Income Distribution of Forest Rights Transfer Cooperation Based on Game Theory: A Case of China

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Income Distribution of Forest Rights Transfer Cooperation Based on Game Theory: A Case of China[1]

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Abstract
Forest resources primarily characterize the terrestrial ecosystem and forest ecosystem is an important part of the global carbon cycle. Multiple participants to complete the large-scale production of forestland can effectively achieve carbon neutrality and realize the economic benefits of the forest industry, requiring far-reaching changes in the way forestland is managed. It is imminent to promote forest rights transfer between forest farmers and social capital. Based on the evolutionary game theory, we find that income distribution is a significant factor affecting the stable cooperation between business enterprises and forest farmers. To distribute income effectively within this cooperative framework, whereby farmers transfer their forest rights in different ways, we use a trapezoidal fuzzy number weighting method. This method improves the traditional Shapley value based on the investment and risk level of each participant in the cooperative alliance. Using a case study of forest rights transfer in Xin'tai city of China, we show that the improved Shapley value method can optimize the income distribution of forest rights transfer and ensure that all parties obtain long-term and stable benefits.

Keywords Forest rights transfer • Cooperation • Income distribution • Evolutionary game theory • Cooperative game theory

[1] Wei Zhang and Xian Qin contributed equally to this paper.

Declarations

- **Ethics approval and consent to participate**

Not applicable

- **Consent for publication**

Not applicable

- **Availability of data and materials**

All data generated or analysed during this study are included in this published article [and its supplementary information files]

- **Competing interests**

The authors declare that they have no competing interests

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- **Authors' contributions**

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Writing - original draft preparation:Xian Qin;
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Wei Zhang and Xian Qin contributed equally to this paper. Wei Zhang and Xian Qin read and approved the final manuscript.

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1. Introduction

Satellite remote sensing data up to 2017 reveals China`s manifest forest scale, which plays a leading role in the growth of the global forest area. Increasing forest cover is considered one of the most efficient strategies for GHG emissions.The future forest carbon sink supply potential is great, and it is the key aspect of China's "Forestry Action Plan to Address Climate Change".The 13th Five-Year Plan for Ecological Environmental Protection in the People`s Republic of China also considers strengthening environmental protection such as increasing forest utilization and ultimately achieving sustainable economic and social development to be core tasks. Such tasks are not only dependent on forestland management by government as the sole actor. As per the report of the 19th National Congress of the Communist Party of China, the government proposes to build an environmental governance system led by it, along with the participation of social organizations and the public (Xi 2017). It seeks to explore green development with the participation of multiple entities (Liu et al. 2016; Emerson et al. 2012; Mohammed et al. 2017; Gray et al. 2012).

Forestry is not only the main front of the construction of an ecological civilization, but also crucial to economic and social benefits (Kline et al. 2005; Dai et al. 2009; Hou et al. 2019; Liu et al. 2019).Small-scale forest farmers in China are the main force of forest management and the main body of forest carbon sink supply. Management of traditional forest fragmentation has higher operating costs due to lack of scientific management, and small area of forestland; this also means there is poor ability to resist natural disasters (Stone et al. 2012; Mehmood et al. 2001; Butler et al. 2004; Haines et al. 2011). Further, scale and industrialization of trees or undergrowth cash crops becomes difficult. Smallholder farmers`information asymmetry and weak market negotiation capabilities are not conducive to carbon sink trading and hinder the timely adoption of preferential policies such as forestry subsidies and special funds for forest rights transfer (Liu et al. 2011), which become barriers to achieving carbon neutrality. Promoting forest rights transfer is an vital way to develop forestry carbon sinks and achieve carbon neutrality.

Therefore, it is necessary to change the non-cooperative state of the decentralized management of forestland, explore key factors affecting the cooperation of forestry rights transfer, and promote cooperation among transfer parties.

So far, cooperation between forest farmers and social capital has achieved fruitful results in some areas of China: Zhejiang province was first to implement certificates for forestland management rights transfer to promote a shareholding system, such as family forest farms. Thus, the province accelerated the reform of the forest tenure transfer mechanism and increased forest carbon sink through reforestation and forest quality improvement . Poor areas in the central and western regions of China have also promoted the transfer and cooperative management of forestland. Support policies for the natural resources industry have been introduced, for instance, to develop emerging industries, such as forest tourism, recreation and leisure services, forest economy, and forestry carbon sink trading. Thus, these regions have explored the development path of modern forestry that is conducive to achieving carbon neutrality , realized the vision that “lucid waters and lush mountains are invaluable assets.”

With the implementation of forest rights transfer, relevant research, primarily in two areas, has also increased. First, studies have analyzed and evaluated the economic, ecological, and social benefits of forest right transfer; determined the advantages of forest right transfer for grassroots livelihood construction and environmental protection; and proposed policy recommendations thereof (Yi et al. 2014; Castella et al. 2006). Second, a wide range of literature is now available that studies the influencing factors of forest rights transfer. These factors include: age, gender, education level of the household`s head (Markowski-Lindsay et al. 2017), household economic characteristics (Xu et al. 2013), size of reserved forestland by owners (Zhu et al. 2019), use of forest management plans, professional forestry consultation, use of forestry cost sharing funds (Hatcher et al. 2013), urban–rural characteristics (Pan et al. 2009), buyer or seller satisfaction with the transaction price (Markowski-Lindsay et al. 2017; Xu et al. 2013), and regulatory uncertainty (Mehmood et al. 2001). However, few studies exist on forest rights transfer from the perspective of income distribution. The extant literature has mostly analyzed strategies of co-management involving local communities in the management of forest resources based on a cost–benefit of the *transferor* and the *transferee*. These studies have proposed measures to improve the income level of both parties and strengthen cooperation (Shahi et al. 2007; Andrés-Domenech et al. 2015).

In the forest rights transfer between forest farmers and social capital, income is a key and contradictory issue. It concerns the economic interests of forest farmers and long-term cooperation. In this context, scholars have applied evolutionary games to joint forest management (Shahi et al. 2007), construction of ecological corridors (Li et al. 2017), local commons management (Ito 2012), and land management (Xie et al. 2018; Zhang et al. 2015). Drawing on these extant studies, we use evolutionary game theory in the context of cooperation of forest rights transfer between business enterprises and forest farmers. We thus establish an evolutionary game model to determine key factors that influence participants' strategies in forest rights transfer. We further analyze cooperative income distribution as the main factor and use the improved Shapley value method to design the income distribution plan of each participant. Our objective is to use these methodologies to ensure long-term stable benefits to both partners, which would increase the stability of the cooperation and realize the ecological and economic goals of large-scale management of forestland.

2. Evolution game theory of forest rights transfer

2.1 Theoretical background

Decentralized forestland management poses difficulties for carbon neutrality and creating economies of scale. The uneven distribution pattern of forest rights has led to the failure of centralized utilization of forest resources. Therefore, it is essential to achieve *Pareto optimality* by adjusting this distribution.

Property rights theory emphasizes that the "property right" allows the exclusive ownership of natural resources, whereby incentives can mobilize subjects of property rights (Batty 2006).

The transfer of forest rights is manifest in the replacement of business entities; it is the further division of labor in forestry production and management (Zhang et al. 2017b; Qin et al. 2013). Being the transferees of forestry rights, business facing carbon emission requirements enterprises have more advantages by way of better capital, technology, and social network than forest farmers do in afforestation or processing. According to the theory of comparative advantage, business enterprises participating in forestland management can promote intensive and large-scale operation of forestland to increase carbon sink , stimulate the inherent potential of forest resource quality improvement, and realize win‑win strategies where they profit while increasing the income of forest farmers. Under the premise of the interest accord and the consistency of ecological goals, forest rights transfer is the best choice for transfer parties. The transfer parties thus form a cooperative alliance for benefit sharing, risk sharing, coordination, and symbiosis (Dai et al. 2013; Butler et al. 2004).

