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Study on income distribution of stakeholders in renewable energy power projects under PPP Mode

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Abstract. Recently, mobilizing the investment of private capital in the field of renewable energy power, and distributing the income of PPP (Public-Private-Partnership) project rationally are highly sought. In this paper, two core departments are selected as the object of income distribution: public and private sectors. Considering the influence of investment ratio, risk allocation and the enterprise's implementation capacity on energy project, the cooperative game models about income distribution are constructed based on Nash negotiations and Shapely value, to study the benefit distribution of stakeholders in renewable energy power projects under PPP mode. The risk-sharing factors are scientifically determined by the risk index system, in which the whole life cycle risks of the renewable energy projects under PPP mode are listed. By the means of sensitivity analysis, the applicability of the two distribution models was compared. Finally, the purpose is realized which is to give suggestions on how to make the income distribution more reasonable just promoting the development of PPP model in the field of renewable energy power.

Key words. renewable energy, PPP, income distribution, Nash negotiations, Shapely value.

1. Introduction

In the thirteenth Five-Year Plan period, China focus on adjusting the energy strategic planning. The renewable energy industry subsidies and preferential policies are introduced to promote the trading mechanism of green power. Latest guidance proposed that investment from private capital should be used in wind power, biomass and other new energy projects. The issue of these policies makes renewable energy power projects under PPP mode become a hot topic.

Compared with foreign country, however, the application of PPP model will effectively solve the shortage of government funds in renewable energy investment,

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the development is slow. Unreasonable distribution of income will seriously affects the enthusiasm of the participants in investment. Therefore, it is of great significance to study the income distribution of renewable energy power projects under PPP mode. Ensuring the reasonable profit distribution among all the project participants could promote the PPP financing mode in the field of renewable energy applications.

At present, there are many studies on the project income distribution under PPP mode. Considering the factors such as concession period, cost of project transaction and renegotiation, Viegas studied the benefits distribution of the participants in the PPP project (J M, 2010). He Shoukui et al. put the risk-sharing and investment ratio into the linear model of income distribution, and discussed the investment decision and income distribution of public and private parties (He, 2006). Hu Li et al. fully considered the factors such as resource input, risk allocation, effort level and supervisory strength to correct the public-private profit distribution model determined by Shapely value method (Li, 2011). MH Sobhiyah et al. studied the public-private partnerships in power plant investment projects by considering the value of output / service (VFM) (M H, 2009). However, the research on the application of PPP model in China's renewable energy power field is not many (S, 2010). Zhao Zhenyu et al. investigated the successful factors of the PPP mode application in China's wind power industry (Zhao, 2010), he explored the basic structure and distribution of the success factors, and provided valuable references for all parties involved in the PPP power project development. Song Jinbo et al. based on system dynamics, constructed a revenue model about simulation of the waste incineration power generation under PPP mode (Song, 2015), he gave the concession period and the subsidy alternatives, by using prospect theory and fuzzy set theory to optimize the alternative.

Based on the cooperative game model, this paper comprehensively considers three key influencing factors that affect the profit distribution of new energy projects under PPP mode: investment ratio, risk allocation and the enterprise's implementation capacity coefficient on energy project. Combined with the risks that the public and private sectors will face in the renewable energy construction projects, in this paper, the profit distribution model under the Nash negotiation and Shapely value method is constructed. Through the examples and the sensitivity analysis, two models are compared and the results will be used to guide practical activities of renewable energy power projects under PPP mode.

2. Model analysis based on cooperation game

The results show that individual rationality is not the optimal choice (Zhang, 2012); however, the joint rational behavior tends to make decision-making better. When the decisionmaking behavior of individual is hindered, generally, it will use improper behavior to get rid of difficulties. On the contrary, the joint rational will constrain the behavior of project participants through reasonable agreement, just to ensure that all members strive for the interests to the maximum. That is, through cooperative game analysis to solve the problem. PPP mode is typical of joint rational decision-making behavior.

