The Distribution of Benefits for Players in Agricultural Industrial Chain

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Abstract Players of the agricultural industrial chain pursue their own profit maximization, which can lead to conflicts of interest and affect the stability of the industrial chain. Therefore, fair and reasonable profit allocation mechanism is the key to guaranteeing the development and strengthening the strategic alliance relationship between participate members. Shapley model is an effective method to solve the profit distribution in cooperative relations. But it does not consider the three factors: risks faced by players during the operation of the agricultural industrial chain, technology innovation ability, and the degree of participating in the cooperation. So, correction factors are introduced to modify the Shapley value model, in order to make the distribution of benefits more equitable and reasonable, and effectively guide practice.

Key words Agricultural industrial chain, Players, Distribution of benefits, Shapley value method, Correction model

With the development of agriculture and rural economy, the building of agricultural industrial chain plays a key role in promoting agricultural industrialization, marketization process, farmers' income, agricultural efficiency and rural advances. Fu Guohua[1] developed the concept of agricultural industrial chain for the first time, and he believed that agricultural industrial chain was that around a "competitive product", planting, processing, transportation and marketing industry relied on market resources, and gathered land, labor, capital and other production elements to implement largescale operation and chain rotation. Zuo Liangjun *et al.* [2] believe that the agricultural industrial chain includes the agricultural production, processing, circulation and consumption. The agricultural industrial chain is an organic whole combining the value chain, information chain, logistics chain and organizational chain, covering agricultural production, processing, marketing, transportation and many other links, involving various sectors and organizations during the whole process of agricultural production. In the course of economic operation, the players of agricultural industrial chain cooperate based on division of labor in order to adapt to market changes and complete unified strategic objectives, thus forming a strategic alliance relation and a marketoriented agricultural production and management mechanism[3]. This strategic alliance can integrate the resources owned by scattered members, improve the operational efficiency of the industrial chain, increase revenue and reduce risk. Meanwhile, the stable strategic alliance can make the agricultural industrial chain more stable and standardized, overcome the looseness and vulnerability of agricultural industrial chain, ensure the players' interests, expand and extend the industrial chain, and enhance the function of agricultural industrial chain. The key to maintaining and consolidating this strategic alliance is the distribution of interests among the players of industrial chain due to cooperation, but all members under this agricultural production mechanism are rational economic man, each pursuing profit maximization, inevitably leading to conflicts of interest, rupture of the alliance, and breaking of industrial chain. Only when the players get fair and equitable distribution of benefits under the cooperative game can a strong stable alliance be formed. Shapley proposed Shapley value method as an effective solution to the problem of distribution of benefits for the players of agricultural industrial chain under cooperative game. This distribution method based on Shapley value method is a mode based on the marginal contribution of each player involved in the production process, and it has certain rationality[4].

1 Shapley profit distribution model

There is a cooperative game relationship between the players of agricultural industrial chain, and Shapley value method is just a mathematical method to solve the problem of n-person game. The Shapley value is characterized by a collection of desirable properties. The setup is as follows: a coalition of players cooperates, and obtains a certain overall gain from that cooperation. Since some players may contribute more to the coalition than others or may possess different bargaining power (for example threatening to destroy the whole surplus), what final distribution of generated surplus among the players should arise in any particular game? Or phrased differently: how important is each player to the overall cooperation, and what payoff can he or she reasonably expect? The Shapley value provides one possible answer to this question. Shapley value method is a program to distribute the maximum benefit stemming from n-person cooperation[5].

1.1 Overview of Shapley value model Assuming the set $R = \{1, 2,, 3, \cdots, n\}$, and there is a real valued function $U(X)$ that

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corresponds to any subset X of R. If $U(\varnothing)=0$, $U(X_i \cap X_j) \geqslant U(X_i)+U(X_j)$, $X_i \cap X_j=\varnothing$, $(X_i \in R,\ X_j \in R)$, then $[R,\ U]$ is called multiplayer cooperative game, U is characteristic function, and $U(X)$ is the return value of cooperative alliance X. P_i represents the income in the maximum benefit $U(R)$ obtained by member i in R due to cooperation. On the basis of cooperation R, $P=(P_1,\ P_2,\ P_3,\ \cdots,\ P_n)$ is the allocation strategy of cooperative games.