However, participants often seek trading partners to maximize income, revealing conflicts in the transfer of forest rights. In the transaction between forest farmers and social capital, some social capital will also consume a considerable portion of the differential rent while earning engineering profits. The transaction of forest rights transfer lacks a standardized pricing mechanism. Forest farmers can easily underestimate the value of forestland due to the objective influence of "rent-seeking" behavior and subjective misjudgment of market conditions. The distribution of income thus depends on the strength of the two parties in the transaction. However, the business enterprise is a more dominant actor, placing forest farmers at a disadvantage. Hence, the business enterprise is very likely to overpower the rights and interests of forest farmers (Tang et al. 2013). Therefore, participants usually adjust their strategies according to their own conditions, the external environment, and the competitors itself in the forest rights transfer. After this dynamic correction process, participants finally attain stability.

2.2 Hypothesis of the evolutionary game

Hypothesis 1: The participants of forest rights transfer include a business enterprise and some forest farmers. The business enterprise is engaged in the large-scale operation of forestland and pursues carbon sink reserves and the maximization of profits. Whether the forest farmers transfer the forestland depends on the size of the transfer income.

Hypothesis 2: The net income of a business enterprise and forest farmers is respectively I_1 and I_2 without the forest rights transfer. They will achieve large-scale production and realize the added value of the forestland after cooperation. The additional income obtained by the two parties is respectively e_1 and e_2, and the distribution of the additional income affects the stability of the cooperative alliance.

Hypothesis 3: The government subsidizes business enterprises in afforestation, tree tending and protection, management of forest fire prevention, pest control, forestry, and biogas construction every year (Lu et al. 2018; Qin et al. 2015; Dai et al. 2011), denoted by B. When business enterprises have cooperative intentions, they usually look for intermediaries to understand the status of forest farmers' transfer, hire experts to consult information, estimate forestland prices, and re-plan forestland. Therefore, the information, inquiry, negotiation, transaction, valuation, and contract costs (Gong et al. 2010) involved in forest rights transfer and the cost of arranging forestland are indicated by T.

Hypothesis 4: Forest farmers invest in the construction of houses, equipment, and other fixed assets on the forestland. However, these fixed assets are demolished without reaching their expected useful life because of the forest rights transfer. Therefore, forest farmers lose the discounted value of fixed assets denoted by F when participating in the cooperation. If some forest farmers work in forestland managed by business enterprises, receiving wages after transferring, this part of the compensation does not belong to the forest farmers' income in the transfer of forest rights.

2.3 Evolution path of forest rights transfer cooperation

Based on the analysis in the previous section, Table 1 reports the payoff matrix of the cooperative evolutionary game.

Table 1 Payoff matrix of the cooperative evolutionary game

		Forest farmers	
		Cooperation	Noncooperation
The enterprise	Cooperation	（I_1+B-T+e_1，I_2-F+e_2）	（I_1-T，I_2）
	Noncooperation	（I_1，I_2-F）	（I_1，I_2）

The transfer of forest rights between business enterprises and forest farmers is uncertain and both parties may change their willingness to cooperate according to changes in the cooperation conditions. Therefore, *cooperation is a probabilistic event*. Assume that the proportion of business enterprises choosing the strategy of forest rights transfer is $p(0\leq p\leq 1)$ and the proportion not choosing is (1-p). Then, the probability of forest farmers choosing the strategy of forest rights transfer is $q(0\leq q\leq 1)$ and the probability of not choosing is (1-q).

The income of a business enterprise that chooses to cooperate with forest farmers is

$$E^{a}{}_1 = q(I_1 + e_1 + B - T) + (1-q)(I_1 - T) \quad (1)$$

The income of a business enterprise that does not choose to cooperate with forest farmers is

$$E^{b}{}_1 = qI_1 + (1-q)I_1 \quad (2)$$

The average income of a business enterprise is

$$\overline{E}_1 = pE^{a}{}_1 + (1-p)E^{b}{}_1 = p[q(I_1 + e_1 + B - T) + (1-q)(I_1 - T)] + (1-p)[qI_1 + (1-q)I_1] \quad (3)$$

According to the same method, the average income of the forest farmers is

$$\overline{E}_2 = q[p(I_2 + e_2 - F) + (1-p)(I_2 - F)] + (1-q)[pI_2 + (1-p)I_2] \quad (4)$$

The replication dynamic equation of the business enterprise and forest farmers according to time is respectively

$$\frac{dp}{dt} = p(\overline{E}_1 - E^{a}{}_1) = p(1-p)[q(e_1 + B) - T] \quad (5)$$

and

$$\frac{dq}{dt} = q(1-q)[pe_2 - F] \quad (6)$$

We can obtain the stability of the population evolution dynamic system through the local stability analysis of the system Jacobian matrix (Friedman 1991). This allows us to study the decision evolution of forest rights transfer between the business enterprise and forest farmers.

The Jacobian matrix for the dynamics of the system is

$$J = \begin{Bmatrix} \dfrac{\partial Fp}{\partial p} & \dfrac{\partial Fp}{\partial q} \\ \dfrac{\partial Fq}{\partial p} & \dfrac{\partial Fq}{\partial q} \end{Bmatrix} = \begin{Bmatrix} (1-2p)[q(e_1 + B) - T] & (e_1 + B)p(1-p) \\ e_2 q(1-q) & (1-2q)(pe_2 - F) \end{Bmatrix} \quad (7)$$

The determinant of the Jacobian matrix is *detJ* and the trace of the matrix is *trJ*. Then, their respective expressions are

$$\det J = \frac{\partial Fp}{\partial p}\frac{\partial Fq}{\partial q} - \frac{\partial Fp}{\partial q}\frac{\partial Fq}{\partial p} = (1-2p)(1-2q)[q(e_1 + B) - T](pe_2 - F) - pq(1-p)(1-q)(e_1 + B)e_2$$

and (8)

$$trJ = \frac{\partial Fp}{\partial p} + \frac{\partial Fq}{\partial q} = (1-2p)[q(e_1 + B) - T] + (1-2q)(pe_2 - F) \quad (9)$$

We conduct the dynamic analyses of the two equations according to the stability condition: $\frac{dq}{dt}=0$ $\frac{dp}{dt}=0$. The saddle point of the system is $p^*=\frac{F}{e_2}$, $q^*=\frac{T}{e_1+B}$. Therefore, the equilibrium points of the dynamic game matrix of the forest rights transfer are respectively O(0,0), A(0,1), B(1,0), C(1,1), and E(p^*,q^*). These five equilibrium points are substituted into the *detJ* and *trJ* of the Jacobian matrix. Table 2 reports the stability of each equilibrium point. O and C are the stable strategies of the evolutionary game, which respectively correspond to the strategies of both *noncooperation* and *cooperation*. There are two unstable points A and B, along with one saddle point E, in the system.