Cooperative game can be divided into two cases (Wang, 2011). First, there is no internal alliance between the project participants, this time, what the participants concerned is not how to form an alliance, but how to get a profit distribution plan so that all participants are satisfied with. Nash negotiation model can solve such distribution problems. Second, there is a formation of alliances between the parties involved, this time, Shapely value method of cooperative game model can be used for the income distribution. In this paper, we will construct the income distribution model between PPP stakeholders (ie, public and private) in both cases.

2.1. Income distribution model based on Nash negotiation

(1) Assumptions

In renewable energy power projects under PPP mode, the following assumptions should be made to establish the cooperation among projects participants under the game Nash negotiation model.

a) The choice of partners is not constrained, project sponsor could select the best partners to complete the project jointly, according to the actual needs of renewable energy power projects;

b) The concession agreement, which has the same binding force to the parties, is drawn up by n project participants, and the project can only be completed by the joint efforts of n parties;

c) It is risk neutral for all participants;

d) The contribution of each participant in project can be measured by the weight coefficient x_i which is different in general;

e) In the consultation, the participants have their own psychological bottom line and psychological satisfaction, consultation with no less than the psychological bottom line as a benchmark;

f) The renewable energy subsidy has been taken into account in the proportion of income allocation that public and private sectors proposed initially, the model will no longer discuss as a separate factor.

(2) Income Distribution Analysis

Regardless of the internal alliance, the project participants put forward their own income distribution plan, in accordance with their actual pay in the project. Suppose that each of the n participants can only propose one solution, such as $B_i = \{b_{1i}, b_{2i}, \ldots b_{ni}\}$ represents the distribution proposed by the i-th participant, and b_{ji} represents the distribution coefficient of the i participant's contribution to the j-th participant, there is:

$$0 < b_{ji} < 1, \quad \sum_{j=1}^{n}, b_{ji} = 1\,. \tag{1}$$

The matrix of income distribution coefficients is as follows, which is composed of the income distribution scheme proposed by n project participants.

$$B = \begin{bmatrix} b_{11} & b_{21} & ... & b_{n1} \\ b_{12} & b_{22} & ... & b_{n2} \\ ... & ... & ... & ... \\ b_{1n} & b_{2n} & ... & b_{nn} \end{bmatrix} . \tag{2}$$

The distribution of proceeds is negotiated until distribution plan is satisfactory to all participants. For i-th project participant, the most satisfactory distribution coefficient is: $b_i* = \max\{b_{i1}, b_{i2}, \ldots b_{in}\}$, the most dissatisfied income distribution coefficient is: $b'_i = \min\{b'_1, b'_2, \ldots, b'_n\}$. The optimal and the worst allocation scheme of each participant in the PPP project is:

$$b^* = \{b^*_1, b^*_2, ..., b^*_n\} , \tag{3}$$

$$b' = \{b'_1, b'_2, ..., b'_n\} . \tag{4}$$

For each participant, if they all choose the optimal solution, then there should be:

$$\sum_{i=1}^{n} b^*_i \geq 1 . \tag{5}$$

It doesn't satisfy the constraint. In general, each project participant can negotiate a discount of the best income distribution result at the same time, so as to get a satisfactory distribution plan. If f_i denotes the discount of the i-th project participant, the final income can be expressed as:

$$\bar{b}_i = b^*_i - f_i . \tag{6}$$

However it should satisfy $\bar{b}_i \geq b'_i$. The psychological satisfaction degree of each participant is expressed by formula (7),

$$\lambda_i = \frac{\bar{b}_i}{b^*_i} . \tag{7}$$

Among them, $0 \leq \lambda_i \leq 1$, λ_i is the psychological satisfaction, the basis for consultation is:

$$\lambda'_i = \frac{b'_i}{b^*_i} . \tag{8}$$

Negotiation should be based on the establishment of $\lambda_i \geq \lambda'_i$, until the two sides meet the results so far.

