, 2000). The economic model based on income distribution in supply chain cooperation, which points out that this kind of model is suitable for products with larger price elasticity of demand (Cachon and Lariviere, 2005). The benefits and risks evaluated by game theory models are analyzed to both supplier and manufactures in alliance environment (Bakkal and Akcale, 2006; Foros and Kind, 2008). Researches of domestic scholars now mainly focus on the following methods: Shapley value method, core method, product pricing method and bargaining method. The papers apply the Shapley value method to supply chain profit distribution and put forward the combined function of risk factors, which combines the profit distribution and value added (Xu and Du, 2011). The modified core method is used to solve the model they built and apply the results to distribution scheme (Yang *et al*., 2009). The paper puts forward that using the price leverage to motivate upstream and downstream enterprises' sharing information in supply chain and gives out the optimal pricing strategy for the manufacturers to the retailers under the condition of enterprise profit maximization (Zhang and Liu, 2004). The profit game of manufacturers and retailers in supply chain by the bargaining model is analyzed and the conclusion that the profit increment of both sides depends on the discount factor is researched (Chen, 2012). However, the profit distribution methods mentioned in the existing researches are basically used for manufacturing enterprises and there are fewer researches on profit distribution problems of agricultural supply chain. Therefore, this study attempts to have a research on profit distribution problems in agricultural supply chain by combining game model with Shapley value method, which tries to provide a reference way for the behavioral decision in practice of each subject in supply chain.

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PRESENTATION OF QUESTIONS AND VARIABLE DECLARATION

Combined with economic order quantity model, this study builds the two-stage supply chain, which supposes upstream supplier as the single farmer, while downstream enterprise as the single supermarket. This study has the analysis in two kinds of situations:

- The farmer and the supermarket have no direct cooperative relations, sales volumes are mutual independent stochastic variable q. Agricultural sales depend on the random selection of the farmer and he looks for buyers or rents the site, while supermarket puts into certain financial and material resources to find the suitable supply farmer.
- The farmer and the supermarket sign an agreement to implement the direct link and carry out order-based agriculture, under such condition the products quantities q are same between the farmer and the supermarket. Finally, it will have a solution to cooperative model by applying Shapley value method and give a profit distribution between the farmer and the supermarket.

Assumption terms:

- Only one single farmer and one hypermarket are being considered in the model.
- If price fluctuation is not big, never consider the trade discount.
- The farmer and the supermarket are bounded rationality and risk neutrality.
- No shortage situation.

Model symbol:

p_1 : Unit product trade price for farmer.
q_1 : Production quantity of farmer household, among which $q_1 = a\text{-}bp_1$ (a stands for the largest output intercept item in one given period, b stands for price sensitivity coefficient), namely trade price decided by farmer household and production quantity are inversely proportional, which is farmer household's decision variable.
c_1 : Farmer household unit production cost.
p_2 : The supermarket retail price.
q_2 : Supermarket order quantity, for supermarket can comprehensively grasp market information so the order can be regarded as market demand, which is the supermarket decision variable. The product demand is set as price negative exponential function $q_2=\beta p_2^{-\theta}$ is (β>0, θ>1), β proportional constant, θ is price elasticity. For vegetables belong to the necessaries of life so they are full of price elasticity, therefore θ>1.
c_2 : Supermarket unit inventory cost.
π : Supply chain profit expectations.
π_1 : Farmer household profit.
π_2 : Supermarket profit
π' : Whole supply chain profit of non-cooperation.
π'' : Whole supply chain profit of cooperation.
$\Delta\pi$: Profit difference quantity of the whole supply chain before and after the cooperation.