Table 2 Stability analysis of the partial equilibrium points of the forest rights transfer

Equilibrium	Symbol of *detJ*	Symbol of *trJ*	Partial stability
$p=0$, $q=0$	+	-	Evolutionary stable
$p=0$, $q=1$	+	+	Unstable strategy
$p=1$, $q=0$	+	+	Unstable strategy
$p=1$, $q=1$	+	-	Evolutionary stable
$p=p^*$, $q=q^*$	-	0	Saddle Point

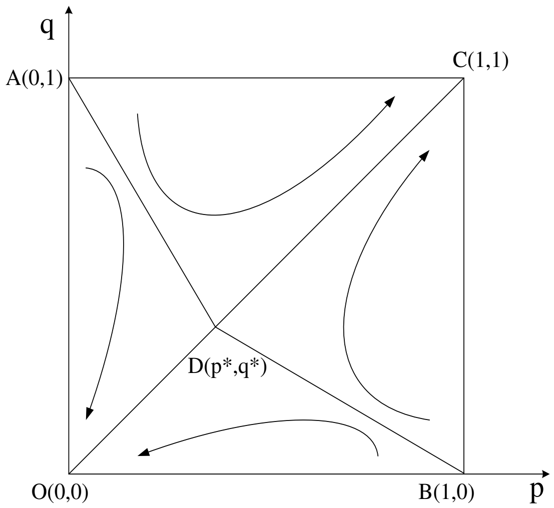

Fig. 1 Phase diagram of the evolution game in the cooperation of forest rights transfer

Figure 1 illustrates the dynamic evolution. The evolutionary game system is divided into two regions with different evolutionary processes by the equilibrium point. The critical line between the different states of the evolutionary game of cooperation is the connection between each equilibrium point and the saddle point. The equilibrium point ADBC constitutes the upper-right area of the evolutionary game system. When the initial state falls in this area, the system converges to C(1,1), whereby the evolutionary stable strategy is the one in which the business enterprise and forest farmers choose cooperation. The equilibrium point ADBO constitutes the lower-left area of the evolutionary system. When the initial state falls in this area, the system converges to O(0,0), whereby the evolutionary stable strategy is the one in which the business enterprise and forest farmers choose noncooperation. The centralized operation of decentralized forestland can reach Pareto optimality and generate additional cooperation income, ensuring the overall income is greater than the sum of the benefits obtained by each participant when operating alone, thus achieving the effect of 1+1>2. Forest farmers will also receive more benefits through cooperation than when operating forestland alone.

To make the initial state fall in the ADBC area to the best extent possible *and* make saddle point E approach point C along the OC path, we must determine how to distribute additional income (e_1, e_2) to business enterprises and forest farmers. This is crucial to the forest rights transfer as well as for increasing subsidies for forest rights transfer (B) and reducing transaction costs (T), as reported in Table 3.

Table 3 The influence of various parameters on the cooperative evolution of forest rights transfer

Change of parameters	Change of saddle point	Change of phase area and evolution direction
F↓	p*↓	S_{ADBC}↑, Cooperation
e_2↑	p*↓	S_{ADBC}↑, Cooperation
T↓	q*↓	S_{ADBC}↑, Cooperation
e_1↑	q*↓	S_{ADBC}↑, Cooperation
B↑	q*↓	S_{ADBC}↑, Cooperation

The cooperative alliance sets the distribution rules to achieve Pareto improvement, ensuring that each participant can obtain more benefits than before joining the alliance. However, the additional income is certain under the conditions determined by the scale and technical level. Further, the amount of income distributed among the participants will affect their willingness to cooperate. If distribution of additional income is unreasonable among the participants, only a few forest farmers would have the willingness to cooperate with the business enterprise. Hence, the forestland after the transfer can still not achieve large-scale operation to realize carbon neutrality and economic value-added benefits.

Income distribution is an important part of the cooperation agreement because it guarantees a contract and incentive. It affects the interests of the two parties, by motivating them to participate in the cooperation as well as long-term willingness to cooperate. Therefore, it is necessary to design a reasonable income distribution mechanism.

Scholars have used the Shapley value method to solve the distribution of gas emissions reduction through cooperation of neighboring areas (Xie et al. 2016; Luqman et al. 2018); distribution of costs and benefits from international transmission interconnections under a cooperative agreement (Kristiansen et al. 2018); and revenue distribution in the cooperation among farmers sharing complementary resources (Gerichhausen et al. 2009). Based on the previous research, the Shapley value method is adopted as the basis for the income distribution by using the principle of the cooperative game.

3. Materials and methods

3.1 Interest of participants

It is imperative to clarify the interest relationship between the business enterprise and forest farmers in the forest rights transaction in order to study the distribution of income. Notably, different types of forest rights transfer will produce different interest associations.

There are three main types of forest rights transfer in China: The first form is the one-time transfer (Liu et al. 2011). The parties of the transaction establish contractual relationships by negotiation or auction. The business enterprise obtains all or part of the management rights of the forestland, and the forest farmers receive a one-time transfer income. The forest farmers who choose the one-time transfer usually need a large amount of capital inflow, but also need to bear the risk of losing land.

In the second type of transfer, the forest farmers share the forest right as an investment into the business enterprises to form a forestry cooperative organization. In the future, the forest farmers will receive dividends according to the shareholding ratio in order to obtain long-term stable income (Song et al. 2004; Gong et al. 2010). Generally, the method of “guaranteed income and value-added income” is adopted. The guaranteed income is available every year, while the value-added income is distributed to forest farmers based on a certain proportion. In practice, it is represented by a forestry stock cooperation.

The third type of transfer is leasing (Siikamäki et al. 2015). The business enterprise leases the forestland decentralized by the forest farmers for several consecutive years and pays the rent to the forest farmers. The business enterprise enjoys the profit and bears the risk independently after leasing.

According to the analysis above, we establish the utility function of the forest rights transfer, derive the utility function of the alliance cooperation, and use the Shapley value as the initial distribution method of the alliance cooperation income to explore the optimization strategy of income distribution of forest rights transfer.

3.2 Utility function of forest rights transfer

Suppose there exist is a business enterprise E and a number of forest farmers F to transfer forest rights using the three types of transfers explained above, in which j area of forestland is transferred to the business enterprise at one time, k area of forestland is invested into the business enterprise, and l area of forestland is leased to the business enterprise. J^E represents the utility function of the business enterprise and J^F represents the utility function of all the forest farmers who participate in the forest rights transfer in the region. J^T is the total effect function of the business enterprise and forest farmers.

Since the time of forestland management after transferring is long, the business enterprise obtains income and annually pays the cost during the operation period. The forest farmers who share the forest right as an investment will receive the break-even income and dividends according to the capital contribution ratio annually. The forest farmers who rent the forest right will also receive an annual rental income. Further, the government subsidizes the forestland annually, so we introduce a discount rate, denoted by r, and t indicates the length of the years after the forestland is transferred to the business enterprise. It takes m years to delay from the completion of forest rights transfer to achieve earnings.

The utility function of a business enterprise can be divided into two parts: one for income and the other for expenditure. Income involves forest carbon sink or productive income and government forestland subsidies. Expenditure includes the total transaction cost, cost of forestland consolidation, operating cost after transferring, cost of one-time transfer, continuous dividend, and leasing during the forestland use period (Zhu et al. 2018). Assuming that the period expenses and taxes generated in the operation process of the business enterprise are excluded, the utility function of the business enterprise is

$$U^E = \sum_{t=m}^{n} \frac{PQ}{(1+i)^t} - \sum_{t=1}^{n} \frac{C_v Q + C_f}{(1+r)^t} + \sum_{t=1}^{n} \frac{GQ}{(1+r)^t} - HQ - wO - \Big(jS + k \sum_{t=1}^{n} \frac{Z}{(1+r)^t} +$$

$k\sum_{t=m}^{n}\frac{aD}{(1+r)^t} + l\sum_{t=1}^{n}\frac{B}{(1+r)^t}\Big)$,

(10)

where P is the annual income per unit area of the forestland after re-planning. C_v is the variable cost per unit area of forestland. Q is the forestland area. C_f is the fixed cost. G is the government's subsidy income per unit area of forestland. H is the planning cost per unit area. O is the transaction price of the forestland and w is the agency fee divided by forestland price. S is the compensation per unit area for forest farmers of one-time transfer. D is the annual operation income after the forest rights transfer and a is the percentage of dividend income obtained by the forest farmers who share the forest rights as an investment into the business enterprises divided by operating income. Z is the annual guaranteed income. B is the annual forestland rent obtained by the forest farmers through leasing.