(3) Determination of Model Parameters

a) Determination of Weight Coefficient

Assuming that x_i is the weight of each project participant, there is:

$$\sum_{i=1}^{n} x_i = 1 . \tag{9}$$

For renewable energy PPP projects, the value of x_i is determined by the investment ratio (I_i) of the renewable energy power project, the enterprise's implementation capacity (Ω_i), and the risk allocation (R_i). The expression for x_i is:

$$x_i = (I_i \times \Omega_i \times R_i) / \sum_{i=1}^{n} (I_i \times \Omega_i \times R_i) \,. \tag{10}$$

In the above formula, the investment ratio can be determined directly according to the concession agreement, the enterprise's implementation capacity and renewable energy risk allocation coefficient can be obtained by fuzzy analytic hierarchy process.

b) Determination of investment ratio for the public and private sector

The investment ratio here includes not only the initial investment, but also includes the follow-up to the implementation of additional investment, such as: technology, equipment, labor and other inputs. Set the investment ratio of the public as a_{11}, the private as a_{21}, there is: $a_{11} + a_{21} = 1$.

Generally determine the investment ratio of both parties referring to the following steps:

First of all, make sure the investment conditions of renewable energy project, and investigate the financing conditions of private sector;

Second, consider the project construction and the needs of operation, design to meet the different income requirements of public and private sectors in the financing program;

Finally, determine the optimal capital structure of the project, according to the concession agreement determine the investment ratio of the public and private.

c) Determination of risk allocation

The method of fuzzy analytic hierarchy process (AHP) is adopted to determine the risk allocation coefficient of public and private parties. Assume that a_{12}, a_{22} are the proportion of public and private risk allocation the project has m risks, each of which is sharing between the public and private with the coefficient as p_i, q_i, $p_i + q_i = 1$ there is:

$$a_{12} = w_1 p_1 + w_2 p_2 + ... + w_m p_m \,, \tag{11}$$

$$a_{22} = w_1 q_1 + w_2 q_2 + ... + w_m q_m \,, \tag{12}$$

Where w_i is the weight proportion of each risk. Based on the identification of renewable energy risks and the characteristics of PPP projects, this paper divides the risks of renewable energy PPP projects into four categories (Liu, 2013) according to the life cycle of the project, taking into account the respective interests of the project participants. There are several sub-factors for each type of risk factor, which establishes the hierarchy of risk indicators and identifies the main stakeholders of the risk, as shown in Figure 1.

Taking the construction phase of renewable energy PPP project as an example, this paper gives the method of determining single risk coefficient. As shown in Figure 1, F3={financing risk, duration extension risk, construction security risk, construction cost risk, construction quality risk }, according to the influence of sub-factor risk on the total construction risk, the weight is $a = (a_1, a_2, a_3, a_4, a_5)$, set up the evaluation standard of membership degree as $v = (0.1, 0.3, 0.5, 0.7, 0.9)$. The project management experts are invited to carry out the evaluation of the construction stage risks, and the experts' evaluation results are gathered and the fuzzy vectors U_i of each factor are obtained, and the fuzzy relation matrix is obtained as follows:

$$R_3 = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} \end{bmatrix}. \tag{13}$$

The risk factor matrix Z_3 of the single-factor risk in the construction stage is evaluated as follows:

$$Z_3 = a \times R_3 = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix}^{\mathrm{T}} \times \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} \end{bmatrix} = (z_1, z_2, z_3, z_4, z_5). \tag{14}$$

The share of public and private risk ratio is: $p_3 = Z_3 \times V^T$, $q_3 = 1 - p_3$.