Game model of the supply chain members: This study builds the following model from the cooperation and non-cooperation models of game theory, which sets the farmer and supermarket as the research objects, complies with the bilateral profit maximization principle and considers the problems of price, quantity and inventory, etc. during the game process of the bilateral trading:

Decision of the farmer and supermarket in non-cooperation state: In non-cooperation state, the farmer and the supermarket make their own decisions, while actual output of the farmer has a certain difference from the supermarket order, the profits are as follow:
Farmer household profit:

$$\pi_1=(p_1\text{-}c_1)q_1 \tag{1}$$

Supermarket profit:

$$\pi_2=(p_2\text{-}p_1\text{-}c_2)q_2 \tag{2}$$

Whole supply chain profit:

$$\pi'=(p_1\text{-}c_1)q_1+(p_2\text{-}p_1\text{-}c_2)q_2 \tag{3}$$

To make (1) get the maximum, the vegetable production q_1 of farmer household is regarded as continuous variable, have a derivation for q_1:

Make $\frac{\partial\pi_1(q_1)}{\partial q_1}=0$

$$q_1=\frac{a\text{-}c_1b}{2} \tag{4}$$

Similarly for:

$$q_2=\beta\left(\frac{1\text{-}\frac{1}{\theta}}{p_1+c_2}\right)^{\theta} \tag{5}$$

Taking q_1 q_2 into (1) and (2),
Farmer's profit:

$$\pi_1=\frac{(p_1\text{-}c_1)(a\text{-}c_1b)}{2} \tag{6}$$

Supermarket's profit:

$$\pi_2=\beta\left(\frac{1-\frac{1}{\theta}}{p_1+c_2}\right)^{\theta}(p_2\text{-}p_1\text{-}c_2) \tag{7}$$

Therefore, the whole supply chain profit of non-cooperation is as follow:

$$\pi'=\frac{(p_1\text{-}c_1)(a\text{-}c_1b)}{2}+\beta\left(\frac{1-\frac{1}{\theta}}{p_1+c_2}\right)^{\theta}(p_2\text{-}p_1\text{-}c_2) \tag{8}$$

Decision of farmer household and supermarket in cooperation state: Farmer household and supermarket have the mutual cooperation by implementing direct link and signing long-term buying and selling agreement, thus having common decisions and risks and developing order agriculture. According to the supermarket order, farmer household cultivates corresponding quantity and standard agricultural products, namely $q_1 = q_2 = q^*$, which solves the excess capacity or insufficient risk loss of farmer household. The total benefit maximum of direct link between farmer household and supermarket will be the purpose for mutual interests.

Total benefit of the direct link is as follow:

$$\pi''=(p_1\text{-}c_1)q^*+(p_2\text{-}p_1\text{-}c_2)q^* \tag{9}$$

Have a derivation for q^* in (9) and make the differential coefficient for 0, getting:

$$q^*=3\beta\left(\frac{1-\frac{1}{\theta}}{2(c_1+c_2)}\right)^{\theta} \tag{10}$$

Taking q^* into (9), supply chain total profit in cooperation state is as follow:

$$\pi''=3\beta\left(\frac{1-\frac{1}{\theta}}{2(c_1+c_2)}\right)^{\theta}(p_2\text{-}c_1\text{-}c_2) \tag{11}$$

$$\Delta\pi=\pi''\text{-}\pi'=\beta\left(1\text{-}\frac{1}{\theta}\right)^{\theta}\left[(p_2\text{-}c_1)\frac{(p_1\text{-}c_1)(a\text{-}c_1b)}{2\beta\left(1\text{-}\frac{1}{\theta}\right)^{\theta}}\right]^2>0 \tag{12}$$

The analysis on the built model shows that the whole supply chain profits between the farmer and the supermarket under the condition of cooperation and non-cooperation are different. By sharing information and adopting cooperation method on the basis of the economic order quantity as the bilateral trading volume, the whole supply chain earning has a promotion, while the new supply chain profit distribution after cooperative game draws much attention for the farmer and supermarket. This study has the distribution of the total profit after their cooperation by Shapley value method. Shapley value method has the profit distribution based on their own contribution to the whole supply chain and has nothing to do with individual investment and size, thus embodying the principle of fair and justice to a certain extent. Shapley value method applying to solve the inter subjective profit distribution problems of agricultural supply chain can avoid the bilateral disputes brought about by the investment or scale problems.