Obviously, to ensure cooperation between members, it must have the following two characteristics:

$$\sum_{i=1}^{n} P_i = U(R) \quad (1)$$

$$P_i \geqslant U(i),\ i=1,2,3,L,n \quad (2)$$

where $U(i)$ is the profit when there is no alliance between members.

In the Shapley value method, the value of benefits obtained by players under cooperation R is called Shapley value, denoted as $\Phi(U)=(P_1(U)\ ,P_2,\ P_3(U),\ L,\ P_i(U))$, where $P_i(U)$ is the benefits obtained by cooperative member i. Shapley value meets the following three axioms.

(i) Symmetry. Assuming φ_i is a permutation of $P_{\varphi_i}(U)=P_i(U)$, then R is the correspondence of its own. If φ_i is the correspondence of i, φ_X is the correspondence of $X(X \subset R)$, denoted as $U(\varphi_X)=V(S)$, then for $i=1,\ 2,\ 3,\ L\ n$, there is $P_{\varphi_i}(U)=P_i(U)$. The benefit of each player is nothing to do with the assigned serial number i, that is, the relationship between the players is equal.

(ii) Effectiveness. If there is $P_i(U+V)=P_i(U)+P_i(V)$ for the subset Xcontaining i, then $P_i(U)=0$ and $\sum_{i=1}^{n} P_i(U)=U(R)$. This means that if the players contribute nothing to the cooperative earnings, then the allocated benefit is zero, and the sum of benefit allocated to the players is equal to the whole cooperative benefit.

(iii) Additivity. For any two characteristic functions U and V defined on R, there is $P_i(U+V)=P_i(U)+P_i(V),i=1,2,3,L,n$. This shows that when many players simultaneously conduct two kinds of cooperation, the benefit obtained by everyone should be the sum of benefits allocated from two kinds of cooperation.

Shapley value only exists for any n-person cooperative game strategy, and in the cooperation R, the benefit $P_i(U)$ allocated to player i can be calculated as follows:

$$P_i(U)=\sum_{X_i \in X} w(|X|)[U(X)-U(X-i)],i=1,2,3,L,n)$$

$$w(|X|)=\frac{(n-|X|)!\ (|X|-1)}{n!}$$

where X_i is the subset containing i in R; $|X|$ is the number of elements contained in subset X; $w(|X|)$ is the probability, which can be seen as a weighting factor; $U(X)-U(X-i)$ is the benefit stemming from player i joining the alliance, namely the marginal contribution of player i.

1.2 The application of Shapley value method in the distribution of benefits in agricultural industrial chain In order to better use and understand Shapley value, assuming there are three companies A, B, C, operating independently, and they can obtain the benefit of 100000 yuan, respectively; if A cooperates with B, they can get benefit of 500000 yuan; if A cooperates with C, they can get benefit of 700000 yuan; if B cooperates with C, they can get benefit of 400000 yuan; if the three companies cooperate, they can get benefit of 1000000 yuan. If the benefit of 1000000 yuan obtained by the three companies due to cooperation is equally distributed, then each company can get 333000 yuan, greater than the profit when operating alone, but it is difficult to mobilize the enthusiasm of some of the players. If the sum of benefit of A and C is less than the benefit of 700000 yuan due to cooperation between the two, A and C must not participate in the three-player cooperation. Shapley value method can solve this problem, and according to Shapley value method, the benefit allocated to player A $P_1(U)$ is calculated as shown in Table 1.

Table 1 Calculation of benefit allocated to A using Shapley value method

Forms of cooperation	A	A U B	AU C	A U B U C
$U(X)$10	50	70	100	
$U(X-i)$	0	10	10	40
$U(X)-U(X-i)$	10	40	60	60
$\|X\|$	1	2	2	3
$w(X)$	1/3	1/6	1/6	1/3
$w(X)[U(X)-U(X-i)]$	10/3	20/3	10	20