The total utility function of forest farmers comprises the total income and the total expenditure. The income includes the one-time transfer income, break-even income, continuous dividends, and rent income. Expenditure includes the fixed asset investment cost C_P. The total utility function of forest farmers is

$$U^F = jS + k\sum_{t=1}^{n}\frac{Z}{(1+r)^t} + k\sum_{t=m}^{n}\frac{aD}{(1+r)^t} + l\sum_{t=1}^{n}\frac{B}{(1+r)^t} - C_P. \quad (11)$$

Taking the two utility functions into consideration, the total utility function of the business enterprise and forest farmer is summed up by equations (1) and (2) as follows:

$$U^T = \sum_{t=m}^{n}\frac{PQ}{(1+i)^t} - \sum_{t=1}^{n}\frac{C_vQ+C_f}{(1+r)^t} + \sum_{t=1}^{n}\frac{GQ}{(1+r)^t} - HQ - wO - C_P. \quad (12)$$

In comparison, forest farmers have relatively less explicit contributions to the alliance, but they pay for the use of forestland. After the transfer, the forestland operated by the business enterprise needs to produce higher economic benefits in the future to protect the interests of forest farmers. To gain higher economic benefits, scattered forestland must be concentrated to allow both the business enterprise and forest farmers to bear the risk of cooperation. In the production and operation process, the increase of forestland leads to the increase of forestland output. The fixed cost is constant, so the average cost decreases with the increase in output, while the total utility function increases with the decrease in average cost and the increase in scale return of cooperation.

3.3 Improved Shapley value of income distribution

The Shapley value method distributes the participants' income according to the contribution of the members of the cooperative alliance, which is fairer than the average distribution or the proportion according to the input resources (Shapley 1953).

$$\phi_i(v) = \sum_{s\in S_i}\frac{(n-k)!(k-1)!}{n!}[v(s) - v(s\backslash\{i\})].$$

(13)

We define n as the total number of participants in the cooperative alliance game $B(n,V)$, i as a participant in the cooperative alliance, s as an alliance comprising two or more participants, and k as the number of participants in this alliance. The expression $\frac{(n-k)!(k-1)!}{n!}$ is the probability that participants i will participate in the alliance s when they cooperate in a random form. $v(s)$ is the total income of the alliance. $v(s\backslash\{i\})$ indicates income that alliance s excludes from participant i, and thus $v(s)$- $v(s\backslash\{i\})$ is the marginal loss caused by the loss of participant i to the total income, which can be considered contribution to the alliance of participant i.

In the default condition of the traditional Shapley value, the alliance participants equally share the investment and risk. However, this is inconsistent with reality, wherein different participants of the alliance take on different proportions of investment and risk. The participants that bear greater risk and invest more in the alliance should be distributed additional income to ensure stable cooperation (Xu et al. 2018). For example, there is a considerable difference in investment (or "devotion") between the business enterprise and forest farmers. The business enterprise needs to invest in management of forestland, provide jobs for some forest farmers (Whiteman et al. 2015), improve the local ecological environment, and achieve social, economic, and ecological benefits. There is considerable difference in risk sharing among forest farmers depending on how they transfer forest rights. Forest farmers who choose a one-time transfer can achieve income once, while those who transfer through leasing can obtain a stable annual rent. However, the incomes of forest farmers who share the forest rights as stock depend on the net income of the business enterprise, which entails significant uncertainty. Therefore, the Shapley value should be updated by introducing a *devotion factor* and *risk factor* for achieving fair and effective income distribution.

Following Wang et al. (2009) and Chou et al. (2008), we use the trapezoidal fuzzy number weighting method to calculate the weight of the participants in the cooperative alliance. This is a widely used fuzzy number form that can reflect the fuzziness of expert evaluation.
The first-level factor is the participant of the forest rights transfer and the second-level factor is the level of devotion and risk (Table A.1). Each factor of the first level is weighted based on the second-level factor. Table A.2 lists the importance of the weights of the individual factors using linguistic variables.

The procedure for the trapezoidal fuzzy number weighting method is as follows:

(1) We first choose members of the appraisal group and determine their weight first. To reflect the scientific quality and fairness of the appraisal, the appraisal group comprises third parties independent of the cooperative alliance, such as university scholars, government representatives, business enterprises, and forest farmers. Assume that the group of experts is a homogeneous group and the number of experts is n and the weight of each member is $R=1/n$.

(2) The members of the appraisal group evaluate the importance of each level factor according to Table 2, and then calculate the comprehensive weight. Assume that the k$^{\text{th}}$ ($k=1,2,\ldots,n$) member evaluates the importance of the second-level factor I_m as $W_{mk}=(a_{mk}, b_{mk}, c_{mk}, d_{mk})$ and the aggregated fuzzy weight of the factor I_m is $W_m=(a_m, b_m, c_m, d_m)=(\sum_{k=1}^{n} R_k a_{mk}, \sum_{k=1}^{n} R_k b_{mk}, \sum_{k=1}^{n} R_k c_{mk},$

$\sum_{k=1}^{n} R_k d_{mk})$.

(3) The defuzzification weight of I_m is $d(W_m)=(a_m+b_m+c_m+d_m)/4$ and the normalized fuzzy weight of I_m is $W_m`=d(W_m)/\sum_{m=1}^{t} d(W_m)$. In this study, there are two second-level factors. Similarly, the normalized fuzzy weight of another factor can be calculated. Therefore, the weight vector of

the second-level factor is $W_2=(W_{21}`,W_{22}`)$.

(4) We repeat the previous steps to determine the weight of the first-level factor with the same method. There are four first-level factors and the weight vector is $W_1=(W_{11}`,W_{12}`,W_{13}`,W_{14}`)$. The first-level factor weight vector W_1 and the second-level factor weight vector W_2 are multiplied, that is, $W_S=(W_{S1}, W_{S2}, W_{S3}, W_{S4})=W_1\times(W_2)^T$. The unitization of W_S is $W_{Si}`=W_{Si}/\sum_{i=1}^{4} W_{Si}$ . Therefore, the weight of income distribution determined by the appraisal group is $W_S`=(W_{S1}`,W_{S2}`,W_{S3}`,W_{S4}`)^T$.

As discussed, the traditional Shapley value method distributes the income of the participants in the cooperative alliance based on the same weight 1/n, disregarding the influence of other factors. Thus, it is modified based on the weights of participants (Xu et al. 2018).

We introduce a comprehensive correction factor $\Delta W_{Si}`=W_{Si}`-1/n$, where $\sum_{i=1}^{n} \Delta W_{Si}`=0$. Assume that the initial income distribution of the participants in the cooperative alliance is $H_i$, the income when forming the largest cooperative alliance is $C_S$, and the adjusted income distribution of the participants is $\Delta H_i=C_S\times\Delta W_{Si}`$. Then, the final income distribution of the cooperative alliance is $H(i)=H_i+\Delta H_i$.

