Profit distribution model of industry-university-research alliance based on Shapley algorithm

Tao Wang*, You Jiang

Marketing management, Wuhan University, Wuhan, 430072, Hubei, China

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Abstract

Traditional Shapley algorithm is unfair in the profit distribution of industry-university-research alliance. In view of this situation, this paper puts forward a profit distribution model based on improved Shapley algorithm optimized by fairness factors. It firstly evaluates the contribution ratio of each member in the alliance with contribution factor, and then evaluates the risk each member bears with risk factor, evaluates the technological innovation ability with technological innovation factor, and finally adjusts the profit distribution with these evaluation results to get the final distribution. Simulation results show that compared with traditional Shapley algorithm, the improved Shapley algorithm is fairer and more stable, and makes the satisfaction degree of each member in accordance, which is conducive to the sustainable development of industry-university-research alliance.

Keywords: Shapley Algorithm, Fairness Factor Optimization, Industry-University-Research Alliance, Profit Distribution Model, Contribution Factor

1 Introduction

With the advent of knowledge economy era, technological innovation has been the power and source of enterprises and even the country [1]. Because of the resource and know-how limits of enterprises themselves, it becomes more and more difficult for them to make knowledge creation and technological innovation [2]. Therefore, different organizations encourage innovation cooperatively via building technological alliance to promote the research and development and commercialization of new technologies. Industry, university and research institutes have strong heterogeneity and complementarity in resources and abilities, which makes them collaboratively and efficiently innovate[3]. Recently, some enterprises focus on cooperating with universities and research institutes and seek mutual or complementary technological innovation purpose through industry-university-research alliance which is a perfect profit distribution mechanism. Therefore, our country urges to establish a scientific and perfect profit distribution mechanism to supervise and guide this process, and guarantee its fairness.

Foreign scholars have conducted large amount of studies on industry-university-research alliance from different perspectives. J.P. Grander took mathematical analysis method to describe and analyse the industry-university-research process from both bilateral and mutual perspectives of university and industry, which indicates the research on collaborative innovation proceeding from phenomenon description and generalization and summarization to theoretical discussion, from fragmentary to systematic analysis [5]. Turpin. T and S. Garrett studied the characteristics of collaborative innovation under different macroscopic systems aspects[6] F. Bidaun and W. A. Fisher, from microscopic level, applied modern theory of the firm to explore the optimal system arrangement of the cooperation under incomplete market environment[7]. Meade L.M. and LI lesaD pointed out that reasonable profit distribution mechanism is the key of the establishment and successful operation of the dynamic alliance and the guarantee of developing the performance of each side[8]. Nash gave a Nash negotiated settlement for negotiation problems initially with axiomatization method[9]. Lemaire built a cooperative game model of the shared profit distribution of the alliance enterprises to keep normal operation and minimize the cost of dismission[10]. Masatoshi et .al established a fuzzy programming model coordinating the production and transport, and applied game theory, the concept and solving method of solution to obtain the profit distribution strategy between production and transport department[11]. Hendrik studied the profit distribution problem in non-gradable productive cooperation network, and put forward a unit evaluation model[12]. Luo Li et.al analysed the role of Shapley value in profit distribution with game theory, and concluded that it was workable and practical in reducing some adverse factors.[13] Zhang Wei elaborated the economic benefits and social benefits of each side in the industry-university-research alliance, analysed the profit distribution mechanism and proposed a series of supporting measures[14]. Yang Deqian established an evolutionary game theory model for university-industry cooperation and the analysis result showed that the higher profit was, more equitable the profit distribution would be[15]. From these studies about the profit distribution mechanism of industry-university-research alliance, it is seen that they pay more attention to the mode and method, not the systematic study.

* ***Corresponding author's*** e-mail: jianying8037@163.com

In view of the characteristics of the industry-university-research alliance profit distribution, this paper put forward a profit distribution model based on Shapley algorithm optimized by fairness indexes, including contribution factor, risk factor and technological factor.

2 Shapley algorithm

Shapely algorithm is a method for solving cooperative game problems. It focuses on the distribution of cooperative profit according to their contribution to the alliance, which reflects the importance of each member. The biggest advantage of Shapley algorithm is its fair principles and results which are widely accepted by all the members.

1) Player set N

Player means the participant in the game, specifically, the industry, university and research institute. The whole is noted as N, usually $|N|=n$, representing n persons play the game.

2) Strategy set S_i of player i

The strategy set S_i of player $i(i \in N)$, refers to the possible and feasible strategies set, $S_i = \{s_i\}$.

3) Payment function P_i of player i

For any strategy profile, the profit and loss of player i is the payment function P_i. Due to different research background, the payment function sometimes can be profit and loss function, sometimes utility function.