By totaling the figures in the last line of table according to formula, we can get A's benefit as follows:

$$P_1(U)=\frac{10}{3}+\frac{20}{3}+10+20=40\ (10^4\ \text{yuan}).$$

Similarly, we can calculate B's benefit as follows:

$$P_2(U)=\frac{10}{3}+\frac{20}{3}+5+10=25\ (10^4\ \text{yuan}).$$

C's benefit is as follows:

$$P_3(U)=\frac{10}{3}+10+5+\frac{50}{3}=35\ (10^4\ \text{yuan}).$$

Through the verification, the sum of benefits of A, B and C is equal to their cooperative benefits, namely $P_1(U)+P_2(U)+P_3(U)=100\ (10^4$ yuan$)$, $P_1(U)$, $P_2(U)$ and $P_3(U)$ and are all greater than the income from independent operation 10 (10^4 yuan); $P_1(U)\ +P_2(U)>50\ (10^4$ yuan$)$, $P_1(U)+P_3(U)>70\ (10^4$ yuan$)$, $P_2(U)+P_3(U)>40\ (10^4$ yuan$)$.

Therefore, the distribution of benefits based on Shapley value method has made the benefits of three cooperative companies more than the benefits obtained from independent operation of one single company or the benefits obtained from the cooperation of any two companies. Consequently, the three companies are motivated to participate in cooperation, thereby ensuring the stable coalition.

2 Correction of Shapley value method

Through the above analysis, we can see that Shapley value method gives full consideration to the contribution of each player of agricultural industrial chain to cooperation in varying degrees, which is conducive to mobilizing the enthusiasm of members for participating in cooperation. However, Shapley value method does not consider the risk tolerance, technological innovation capacity and cooperation players, and these factors will have an impact on the distribution of benefits, so there is a need to adjust the distribution of benefits based on Shapley value method to make it more reasonable.

2.1 Risk factors During the agricultural industrial chain operation, players will always face environmental risks, decision risks, market risks and other uncertainties, and the risks faced by players are different. In Shapley value method, the risks borne by players are seen as the same ($1/n$), and the differences in the distribution of benefits are ignored when distributing benefits, which will inevitably lead to a mismatch between benefits and risks. Therefore, in accordance with the risk-sharing principle, it is necessary to increase benefits for the players assuming great risks and reduce benefits for the players bearing small risks. In the evaluation of risk, we can use fuzzy comprehensive evaluation method, AHP, relative risk allocation method and other methods. R_i is used to represent risk factor, and the normalization is performed. The risk factor can be expressed as: $a_i = R_i / \sum_i^n R_j$.

2.2 Technological innovation capability Facing complex and volatile market environment, the development of new products, introduction of new technologies and technological innovation of one link in the agricultural industrial chain, will have an impact on the whole industrial chain, and increase the overall benefits of cooperation. Therefore, the agricultural industrial chain must have core competitiveness, and the technological innovation is a critical factor. There is a need to take into account the technological innovation capacity during the distribution of benefits, rewarding the players for introducing new technologies or carrying out technological innovation, and punishing the players for the lack of new technology introduction or technological innovation. It is necessary to consider the player's technological innovation capacity status in the whole industrial chain, and the level of collaboration, as well as the contribution of player's technical innovation to the overall cooperation earnings. W_i can be used to represent the value added for player i due to the technological innovation, and W_i is normalized. We get the share of contribution of each player to technological innovation as follows: $s_i = W_i / \sum_i^n W_i (i = 1, 2, 3, L, n)$.

2.3 The degree of cooperation Cooperative members may show different levels of enthusiasm and effort in the process of participation and cooperation, or withdraw from cooperation at any time, which is bound to affect the stability of cooperation, and cause great losses to the entire agricultural industrial chain. During the distribution of benefits, it is necessary to ensure the stability of cooperation, giving appropriate incentives for the players with high enthusiasm for participating in cooperation, and punishing the players with low enthusiasm. We can make assessment from players' input, information openness and level of trust, conduct quantitative analysis of the assessment results, and score each player in terms of the level of cooperation. $f_i (i = 1, 2, 3, L, n)$ is used to represent the assessment result about cooperation level of player i. Through the normalization, we can get $b_i = f_i / \sum_i^n f_i$ as the influence coefficient of cooperation level.