4. Results and discussion

4.1. Case study

Xin'tai City, Shandong Province is located in the connecting area between Mount Tai and Mount Meng, a region that is mountainous and hilly, making the development of forestry suitable. In recent years, the government has systematically standardized forest rights transfer, attracting social capital into the forest through auctions, biddings, and shareholding cooperation. It has been guiding the cooperation between business enterprises and forest farmers in particular, with the area under forest rights transfer reaching 250,000 mu. The ecological effect is thus remarkable.

The committee of Yuzaolin Village seized the opportunity arising from new constructions in rural communities by encouraging forest farmers to transfer forest rights to business enterprises through the "shares + cooperation" model. It established Demonstration Park Co., Ltd. to double the value per mu of land. This strategy allowed villagers to earn rent, salary, and capital paid for shares in the development of the industry. The forest farmers in Zhangjialanzi Village and Mayu Village of Quangou Town transferred forest rights to professional cooperatives. Under central planning, they planted walnut trees, which have market competitiveness, conserve water, prevent strong winds, and consolidate land. Moreover, they established ecological forest tourist areas to increase carbon sink income and tourism income.

4.2 Data

Based on the actual status of forest rights transfer in Xin'tai City and to simplify the expression of the utility function, we assume that the area of forest rights transfer by one-time transfer, shareholding, and leasing is equal. The income per unit area of forestland, variable cost per unit area, and fixed cost are calculated from the average value of carbon sink, various forestry crops, tourism, and healthcare services after forest rights transfer. Table 4 reports the values of all variables.

Table 4 Description of variables

Notation	Variable name	Variable value	Unit
P	Income per unit	1	10,000 RMB/mu
C_v	Variable cost per unit	0.2	10,000 RMB/mu
C_f	Fixed cost	15	10,000 RMB
G	Government subsidies per unit	0.01	10,000 RMB/mu
H	Planning cost per unit	0.5	10,000 RMB/mu
w	Agency fee divided by forestland price	0.01	——
j	One-time transfer area	1000	mu
S	Price of one-time transfer per unit	1.4	10,000 RMB/mu
k	Shareholding area	1000	mu
Z	Guaranteed income per unit	0.05	10,000 RMB/mu
a	Percentage of dividends	0.08	——
l	Leased area	1000	mu
B	Rent per unit	0.09	10,000 RMB/mu
C_P	Fixed asset investment cost	0.01	10,000 RMB/mu
m	Lag time of achieving earnings	2	Year
n	Operating time after forest rights transfer	20	Year
r	Discount rate	0.03	——

4.3 Measure of Shapley value

The business enterprise E and forest farmers J, K, and L who transferred out of forest rights through one-time transfer, shareholding, and leasing are involved in the transfer of forest rights. Therefore, the combination of participants is N={J, K, L, E}. The cooperative alliance S is a subset of the set N. Since the forest rights transfer process is completed by the business enterprise and forest farmers in one or more form of transfer, there are seven cooperative alliances that can be formed. Using the variables in Table 4 in combination with the total utility function formula (12), we generate seven cooperative alliance benefits (Table A.3).

We calculate the Shapley value of the participants according to formula (13); Table 5 reports the Shapley value of forest farmers under a one-time transfer.

Table 5 Shapley value of forest farmers with one-time transfer

S	V(S)	(n-k)!(k-1)!/n!	(s/i)	V(s/i)	V(s)-V(s/i)
{J,E}	9390.12	1/12	{E}	0	9390.12
{J,K,E}	19009.97	1/12	{K,E}	9396.68	9613.29
{J,L,E}	19004.02	1/12	{L,E}	9390.73	9613.29
{J,K,L,E}	28623.86	1/4	{K,L,E}	19010.58	9613.29

$$\phi(\mathrm{J}) = 9390.12 \times \frac{1}{12} + 9613.29 \times \frac{1}{12} + 9613.29 \times \frac{1}{12} + 9613.29 \times \frac{1}{4} = 4788.05$$

Similarly, $\phi(\mathrm{K}) = 4791.33$, $\phi(\mathrm{L}) = 4788.35$, and $\phi(\mathrm{E}) = 14256.14$.

The income distribution is modified according to the improved Shapley value income distribution system. The appraisal group consists of 3 scholars in the forest rights transfer field, 2 members of government, 2 forest farmers and 2 business enterprise representatives, and adopts the method of affirmative decision-making. The weight is determined by the trapezoidal fuzzy number according to the score of each member of appraisal group. The weight value of the first and second level factor is calculated as shown in Table A.4 and Table A.5 .

The weight vectors of the two-level factors are

$$W_1 = \begin{bmatrix} 0.1784 & 0.1636 \\ 0.1073 & 0.1120 \\ 0.1020 & 0.1334 \\ 0.0966 & 0.1067 \end{bmatrix}, W_2 = \begin{bmatrix} 0.5231 & 0.4769 \end{bmatrix}$$

$$W_S = W_1 \times (W_2)^T = W_S = \begin{bmatrix} 0.1713 & 0.1095 & 0.1170 & 0.1014 \end{bmatrix}^T,$$

$$W_S` = \begin{bmatrix} 0.3431 & 0.2194 & 0.2344 & 0.2031 \end{bmatrix}^T$$

Table 6 reports the income distribution calculated by the utility function, the traditional Shapley value, and the improved Shapley value.

Table 6 Result of income distribution of forest rights transfer

Participant	Income distribution using utility function	Income distribution using traditional Shapley value	Income distribution using improved Shapley value
Business enterprise	22759.71	14256.14	16922.43
Forest farmers choosing the one-time transfer	1390.00	4788.05	3910.75
Forest farmers choosing to invest	1558.38	4791.33	4344.08
Forest farmers choosing leasing	1328.97	4788.35	3446.61

4.4 Comparison of Results

Figure 2 illustrates that comparison of the three income distribution results of forest rights transfer. The cooperation of forest rights transfer improves the overall income of business enterprises and forest farmers. The ratio of income distribution between business enterprises and forest farmers is between 2:8 and 5:5, which is within the range of income distribution.

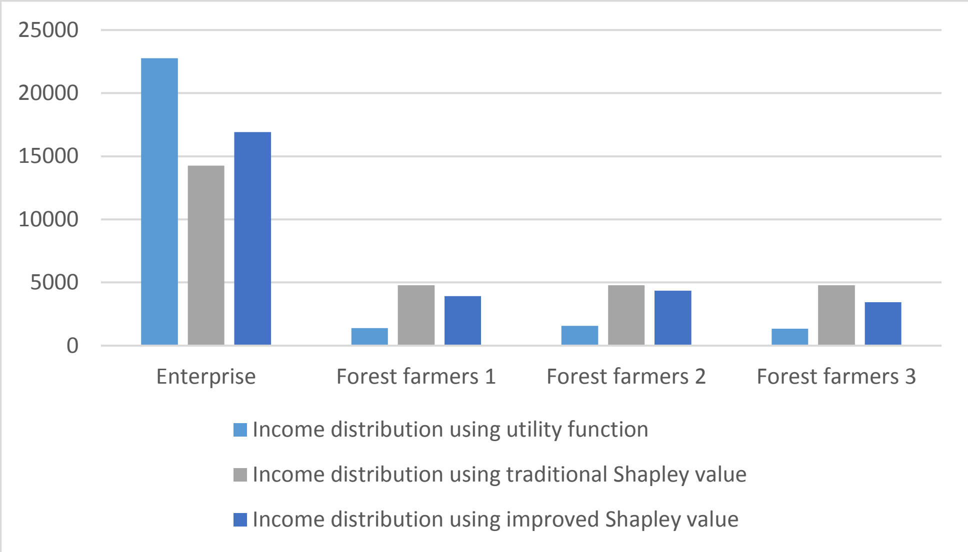

Fig. 2 Comparison of income distribution results of forest rights transfer

The ratio of income distribution between business enterprises and forest farmers, calculated by the utility function value, is about 8:2, which is in line with the ratio of distribution of noncooperation. Forest farmers have limited information and lack sufficient trust in the business enterprise without cooperation. Business enterprises can hardly concentrate forestland to realize large-scale production and operation. Hence, they are more likely to encroach upon most benefits when the overall profit is low. Therefore, forest farmers are more reluctant to transfer forest rights to business enterprises, leading to a vicious circle.