4) Characteristic function

Suppose a set I of n player, $I = \{1,2,3,...,n\}$, any subset S in I represents a possible alliance, and $V(S)$, the characteristic function of alliance S, indicates the maximum profit via coordinating the capacity of each member.

In the cooperative game, $G=[N,V]$, if for arbitrary S, $T \subset N$ and $S \cap T = \phi$, there are,

$$V(S)+V(T) \le V(S \cup T). \tag{1}$$

Then, characteristic function V has super additivity, corresponding to the cooperative game of super additivity.

5) Shapley value

$\phi_i(I)$ represents the gain of player i from the maximum cooperative profit $\phi(I)$ in the I. On this basis, the distribution is noted as $\phi(I) = \{\phi_1(I), \phi_2(I), ..., \phi_n(I)\}$. Apparently, the success of this cooperation must satisfy following condition.

$$\sum_{i}^{n} \phi_i(I) = \phi(I), \phi_i(I) \ge \phi(i). \tag{2}$$

In this equation, the allocation of each member in the cooperation should be more than that from single job at least, otherwise, they will not agree with this distribution. In this paper, the industry, university, research institute should achieve better profit than before, which is the precondition of the alliance.

We use $\phi_i(I)$ as the allocation of player i, thus the Shapley value of the profit is,

$$\phi_i(I) = \sum_{S \subset I} \frac{(n-|S|)!(|S|-1)!}{n!}[V(S)-V(S/i)] , \tag{3}$$

$$\omega(S) = \frac{(n-|S|)!(|S|-1)!}{n!} . \tag{4}$$

Here, $|S|$ is the element number in the subset S, $\omega(S)$ is weighting factor, $V(S)$ is the profit of S, and $V(S/i)$ is the profit of S minus the player i.

If n person cooperative game $G=[N,V]$, satisfies three properties as follows, then the existing Shapley value is unique.

(1) Symmetry, namely for the replacement π, there is

$$\phi_{\pi i}(\pi I) = \phi_i(I) . \tag{5}$$

(2) Effectiveness, namely for each support D of G,

$$\sum_{i \in D} \phi_i = V(D) , \tag{6}$$

where support D is defined as in $G=[N,V]$, $D \subseteq N$ is an alliance. If for any $D \subseteq N$,

$$V(S) = V(S \cap D) + \sum_{i \in S/D} V(i) , \tag{7}$$

then D is a support of game G.

(3) Additivity, for two arbitrary cooperative game, $G_1=[N,V]$ and $G_2=[N,U]$, for any $i \in N$, there are,

$$\phi_i(V+U) = \phi_i(V) + \phi_i(U) , \tag{8}$$

$$(V+U)(S) = V(S)+U(S). \tag{9}$$

Although Shapley algorithm sets rate of contribution as the condition of profit contribution, it doesn't consider other factors, which will lose the fairness of the distribution.

3 Profit distribution model of industry-university-research alliance based on improved Shapley algorithm

In order to achieve more reasonable and equitable profit distribution, in the principle of stage distribution, risk factor and technological factor is added to the distribution algorithm to get three results based on rate of contribution, risk, technological innovation, respectively.

3.1 THE OPTIMIZATION OF CONTRIBUTION FACTOR

Considering the stage distribution, the Shapley value is slightly adjusted. Suppose the cooperative profit distribution of

n player has m stage, cooperation set $N=\{1,2,...,n\}$, then the profit of each member is take as,

$$\phi(N,V)=(\phi_1(v),\phi_2(v),...,\phi_n(v)), \tag{10}$$

where $\phi_i(v)$ is the final profit player i gets, calculated from following equations,

$$\phi_i(v)=\sum_{j=1}^{m}\phi_{ij}(v) \quad , \tag{11}$$

$$\phi_{ij}(v)=\sum_{S\in S_i}\omega(|S|)[v_j(S)-v_j(S/i)] \ , \tag{12}$$

$$\omega(|S|)=\frac{(n-|S|)!(|S|-1)!}{n!} \ , \tag{13}$$

here $\phi_{ij}(v)$ is the profit of stage j of player i, $\phi_i(v)$ is the sum profit of all the stage.

Because player can get more profit in follow-up stage, which offsets their lost at the beginning, and finally larger than that from single job, the players in the alliance will not quit. Therefore, the alliance is stable and practicable. It is seen that after considering the stage distribution, members pursue a long-term profit, and short-term small earnings will not influence their participation.

3.2 THE OPTIMIZATION OF RISK FACTOR

Due to the turbulent market environment or other uncontrollable factors, members in the alliance undertake the changeable risk with time, which will influence the profit distribution under the same allocation rules. To accurately reflect the fairness and motivate the activity of members, the risk each member takes should be re-estimated.