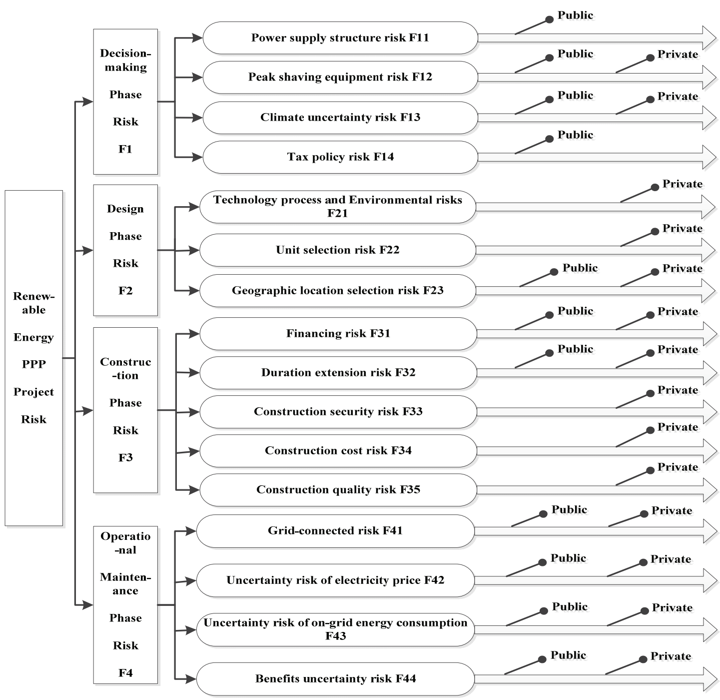

Fig. 1. Renewable energy PPP project risk assessment index system and the main risk bearer

d) Determination of the enterprise's implementation capacity coefficient

The enterprise's implementation capacity is an important measure of the success of the PPP model in the field of renewable energy construction. It includes the core technology, financial support, the management capabilities in stage of renewable energy construction and operation, etc (Xi, 2009) For the public sector, implementation capacity is mainly reflected in the financial support, that is to support the private enterprises in construction and operation through the development of power generation compensation mechanisms and related tax policies; for the private sector, mainly in the renewable energy core technology and operational management capabilities instead. Generally, the private sector's implementation capacity on renewable energy PPP project is in the dominant, which is one of the reasons that China encouraging private capital investment in the construction of renewable energy field. The implementation capacity on energy can be measured by the following steps:

First of all, based on public's and private's unique technology in renewable energy project, patents and human resources to determine the core technical capacity;

Secondly, through the enterprise scale, listing prospects and demand of renewable energy power generation market to measure the financial support;

Finally, through the third-party supervision department, measure to estimate the enterprise's capacity on construction, operation and management,

Owing to high risk of renewable energy PPP project, the capacity to attract private capital is relatively weak. The enterprise's implementation capacity on energy project reflects the willingness of cooperation between the two sides, the stronger the implementation capacity, the greater the willingness to cooperate, the greater likelihood of renewable energy PPP project success. According to the comprehensive judgment and measurement of relevant experts' opinions, the measure value of the coefficient of the implementation capability of the enterprise energy project is a_{13}, a_{23}.

(4) Model Construction

The core stakeholders in the renewable energy PPP project are generally referred to the public sector and the private sector. In this section, the Nash negotiation model is adopted to solve the problem of the public and private income distribution in the renewable energy project under PPP mode. This model can also be applied to solve the problem of multi-party income distribution of project participants more than two. The private sector, as discussed in this paper, refers to a collection of private investors and private construction and operation units. The model can also be used as a reference for the further distribution of private sector internal returns. Taking into account the distribution of income related to the core stakeholder input, the risk allocation and other factors, this paper choose to use asymmetric Nash negotiation model to solve the problem of income distribution. Using the previous set of assumptions, build the model as follows:

$$\max V = \prod_{i=1}^{n} (\frac{\bar{b}_i}{b_i^*} - \frac{b_i'}{b_i^*})^{x_i},$$
$$s.t. \begin{cases} \bar{b}_i \geq b_i' \\ \sum_{i=1}^{n} \bar{b}_i = \sum_{i=1}^{n} (b_i^* - f_i) = 1\,. \\ i = 1, 2, ..., n \end{cases} \tag{15}$$

(5) Model Solving

Substituting (10) into (15), there are:

$$\max V = \prod_{i=1}^{n} (\frac{\bar{b}_i}{b_i^*} - \frac{b_i'}{b_i^*})^{(I_i \times \Omega_i \times R_i)/\sum_{i=1}^{n}(I_i \times \Omega_i \times R_i)}. \tag{16}$$