Profit distribution of supply chain: The mathematical definition of Shapley value method is as follow: set $M=\{1,2,3,\ldots\ldots,n\}$, if for any subject S (stands for any group of n persons' subject) in M, it all has one real function $v(S)$, meeting:

$$\begin{cases} v(\varphi)=0 \\ v(S_1\cup S_2)\geq v(S_1)+v(S_2) \\ S_1\cap S_2=\varphi\ (S_1\subseteq M, S_2\subseteq M) \end{cases}$$

Regarding $[M, v]$ as n persons' cooperative countermeasure v stands for characteristic function of countermeasure and X_i stands for the income of enterprise i in M from cooperative maximum benefit $v(M)$. On the basis of cooperation, distribution of cooperative countermeasure is presented by $X=(X_1,X_2,X_3,\cdots,X_n)$, which should meet the condition:

$$\begin{cases} \sum_{i=1}^{n} X_i=v(M) \\ X_i\geq v(i), i=1,2,\cdots,n \end{cases}$$

In Shapley value method, profit distribution of each enterprise under cooperation M is called Shapley value, presenting as:

$$\varphi(v)=(\varphi_1(v),\varphi_2(v),\cdots,\varphi_n(v))$$

$\varphi_i(v)$ stands for the distribution of i the enterprise under cooperation M, which can be achieved by:

$$\varphi_i(v)=\sum_{i\in n}W(|s|)[v(s)\text{-}v(s/i)], i=1,2,\cdots,n$$

Table 1: Farmer's profit distribution computation in cooperative game

Cooperative form	Farmer	Cooperation between the farmer and supermarket
$v(s)$	855.9	3135.50
$v(s/i)$	0.000	1200.00
$v(s)-v(s/i)$	855.9	1935.5
$\|s\|$	1.000	200000
$W(\|s\|)$	1/2	1/2
$W(\|s\|)[v(s)-v(s/i)]$	427.95	967.75

While, $W(|s|)=\frac{(n-|s|)!(|s|-1)!}{n!}$ is weighting factor. X_i is the whole subject of member i in set M, $|s|$ is element number in subject s, n is element number in set M, $v(S)$ is the benefit of subject s, $v(s/i)$ is the desirable benefit for subject s except enterprise i.

CASE STUDY

Assume that an agricultural supply chain consists one single farmer and one single supermarket. The farmer mainly cultivates and sells mushroom, while the supermarket is one medium-sized retail store in Handan. Setting a single transaction as an example, the unit trade price of farmer's mushroom is 1.6 RMB and the unit cost is 0.7 RMB, while the unit retail price remains at 5 RMB in the supermarket and the unit cost of inventory is 0.9 RMB. Combining with agricultural products' own characteristics and the scoring of the experts, the parameter variable data in the model is as follows:

$a = 1000, b = 70, \theta = 2, \beta = 12000$

Bilateral profits under the both game conditions:

Taking the data above into the (6), (7), (8)
The farmer's profit in non-cooperation condition π' = 855.9 RMB.
The profit of supermarket π_2 = 1200 RMB.
The whole supply chain profit in non-cooperation condition π' = 2055.9 RMB.
Taking the data into (11), the whole supply chain profit in cooperation condition π'' = 3135.5RMB.

From the data analysis, direct link between farmer and supermarket with the economic lot size as the order quantity can promote the whole supply chain profit, meanwhile, use the Shapley value method to have the profit distribution after their cooperation.

Profit distribution: Profit distribution list built by Shapley value method model is as follows:

Add the last column in the Table 1, the farmer finally can get $\varphi_1(v)$ = 1395.7 RMB and in the similar way, the supermarket can get $\varphi_2(v)$ = 1739.8 RMB. Compared with the final results, the profit of farmer and supermarket all have corresponding increase after their cooperation and the Shapley value distribution method avoids the negative influence of the average distribution and makes the supply chain tend to the stable state, which will lead to the bilateral cooperation in future trading.

CONCLUSION

The study builds one two-stage supply chain model between the farmer and supermarket in game theory. The price elasticity and inventory cost are major factors influencing the economic order quantity by the model analysis and the whole supply chain profit is higher than the profit in non-cooperation state when the negotiated order quantity is equal to the final trading quantity in cooperation condition. The profit distribution after cooperation is also one important problem concerning the stability of the supply chain. Considering the unfair or injustice effect for final distribution may caused by the factors of scale or investment size of each subject in supply chain, this study has the profit distribution after cooperation by the Shapley value method based on their own contribution to the whole supply chain. Finally, this study proves out the practical value of the profit distribution in agricultural supply chain by the Shapley value method with empirical analysis, which provides certain guiding significance for future better cooperation between farmer household and supermarket.

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