Firstly, the factors set U_M , U_T and U_C represent three types of risks, market risk, technological risk and cooperation risk with weighting index W_1, W_2, W_3 respectively. There are so many methods determining these weighting indexes, of which fuzzy comprehensive evaluation method is a good one adopted in our paper. Fuzzy relation matrix R_1, R_2 and R_3 is obtained firstly for following fuzzy comprehensive evaluation.

$$Y_i=W_i\cdot R_i \ . \tag{14}$$

If the sum of each component in R_i is not equal to 1, then normalization processing is needed.

$$Y_i'=(y_{i1}',y_{i2}',...,y_{in}') \ . \tag{15}$$

Then the risk is calculated,

$$\begin{cases} R_M=Y_1'\cdot V^T \\ R_T=Y_2'\cdot V^T \\ R_C=Y_3'\cdot V^T \end{cases} . \tag{16}$$

These three types of risks are proved to be in some stage. Therefore, it requires revaluating the risks according to different conditions.

The total risk coefficient of member i at the stage j,

$$R_{ij}=1-(1-R_{ijM})(1-R_{ijT})(1-R_{ijC}) \ , \tag{17}$$

R_{ijM} , R_{ijT} and R_{ijC} represents the market risk, technological risk and cooperative risk of member i at the stage j. The level of evaluation at each stage keep same, but the corresponding weight factor and fuzzy relation matrix may change. After simple normalization processing, the risk vector of stage j is obtained,

$$R_j=(r_{1j},r_{2j},...,r_{nj}) \ . \tag{18}$$

Here, $\sum_{i=1}^{n}r_{ij}=1$, then the profit of each member is,

$$\phi_{ij}(v)=\frac{r_{ij}}{\sum_{i=1}^{n}r_{ij}}v_j(n)=r_{ij}v_j(n) \ . \tag{19}$$

And the final profit they get is

$$\phi_i(v)=\sum_{j}\phi_{ij}(v) \ . \tag{20}$$

3.3 THE OPTIMIZATION OF TECHNOLOGICAL INNOVATION FACTOR

In the cooperative profit distribution, it is necessary to take the technological innovation into consideration, otherwise it will do bad effect on the alliance and influence the development and stability of the whole supply network.

Suppose the member i help create the profit q_{ij} for the alliance through technological innovation at the stage j, then the total profit of this member is $\sum_j q_{ij}$ and the sum profit of all the enterprises in the network at the stage j is $\sum_i q_{ij}$. The ratio of profit single member creates to the total profit all members create represents their profit distribution ratio.

The technological innovation vector of stage j is,

$$P_j=(p_{1j},p_{2j},...,p_{nj}) \ , \tag{21}$$

where $\sum_{i=1}^{n}p_{ij}=1$, $p_{ij}=\frac{q_{ij}}{\sum_i q_{ij}}$. Thus, the profit each member earns is,

$$\phi_{ij}(v)=p_{ij}v_j(N) \ . \tag{22}$$

The final profit of each member enterprise is,

$$\phi_i(v)=\sum_j\phi_{ij}(v) \ .$$

4 Simulation experiment

In order to verify the effectiveness of the improved algorithm, this paper conducted simulation experiment, and compared it with traditional algorithms. Suppose the members in the alliance is school(S), company(C) and government(G), and the profit distribution of each member is made in a certain of period with Shapley algorithm and improved Shapley algorithm. The result is shown in Table 1.

TABLE 1 Alliance for the distribution of benefits and research results were compared

Cycle	Shapley			Im-Shapley		
	S	C	G	S	C	G
1	22.3%	42.7%	35%	36.6%	40.1%	23.3%
2	24.5%	37.5%	38%	41.3%	39.2%	19.5%
3	20.4%	51.2%	28.4%	39.7%	46.3%	14%
4	26.8%	38.5%	34.7%	42.3%	40.4%	17.3%
5	31.3%	44.8%	23.9%	43.6%	38.1%	19.3%
6	29.6%	52.1%	18.3%	33.9%	47.2%	18.9%