Lagrange multiplier method is used to solve the above model:

$$\bar{b}_i = b_i' + (1 - \sum_{j=1}^{n} b_j') \cdot \frac{[(I_i \times \Omega_i \times R_i)/\sum_{j=1}^{n}(I_j \times \Omega_j \times R_j)] \cdot b_i^*}{\sum_{j=1}^{n} [(I_i \times \Omega_i \times R_i)/\sum_{j=1}^{n}(I_j \times \Omega_j \times R_j)] \cdot b_j^*}, i, j = 1, 2, ...n\,. \tag{17}$$

Substituting $x_i = (I_i \times \Omega_i \times R_i)/\sum_{i=1}^{n}(I_i \times \Omega_i \times R_i)$ into (17) simplifies:

$$\bar{b}_i = b_i' + (1 - \sum_{j=1}^{n} b_j') \cdot \frac{x_i \cdot b_i^*}{\sum_{j=1}^{n} x_j \cdot b_j^*}, i, j = 1, 2, ..., n\,. \tag{18}$$

The derivation of the above can be obtained:

$$\frac{\partial b_i^*}{\partial b_i'} = 1 - \frac{x_i \cdot b_i^*}{\sum_{j=1}^{n} x_j \cdot b_j^*} > 0\,, \tag{19}$$

$$\frac{\partial b_i^*}{\partial b_i'} = 1 - \frac{x_i \cdot b_i^*}{\sum_{j=1}^{n} x_j \cdot b_j^*} > 0\,. \tag{20}$$

Through the analysis of the results of model analysis, we can get: the profit distribution coefficient is composed of two parts, one is the retained yield coefficient b_i', and the other is the compensation of the i-th participant according to his contribution From the results of (19) and (20), the profit distribution coefficient of the project participants is positively correlated with the retained earnings coefficient, which is negatively correlated with the profit distribution coefficient of other participants.

2.2. Income distribution model of PPP project based on shapely value

The Shapely value method is proposed by Shapely L.S. to solve the problem of revenue sharing in multiplayer alliance (Xie, 2012). In this paper, we study the impact of public-private alliance on income distribution, and propose an income distribution model based on Shapely value for renewable energy PPP project. Taking into account the influence of contribution factors discussed above, we also use the factors such as investment ratio, risk allocation and the enterprise's implementation capacity coefficient on renewable energy project, to modify the distribution scheme determined by Shapely value method, in that way, to ensure the rationality of the allocation result.

(1) Assumptions

a) The overall income of the renewable energy PPP project is a fixed value;

b) Political and legal environment is stable, no significant impact on the implementation of the project decision-making;

c) The equilibrium of interests is static state, which can be finally achieved through coordination.

(2) Assignment Based on Shapely Value

In the Shapely value method, suppose N is the set of participants, $S \in N$ is a union in N, $v(s)$ is the profit of subset s, and the income of each participant in alliance N is called Shapely, referred to as $\emptyset(v) = (\emptyset_1(v), \emptyset_2(v), ..., \emptyset_n(v))$, Where $\emptyset_i(v)$ denotes the revenue of the i-th member in the coalition N, that is, the Shapely value, then the Shapely value of each member is:

$$\emptyset_i(v) = \sum \frac{(|s|-1)!(n-|s|)!}{n!} \left[v(s) - v(s/i)\right] . \tag{21}$$

Where s denotes the alliance that includes member i; $|s|$ denotes the size of the alliance; $v(s/i)$ denotes the income after deduction of member i in the alliance; $v(s) - v(s/i)$ can be regarded as the contribution of member i to alliance s.

(3) Modify Shapley Value

The above analysis shows that although the Shapely value method avoids the distribution of income among the participants, it is reasonable, but the actual risk of the individual and the contribution of the individual are not taken into account, the degree of influence on allocation of benefits is equal by default, ie. $1/n$. Therefore, it is necessary to consider impact of the above factors on the PPP project income distribution, and revise the shapely value.