To attain an evolutionary balance between the enterprise and the forest farmers, each participant is treated as equal in the traditional Shapley value method. Their benefits are based on their respective contributions to the overall benefit. This rule-based distribution relationship in the cooperative alliance changes the common supply and demand relationship in the market. This way, the income is in an optimally divided state and the stability of the alliance is guaranteed. After rational distribution through the *tangible hand*, a part of the income is transferred from the business enterprise to the forest farmers. The benefit of the forest farmers under one-time transfer, shareholding, and leasing is higher than it would be without any cooperation. Although the business enterprise's income is reduced, it is hard to realize the ideal forestland area without a cooperative alliance. Hence, the overall income of the business enterprise improves compared with a scenario without cooperation. However, these distribution rules ignore the devotion and risk levels of each participant in the cooperative alliance, which is addressed by the improved Shapley value. In this improved method, the business enterprises invest more resources in the cooperative alliance, have higher risk levels, and higher distribution weights. Compared with the business enterprise, the devotion and risk levels of forest farmers are lower, which reduces their weight. However, the income of the distribution is higher than that obtained without participation in the cooperation. The devotion and risk levels of forest farmers who choose different forms of transfers are different, which, in turn, indicates different weights. In the long run, forest farmers who share their forest rights as part of an investment will obtain the highest income. Only by considering the influencing factors of the participants' income comprehensively can the distribution be reasonable and fair, thereby ensuring that the cooperation of forest rights transfer is in a stable state of evolution.

5 Conclusions and Recommendations

For China, it requires extensive reforestation to achieve carbon neutrality by 2060. The government should continue exploring the multiple benefits of forestry resources, expand the scope of forestry resource stakeholders, and attract participation of more social capital and public organizations to achieve efficient forest land use.

Small-scale decentralized management of forest farmers cannot alone achieve the ecological, economic, and social benefits of large-scale operation of forestry. Encouraging cooperation of forest rights transfer between social capital and forest farmers can increase forestry carbon sinks, which can promote carbon neutrality, thus introducing the evolution game framework of forest right transfer cooperation.

We thus emphasize the influencing factors of participants' cooperation through the model and the income distribution of cooperation. Then, we construct the utility function of the participants and of the alliance, and create an improved traditional Shapley value that incorporates the devotion and risk levels as influence factors. We thus design the income distribution of participants. Finally, we quantitatively provide the income standard of the participants of the cooperative alliance in a sample case, compare the benefits of each party under three kinds of income distribution methods, verify the rationality and operability of the improved Shapley value method in the income distribution of forest rights transfer, and follow through with important policy implications for promoting the transfer of large-scale forest rights. Focusing on the analysis of evolutionary game and income distribution scheme, we propose the following policy recommendations that are conducive to achieving carbon neutrality for the improvement of the system construction and distribution mechanism of forest rights transfer.

First, cooperation of multi-subjects is inseparable from a sound forest rights transfer market. The government should improve the operational efficiency of the forest rights transfer market (Zhang et al. 2017a; Zhu et al. 2018), reduce transaction costs in the transfer process, and improve the overall utility of the cooperative alliance. It is imperative to promote the construction of a proper platform for forest rights transfer (Xu et al. 2013), formulate the internal rules of forest rights transactions, regularly publish the trading information of forest rights transfer on the platform, accept the supervision of the public on the transfer price to reduce information asymmetry, and protect the interests of forest farmers. Meanwhile, the cooperative alliance needs to improve the professional level of estimating the value of the transferred forestland, employ an asset appraisal agency that has no interest in the business enterprise, and avoid subjective appraisal by non-professionals of the government or business enterprises, thus ensuring the forest farmers receive reasonable income.

Second, the business enterprise needs substantial capital for investment in forestland, which faces high operational risks. The forestland after the transfer is also inseparable from the support of funds in the growth stage and subsequent expansion of production. If the business enterprise fails to pay the forest farmers' income on time and loses the reputation of the company, it will easily lead the forest farmers to withdraw from the cooperation alliance. There are few financing options in traditional financial institutions. The forest rights mortgage method suitable for financing of the business enterprise is single, with outside financing being difficult to attain (Xie et al. 2014; Zhou et al. 2016). Forestry resources with dual economic and ecological benefits not only have asset attributes that can be mortgaged or pledged in the traditional sense, but also have rights derived from natural resource attributes. The development of green finance, especially natural resource equity finance, can broaden the financing channel for forestry enterprises and reduce their financing costs. To develop green finance, it is necessary to establish a diversified financial system, promote the introduction of policies and laws on rights and interest transactions of natural resources, accelerate the green financial system and technological innovation, and develop green financial research and development for cooperation between the government, market, and financial institutions. It is essential to improve the operating efficiency of financial institutions in the transaction of rights and interests in forestry resources, reduce traditional financing business models, and promote financial institutions to finance green industries such as forestry (Qin et al. 2014a; Qin et al. 2014b).

Third, forest farmers usually choose a transfer form according to their family's economic conditions. Some forest farmers choose a one-time transfer to deliver forestland to the business enterprise due to short-term financial constraints or to avoid future income uncertainty from the cooperative alliance under asymmetric information. However, in this case, farmers lose opportunities of future dividends from the cooperative alliance. Under the voluntary principle that governs them, forest farmers are encouraged to transfer rights through shareholding and participate in relevant internal affairs while gaining more income. This method also reduces the financing burden on business enterprises in forest rights transfers by way of equity financing. The government is expected to guide business enterprises by creating jobs and improving the social security system for forest farmers.

To ensure the long-term cooperation of multiple participants, it is necessary to form a fair and sustainable income distribution mechanism of forest rights transfer. Business enterprises and forest farmers should increase communication channels to reduce information asymmetry, allowing interest distribution decisions to be made based on the consensus of the alliance participants.

We suggest cooperative alliances to establish a fair and reasonable income distribution mechanism and improve the distribution plan by comprehensively considering various influencing factors of participants based on the improved Shapley value. The government, as an intermediary, can moderately participate in the decision-making involving the proportion of forestry rights transfer income, such as standardizing the range of income distribution proportion. Otherwise, it is preferable for the government to establish a scientific income adjustment mechanism of forest rights transfer, formulate different compensation standards according to local conditions, broaden the diversified compensation methods, increase the state's subsidies for forest rights transfer, and promote the flow of income within the alliance.