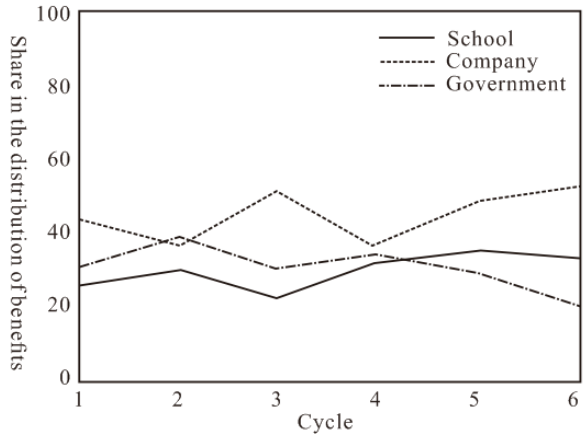

FIGURE 1 Shapley algorithm allocation results interests

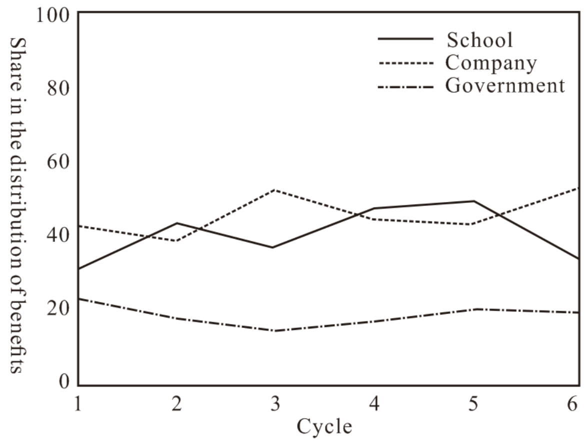

FIGURE 2 Shapley algorithm improved allocation results interests

From the profit distribution result, we can see because of adding the contribution factor, risk factor and technological factor, the improved algorithm shows fairer and increases the profit ratio of technological innovator and risk bearer.

Then, the satisfaction degree of each member is counted as follows.

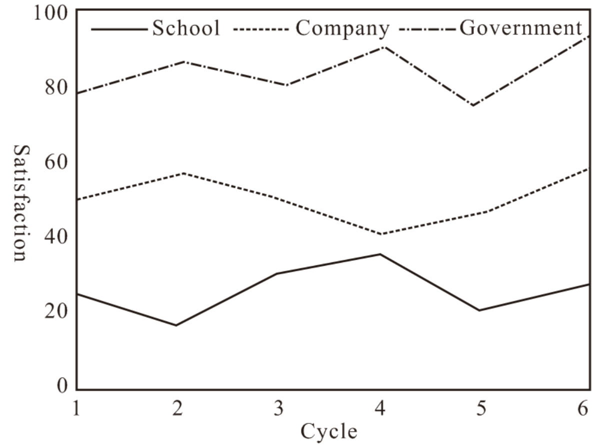

FIGURE 3 Shapley algorithm satisfaction of members

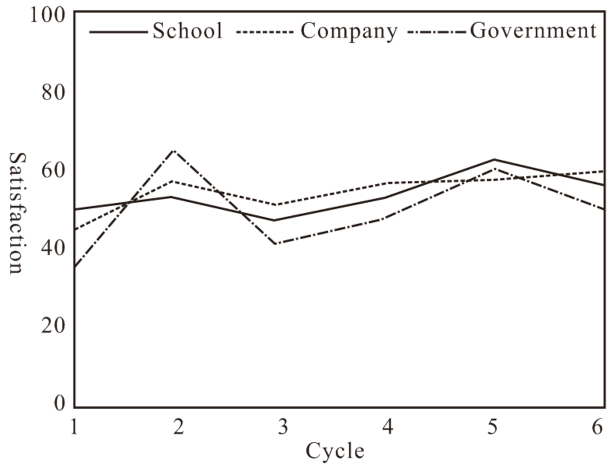

FIGURE 4 Im-Shapley algorithm satisfaction of members

From the statistics, the improved Shapley algorihtm makes the satisfaction degree in accordance while traditional Shapley algorihtm polarizes the satisfaction degree and easily causes the dismiss of alliance.

5 Conclusions

Industry-university-research alliance is a typical organization driven by interest. A reasonable profit distribution of alliance directly influences its development and stability. This paper put forward a profit distribution model of industry-university-research alliance based on improved Shapely algorithm by fairness factors. The simulation results show that this model is more stable in the profit distribution and conducive to the development of alliance.

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Authors

Tao Wang, Dec. 1970, China

Current position, grades: Prof. Wang (Doctor Supervisor) currently holds position as Vice Secretary, Standing Committeeman and Academic Member of China Marketing Association (CMA); vice president of Hubei Provincial Marketing Association; a member of the Marketing Course Group of the Guidance Committee of National MBA Education of China.
University studies: Ph.D of Marketing in 2000.
Experience: Editor of Journal of Marketing Science (JMS).

You Jiang, 23th Dec. 1979, China

Current position, grades: Internet and electronics industrial researcher at Shenzhen, China.
University studies: Marketing management PhD. Study in 2010 in Wuhan University.
Scientific interest: Industrial alliance, internet marketing management, marketing strategy etc.
Experience: National Natural Science Foundation of China (71272226), and 2014 Key Projects of Philosophy and Social Sciences of the Ministry of Education (A Research about the international development strategy of Chinese strategic emerging industries).