On the basis of the Shapely value model, the factors influencing the distribution of benefits are fully considered, and the set of income distribution $J = \{I, R, \Omega\}$ is established. The variables in the set represent three key factors: investment ratio, risk allocation and the enterprise's implementation capacity coefficient on energy project.

The measure value of the j-th correction factor of the i-th partner in the set N is a_{ij}, and the analysis table is established as shown in Table 1.

Table 1. Measured values of Correction factors

$i \backslash j$	I	R	Ω
Public	a_{11}	a_{12}	a_{13}
Private	a_{21}	a_{22}	a_{23}

According to Table 1, the correction matrix A, which affects the profit distribution:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \end{bmatrix}. \tag{22}$$

The matrix A is normalized and the matrix $H = (h_{ij})_{n \times m}$ is obtained. Determine the impact of each factor on the distribution of income $\lambda = [\lambda_1, \lambda_2, \lambda_3]^T$, there are:

$$[R_1, R_2]^T = H \times \lambda\,, \tag{23}$$

R_1 represents the integrated impact of the factors on the public sector's income distribution; R_2 represents the combined effect of the factors on the private sector's income distribution; and the adjusted distribution of the actual benefits to each sector is:

$$V_1 = \phi_1 + (R_1 - \frac{1}{n}) \times V(s)\,, \tag{24}$$

$$V_2 = \phi_2 + (R_2 - \frac{1}{n}) \times V(s)\,. \tag{25}$$

Based on the above formula, we can obtain the profit distribution scheme of PPP project based on modified shapely value. This scheme takes into account the three key factors that affect the distribution of PPP benefits: investment ratio, risk allocation, and the enterprise's implementation capacity coefficient on energy project, by which the income distribution is further amended, making the scheme more fair, justifiable and objective.

3. Numerical example

Stakeholders of a foreign large-scale wind power PPP project are public sector G and private sector S. After expert assessment, the project total income is 20 million yuan. If the project does not adopt the PPP model, the income would be 6.5 million yuan and 7 million yuan by the public sector's or the private sector's independent implementation. The project investment is huge, according to the two sides agreement that the ratio of public and private investment were 0.4 and 0.6; through the assessment of the public and private sector's implementation capacity by experts and relevant advisory institutions, the coefficient is [2, 5]; and the coefficients of the three factors that affect distribution of income are $\lambda = [0.3, 0.6, 0.1]$ according to the expert evaluation, the risk allocation is evaluated according to the expert scoring. The results are shown in Table 2, from which the risk sharing factor can be calculated as: $R = [0.47, 0.53]$

Table 2. Risk index weight and share ratio

First level indicators	Index value	Second level indicators	Index value	Share ratio
F1	0.31	F11	0.26	
		F12	0.18	p1:0.8
		F13	0.21	q1:0.2
		F14	0.35	
F2	0.27	F21	0.35	
		F22	0.38	p2:0.15
		F23	0.27	q2:0.85
F3	0.24	F31	0.24	
		F32	0.16	p3:0.35
		F33	0.14	q3:0.65
		F34	0.18	
		F35	0.28	
F4	0.18	F41	0.26	
		F42	0.18	p4:0.55
		F43	0.24	q4:0.45
		F44	0.32	

3.1. Income distribution based on Nash negotiation

Before the formation of the project company, the public sector and the private sector put forward their own income distribution scheme, the initial income distribution of the coefficient matrix is:

$$B = \begin{bmatrix} 0.35 & 0.65 \\ 0.45 & 0.55 \end{bmatrix} .$$

By the income distribution matrix, the optimal income distribution scheme is:

$$b^* = \max\{b_1 \quad b_2\} = [0.45 \quad 0.65] .$$

The most dissatisfied income distribution scheme is:

$$b'' = \min\{b_1 \quad b_2\} = [0.35 \quad 0.55] .$$

The weight coefficient x_i of public and private parties is:

$$x_1 = (I_i \times \Omega_i \times R_i) / \sum_{i=1}^{n} (I_i \times \Omega_i \times R_i) = \frac{(0.4 \times 2 \times 0.47)}{(0.4 \times 2 \times 0.47 + 0.6 \times 5 \times 0.53)} = 0.19 ,$$

$$x_2 = 1 - x_1 = 1 - 0.19 = 0.81 .$$

According to the formula (18), the optimal profit distribution coefficient can be calculated:

$$\begin{aligned}\bar{b}_1 &= b'_1 + (1-(b'_1+b'_2)) \cdot \frac{x_1 \cdot b_1^*}{x_1 \cdot b_1^* + x_2 \cdot b_2^*} \\ &= 0.35 + \frac{[1-(0.35+0.55)] \cdot 0.19 \times 0.45}{0.19 \times 0.45 + 0.81 \times 0.65} = 0.364\,.\end{aligned}$$

$\bar{b}_1$ represents the satisfied proportion of the public sector, and the satisfied proportion of private sector is $\bar{b}_2$, which is 0.636.

3.2. Income distribution based on shapely value

From the above we can see that the proportion of public sector investment, that is $a_{11} = 0.4$; the proportion of private sector investment is $a_{21} = 0.6$; based on the known risk-sharing situation, the public sector risk allocation coefficient $a_{12} = 0.47$; the private sector risk allocation coefficient $a_{22} = 0.53$; The coefficient of energy project implementation ability of the two sides are respectively $a_{13} = 2$, $a_{23} = 5$.

The first step, calculate Shapely value according to the formula.

$$\begin{aligned}\phi_1 &= \frac{0!+1!}{2!} \times 650 + \frac{1!+0!}{2!} \times (1500-750) = 700\,, \\ \phi_2 &= \frac{0!+1!}{2!} \times 750 + \frac{1!+0!}{2!} \times (1500-650) = 800\,.\end{aligned}$$

In this case, the public and private's income distribution ratio are 0.47 in the public sector and 0.53 in private sector.

The second step, modify the Shapely value. The correction matrix is:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \end{bmatrix} = \begin{bmatrix} 0.4 & 0.47 & 2 \\ 0.6 & 0.53 & 5 \end{bmatrix}.$$

Normalize the above matrix to obtain the matrix H:

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \end{bmatrix} = \begin{bmatrix} 0.4 & 0.47 & 0.29 \\ 0.6 & 0.53 & 0.71 \end{bmatrix}.$$

According to the formula (23) to calculate the impact of various factors on the distribution of public and private benefits:

$$\begin{bmatrix} R_1 \\ R_2 \end{bmatrix} = H \times \lambda^T = \begin{bmatrix} 0.4 & 0.47 & 0.29 \\ 0.6 & 0.53 & 0.71 \end{bmatrix} \begin{bmatrix} 0.3 \\ 0.6 \\ 0.1 \end{bmatrix} = \begin{bmatrix} 0.43 \\ 0.57 \end{bmatrix}.$$

The income distribution scheme of the public and private sector is obtained according to the formulas (24) and (25):

$$V_1 = \phi_1 + (R_1 - \frac{1}{n}) \times V(s) = 700 + (0.43 - 0.5) \times 1500 = 595\,,$$
$$V_2 = \phi_2 + (R_2 - \frac{1}{n}) \times V(s) = 800 + (0.57 - 0.5) \times 1500 = 905\,.$$

After modification, the income distribution ratio of the public and private are 0.4 and 0.6.

3.3. Analysis of calculation results

Based on the above results, draw the income distribution diagram of cooperative game between public and private parties, as shown in Figure 2.