Appendices

Table A.1 Weighting factor

First level factors	Second level factors
Business enterprise (I_{11})	Devotion level (I_{21})
Forest farmers choosing one-time transfer (I_{12})	
Forest farmers choosing to invest (I_{13})	Risk level (I_{22})
Forest farmers choosing leasing (I_{14})	

Table A.2 Linguistic variables and fuzzy numbers

Linguistic variables	Fuzzy numbers
Very low (VL)	(0, 0, 0, 3)
Low (L)	(0, 3, 3, 5)
Medium (M)	(3, 5, 5, 7)
High (H)	(5, 7, 7, 10)
Very high (VH)	(7, 10, 10, 10)

Table A.3 Alliance combination and income

Alliance combination	Income (10,000 RMB)
{J,E}	9390.12
{K,E}	9396.68
{L,E}	9390.73
{J,K,E}	19009.97
{J,L,E}	19004.02
{K,L,E}	19010.58
{J,K,L,E}	28623.86

Table A.4 The subjective weight calculation of first-level factors

First-level factor		Members of appraisal group			Comprehensive weights	Fuzzy weight	Normalized value
Business enterprise	Devotion level	1	2	3	(6.11,8.67,8.67,10)	75.24	0.1784
		(7,10,10,10)	(7,10,10,10)	(5,7,7,10)			
		4	5	6			
		(5,7,7,10)	(7,10,10,10)	(5,7,7,10)			
		7	8	9			
		(7,10,10,10)	(5,7,7,10)	(7,10,10,10)			
	Risk level	1	2	3	(5.44,7.78,7.78,9.67)	69	0.1636
		(7,10,10,10)	(5,7,7,10)	(7,10,10,10)			
		4	5	6			
		(5,7,7,10)	(5,7,7,10)	(3,5,5,7)			
		7	8	9			
		(5,7,7,10)	(5,7,7,10)	(7,10,10,10)			

Forest farmers choosing the one-time transfer	Devotion level	1	2	3	(3,4.89,4.89,7.33)	45.25	0.1073
		(3,5,5,7)	(3,5,5,7)	(0,0,0,3)			
		4	5	6			
		(5,7,7,10)	(3,5,5,7)	(0,3,3,5)			
		7	8	9			
		(5,7,7,10)	(3,5,5,7)	(5,7,7,10)			
	Risk level	1	2	3	(3,5.22,5.22,7.56)	47.25	0.112
		(3,5,5,7)	(3,5,5,7)	(0,3,3,5)			
		4	5	6			
		(3,5,5,7)	(0,3,3,5)	(5,7,7,10)			
		7	8	9			
		(5,7,7,10)	(3,5,5,7)	(5,7,7,10)			
Forest farmers choosing to invest	Devotion level	1	2	3	(2.78,4.67,4.67,7)	43	0.102
		(3,5,5,7)	(3,5,5,7)	(0,0,0,3)			
		4	5	6			
		(3,5,5,7)	(3,5,5,7)	(0,3,3,5)			
		7	8	9			
		(5,7,7,10)	(3,5,5,7)	(5,7,7,10)			
	Risk level	1	2	3	(4.11,6.11,6.11,8.67)	56.25	0.1334
		(5,7,7,10)	(3,5,5,7)	(3,5,5,7)			
		4	5	6			
		(5,7,7,10)	(3,5,5,7)	(5,7,7,10)			
		7	8	9			
		(3,5,5,7)	(5,7,7,10)	(5,7,7,10)			
Forest farmers choosing leasing	Devotion level	1	2	3	(2.56,4.44,4.44,6.67)	40.75	0.0966
		(3,5,5,7)	(3,5,5,7)	(0,0,0,3)			
		4	5	6			
		(0,3,3,5)	(3,5,5,7)	(3,5,5,7)			
		7	8	9			
		(5,7,7,10)	(3,5,5,7)	(3,5,5,7)			
	Risk level	1	2	3	(2.89,5,5,7.11)	45	0.1067
		(3,5,5,7)	(0,3,3,5)	(3,5,5,7)			
		4	5	6			
		(3,5,5,7)	(3,5,5,7)	(3,5,5,7)			
		7	8	9			
		(3,5,5,7)	(3,5,5,7)	(5,7,7,10)			

Table A.5 The subjective weight calculation of second-level factors

Second-level factor	Members of appraisal group			Comprehensive weights	Fuzzy weight	Normalized value
Devotion level	1 (5,7,7,10)	2 (7,10,10,10)	3 (7,10,10,10)	(5.67,8.11,8.11,9.67)	71	0.5231
	4 (5,7,7,10)	5 (7,10,10,10)	6 (3,5,5,7)			
	7 (5,7,7,10)	8 (5,7,7,10)	9 (7,10,10,10)			
Risk level	1 (5,7,7,10)	2 (5,7,7,10)	3 (7,10,10,10)	(5,7.2,7.2,9.3)	64.75	0.4769
	4 (5,7,7,10)	5 (5,7,7,10)	6 (3,5,5,7)			
	7 (3,5,5,7)	8 (5,7,7,10)	9 (7,10,10,10)			

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References

Adrian Whiteman, Anoja Wickramasinghe, Leticia Piña (2015) Global trends in forest ownership, public income and expenditure on forestry and forestry employment. Forest Ecol Manag 352: 99–108 http://dx.doi.org/10.1016/j.foreco.2015.04.011

Andrés-Domenech P, Martín-Herrán G, Zaccour G (2015) Cooperation for sustainable forest management:An empirical differential game approach. Ecol Econ 117:118-128. http://dx.doi.org/10.1016/j.ecolecon.2015.06.016

Batty S (2006) Paradoxes of sustainable Development: Property and participation. Prop Manag 24:207–218. http://dx.doi.org/10.1108/02637470610660110

Butler BJ, Leatherberry EC (2004) America`s family forest owners. J For 102:4–9. https://academic.oup.com/jof/article-abstract/102/7/4/4613202

Castella JC, Boissau S,Thanh NH, Novosad P (2006) Impact of forestland allocation on land use in a mountainous province of Vietnam. Land Use Policy 23:147–160. https:// doi.org/10.1016/j.landusepol.2004.07.004

Chou S, Chang Y, Shen C (2008) A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. Eur J Oper Res 189:132–145. https://doi.org/10.1016/j.ejor.2007.05.006

Dai LM, Wang Y, Su DK, Zhou L, Yu DP, Lewis BJ, Qi L (2011) Major forest types and the evolution of sustainable forestry in China. Environ Manag 48:1066–1078. https://doi.org/10.1007/s00267-011-9706-4

Dai LM, Zhao FQ, Shao GF, Zhou L, Tang LN (2009) China's classification-based forest management: procedures, problems, and prospects. Environ Manag 43:1162–1173.

https://doi.org/10.1007/s00267-008-9229-9

Dai LM, Zhao W, Shao GF, Lewis BJ, Yu DP, Zhou L, Zhou WM (2013) The progress and challenges in sustainable forestry development in China. Int J Sustain Dev World Ecol 20: 394–403. https://doi.org/10.1080/13504509.2013.775193

Emerson K, Nabatchi T, Balogh S (2012) An integrative framework for collaborative governance. J Public Adm Res Theory 22: 1–29. https://doi.org/10.1093/jopart/mur011

Friedman D (1991) Evolutionary games in economics. J Econometric Soc 3:637-666. http://sci-hub.tw/10.2307/2938222

Gerichhausen M, BerkhoutA ED, Hamers HJM, Manyong VM (2009) A quantitative framework to analyse cooperation between rural households. Agr Syst 101:173–185. https://doi.org/10.1016/j.agsy.2009.05.005

Gong Y, Bull G, Baylis K (2010) Participation in the world's first clean development mechanism forest project: The role of property rights, social capital and contractual rules. Ecol Econ 69:1292–1302. https://doi.org/10.1016/j.ecolecon.2009.11.017

Gray S, Chan A, Dan C, Jordan R (2012) Modeling the integration of stakeholder knowledge in socialeecological decision-making: Benefits and limitations to knowledge diversity. Ecol Model 229：88–96. https://dx.doi.org/10.1016/j.ecolmodel.2011.09.011