2.4 Correction model The above three factors play different roles in the distribution of cooperation benefits, and we can use scientific and rational approaches to give a certain weight. According to the different roles of players in the agricultural industrial chain, the Delphi method is used to set the weight, and the weight of three factors can be expressed as $c = (c_1, c_2, c_3)$, then the correction model can be expressed as follows:

$$P_i(U)' = P_i(U) + U(R) + (d_i - \frac{1}{n}), d_i = (a_i, s_i, b_i)\begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix}$$

where $P_i(U)'$ is the benefit allocated to player i after correction; d_i is the actual influencing factor of player i ; $d_i = -\frac{1}{n}$ is the difference between the actual influencing factor of player i and theoretical sharing factor $\frac{1}{n}$ (If it is greater than 0, it means that after taking into account the comprehensive factors, the players' performance is good, and it is necessary to increase interest allocation; if it is less than 0, it means that the players' performance level is less than the average performance level of players in the industrial chain, and it is necessary to lower interest allocation.); $U(R) \times (d_i - \frac{1}{n})$ is the compensation value of profit distribution.

After verification, the corrected actual distribution of benefits for player i still meets the requirements, namely $\sum_{i=1}^n P_i(U)' = \sum_{i=1}^n [P_i(U) + U(R) \times (d_i - \frac{1}{n})] = U(R) + U(R) \times \sum_{i=1}^n (d_i - \frac{1}{n}.)$ Since $\sum_{i=1}^n (d_i - \frac{1}{n}) = 0$, $\sum_{i=1}^n P_i(U) = U(R)$. The correction model is used to correct the above cases. Assuming $a_i = (0.1, 0.3, 0.3)$, $s_i = (0.3, 0.4, 0.3)$, $b_i = (0.3, 0.5, 0.2)$ the weight of the three factors is $c_i = (0.4, 0.4, 0.2)$. The comprehensive factor after integrating the three factors is as follows:

$$d_i = \begin{pmatrix} 0.4 & 0.3 & 0.3 \\ 0.3 & 0.4 & 0.5 \\ 0.3 & 0.3 & 0.2 \end{pmatrix}\begin{pmatrix} 0.4 \\ 0.4 \\ 0.2 \end{pmatrix} = \begin{pmatrix} 0.34 \\ 0.38 \\ 0.28 \end{pmatrix}$$

Based on the calculation results using Shapley value method, we can get the adjusted A, B, C's benefit distribution amount as follows:

$$P_1(U)' = 40 + 100 \times (0.34 - \frac{1}{3} = 41 \ (10^4 \text{ yuan})$$

$$P_2(U)' = 25 + 100 \times (0.38 - \frac{1}{3} = 29.7 \ (10^4 \text{ yuan})$$

$$P_3(U)' = 35 + 100 \times (0.28 - \frac{1}{3} = 29.7 \ (10^4 \text{ yuan})$$

After adjustment, the benefits allocated to A and B increase, while the benefits allocated to C decrease. It is the result of comprehensive consideration of risk factors, technological innovation capacity and level of cooperation, and the distribution of benefits is more equitable.

3 Conclusions

The benefit distribution mechanism of agricultural industrial chain is an important factor affecting the stability of industrial chain. For common interest, the players interact and collaborate and enter into a strategic alliance, ultimately forming a complete chain. The fundamental goal of players' participation in agricultural industrial chain is to rely on cooperation to create greater overall benefits while seeking to maximize their own interests. The nature of members' maximization of their own interests will be bound to make them concerned about the mutual distribution of benefits, and if the distribution of benefits is unreasonable, it will affect the enthusiasm of players for participating in cooperation, thereby affecting the overall interests of the entire chain, or even breaking the industrial chain. Therefore, the reasonable distribution of benefits can ensure the stable operation of agricultural industrial chain. In the cooperative game relationship, Shapley value method provides a reasonable allocation strategy for the distribution of benefits between cooperative members. On the basis of Shapley value, this paper considers the risk factors, technological innovation capacity and level of cooperation faced by the players in agricultural industrial chain, and corrects the Shapley model to make the benefit distribution strategy lay equal emphasis on efficiency and fairness. In short, Shapley value method can provide a theoretically and practically feasible benefit distribution program for the distribution of benefits among players in agricultural industrial chain, reduce the irrational factors in the distribution of benefits, and lay a solid foundation for the stable and continuous cooperation.

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(From page 8)

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