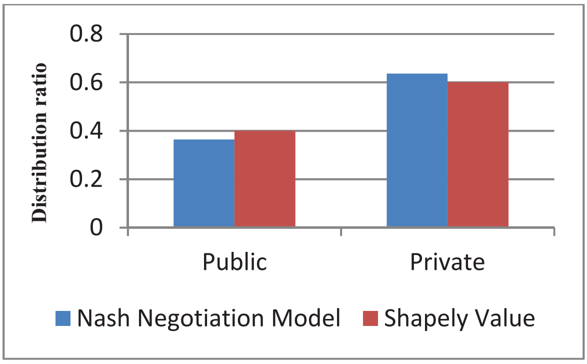

Fig. 2. Income distribution for two cooperative models

It can be seen from the figure that there is little difference between the Shapely value method and the Nash negotiation model From the result of income distribution, the private sector's coefficient is larger, mainly because the private sector is dominant in investment, risk allocation and the energy project implementation capacity, which is proportional to its contribution to the project, with a greater proportion of income as a consequence. Although the capital investment and implementation capacity by the public sector are not dominant, they share a lot of risks (mainly taking risks at the decision stage), so the proportion in the distribution of income is not too low. From the final distribution of income results, the proportion of public and private is about 4: 6, basically in line with the actual situation.

Although the results of the two models are different, they all have certain rationality. In order to study the applicability of the two methods of income distribution in the renewable energy PPP project, sensitivity analysis is carried out on the investment ratio, the enterprise's implementation capacity coefficient on energy project and proportion of risk allocation. Take the public sector's income distribution as the research object, the analysis results are shown in Figure 3.

From the results of sensitivity analysis, it can be seen that the influence of each factor change on the proportion of income distribution in Nash negotiation model is relatively small, mainly because the two most satisfied distribution coefficients of the initial allocation may have already considered their contribution to the project, so there is little change after adjustment of the distribution ratio; differently, there is obvious influence for the distribution of income determined by Shapely value, for which the variation is relatively large (in which the result is the most sensitive to the variation of risk allocation). This just verifies the necessity of modifying the initial Shapely value in the model. From the results of Shapely method, it can be seen that the proportion of the public sector is relatively higher than that of the Nash negotiation model, which shows that the Shapely value is a method of compassion for weak parties. Therefore, in the practical application of renewable energy PPP projects, the advantages and disadvantages of the two distribution schemes should be considered synthetically. The entropy method, just like Wen Jun used in the formation of air alliance (Wen, 2008), can be used to make a compromise on the allocation scheme, however, it will not discuss in this paper.

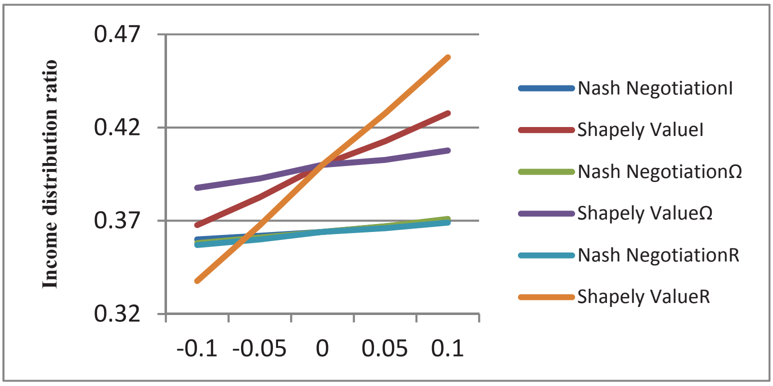

Fig. 3. Comparison of Sensitivity Analysis

4. conclusion

China is gradually encouraging private capital investment in wind power, biomass and other renewable energy projects, which laid foundation for the application of PPP mode in the field of new energy. With the background of renewable energy power, income distribution of PPP project is a new, systematic and complex problem, which directly affects the implementation of renewable energy PPP project.

Based on the analysis of cooperative game model, this paper considers three key factors that affect the distribution of PPP project income: the investment ratio, the risk allocation and the enterprise's implementation capacity on energy project. Combining the risks in the renewable energy construction project that stakeholders would face, the Nash negotiation model and the Shapely value method are given. Application recommendations are put forward through the numerical examples and sensitivity analysis of the results of two kinds of cooperative game model. This study will help to coordinate the interests of all parties involved in the conflict, to fully mobilize the enthusiasm of the private sectors, and laid foundation for the long-term development of private capital investment in the field of renewable energy power project.

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