Haines A, Kennedy T, McFarlane D (2011) Parcelization: forest change agent in northern Wisconsin. J For 109:101–108. https://academic. oup.com/jof/article-abstract /109/2/1014599458

Hatcher JE, Straka T, Greene JL (2013) The size of forest holding/parcelization problem in forestry: a literature review. Resource 2:39–57. https://doi.org/10.3390/resources2020039

Hou J, Yin R, Wu W(2019)Intensifying Forest Management in China: What does it mean, why, and how? For Policy Econ 98:82–89. http://dx.doi.org/10.1016/j.forpol.2017.10.014

Ito J (2012) Collective Action for Local Commons Management in Rural Yunnan, China: Empirical Evidence and Hypotheses Using Evolutionary Game Theory. Land Econ 88: 181–200. https://doi.org/10.1353/lde.2012.0008

Kline JK, Alig RJ (2005) Forestland development and private forestry with examples from Oregon (USA). For Policy Econ 7:709–720. http://doi.org/10.1016/j.forpol.2005.03.009

Kristiansen M, Muñoz FD, Oren S, Korpås M (2018) A Mechanism for Allocating Benefits and Costs from Transmission Interconnections under Cooperation: A Case Study of the North Sea Offshore Grid. Energ J 39:209–234. https://doi.org/10.5547/01956574.39.6.mkri

Li F, Pan B,Wu Y, Shan L (2017) Application of game model for stakeholder management in construction of ecological corridors: A case study on Yangtze River Basin in China. Habitat Int 63:113–121. http://dx.doi.org/10.1016/j.habitatint.2017.03.011

Liu PY, Ravenscroft N (2016) Collective action in China’s recent collective forestry property rights reform. Land Use Policy 59:402–411. https://doi.org/10.1016/j.landusepol.2016.09.011

Liu S, Cannon CH (2011) Impact of socio-economic status on the implementation of China's collective forest tenure reform in Zhang Guying Township, Hunan:potential for increasing disparity. For 84:327–335. https://doi.org/10.1093/forestry/cpr016

Liu S, Xu J (2019) Livelihood mushroomed: Examining household level impacts of non-timber forest products (NTFPs) under new management regime in China's state. For Policy Econ 98:44–53. https://doi.org/10.1016/j.forpol.2018.06.001

Lu S, Chen N, Zhong X, Huang J, Guan X (2018) Factors affecting forestland production

efficiency in collective forest areas: A case study of 703 forestland plots and 290 rural households in Liaoning,China. J Clean Prod 204:573–585. https://doi.org/10.1016/j.jclepro.2018.09.013
Luqman M, Peng,S, Huang S, Bibi A, Ahmad N (2018) Cost allocation for the problem of pollution reduction: a dynamic cooperative game approach. Econ Res-Ekon Istraž 31:1717–1736. https://doi.org/10.1080/1331677X.2018.1515642
Markowski-Lindsay M, Butler BJ, Kittredge DB (2017) The future of family forests in the USA: Near-term intentions to sell or transfer. Land Use Policy 69:577–585. http://dx.doi.org/10.1016/j.landusepol.2017.10.007
Mehmood SR, Zhang D (2001) Forest parcelization in the United States—A study of contributing factors. J For 99:30–34. https://academic.oup.com/jof/article/99/4/30/4614372
Mohammed AJ, Inoue M, Shivakoti G (2017) Moving forward in collaborative forest management: Role of external actors for sustainable Forest socio-ecological systems. For Policy Econ 74:13–19. http://dx.doi.org/10.1016/j.forpol.2016.10.010
Pan Y, Zhang Y, Majumdar I (2009) Population,economic welfare and holding size distribution of private forestland in Alabama,USA. Silva Fennica 43:161–171. http://www.metla.fi/silvafennica/full/sf43/sf431161pdf
Qin P, Xu JT (2013) Forest land rights, tenure types, and farmers' investment incentives in China: an empirical study of Fujian Province,China. Agric Econ Rev 5:154–170. https://doi.org/10.1108/17561371311294829
Qin T, Gu XS, Tian ZW, Deng J (2015) Comparison of agriculture and forestry fiscal subsidy policies in China. J Sustain For 34:683–697. https://doi.org/10.1080/10549811.2015.1025286
Qin T, Tian ZW, Gu XS, Deng J (2014a) Investigation and analysis of the lending needs of forestry households in China: based on data from Zhejiang, Fujian, Guangxi, and Jiangxi provinces. J Sustain For 33:814–826. https://doi.org/10.1080/10549811.2014.925812
Qin T, Tian ZW, Sun XR, Deng J (2014b) Analysis of countermeasure and implementation of forest right mortgage loan business in agricultural bank of China. J Appl Sci 14:1996-2001. https://doi.org/10.3923/jas.2014.1996.2001
Shahi C, Kant S (2007) An evolutionary game-theoretic approach to the strategies of community members under Joint Forest Management regime. Forest Policy Econ 9 :763–775. http://dx.doi.org/10.1016/j.forpol.2006.04.002
Shapley LS (1953) A value for n-person games-Contributions to the Theory of Games. Princeton University Press 307-317.
Siikamäki J, Ji Y, Xu J (2015) Post-reform forestland markets in China. Land Econ. 91: 211–234. https://doi.org/10.3368/le.91.2.211
Song Y, Wang G, Burch WR, Rechlin MA (2004) From innovation to adaptation:lessons from 20 years of the SHIFT forest management system in Sanming, China. Forest Ecol Manag 191:225–238. https://doi.org/10.1016/j.foreco.2003.12.007
Stone SR, Tyrrell ML (2012) Motivations for Family Forestland Parcelization in the Catskill/ Delaware Watersheds of New York. J For 110:267–274.http://dx.doi.org/ 10.5849/ jof. 11-015
Tang M, Wang F(2013) Analysis on the Willingness of Peasant Households for Forestland Use Right Transfer in the Background of Collective Forest Tenure Reform:A Case Study in Guangyuan City in Sichuan Province. Sustainable Agriculture Research 2:76–84. http://dx.doi.or g/10.5539/sar.v2n2p76

Wang W, Xie C, Du X (2009) Landslides susceptibility mapping based on geographical information system, GuiZhou, south-west China. Environ Geol 58:33–43. https://doi.org/10.1007/s00254-008-1488-5

Xi JP (2017) Secure a Decisive Victory in Building a Moderately Prosperous Society in All Respects and Strive for the Great Success of Socialism with Chinese Characteristics for a New Era. The 19th National Congress of the Communist Party of China. http://www.xinhuanet.com/english/special/2017-11/03/c_136725942.htm

Xie H, Wang W, Zhang X (2018) Evolutionary game and simulation of management strategies of fallow cultivated land: A case study in Hunan province, China. Land Use Policy 71:86–97. https://linkinghub.elsevier.com/retrieve/pii/S0264837717311328

Xie Y, Gong PC, Han X, Wen YL (2014) The effect of collective forestland tenure reform in China: does land parcelization reduce forest management intensity? J Forest Econ 20:126–140. https://doi.org/10.1016/j.jfe.2014.03.001

Xie Y, Zhao L, Xue J, Hu Q, Xu X, Wang H (2016) A cooperative reduction model for regional air pollution control in China that considers adverse health effects and pollutant reduction costs. Sci Total Environ 573:458–469. http://dx.doi.org/10.1016/j.scitotenv.2016. 08.077

Xu X, Zhang Y, L L, Yang S (2013) Markets for forestland use rights: A case study in Southern China. Land Use Policy 30:560–569. http://dx.doi.org/10.1016/j.landusepol.2012.05.001

Xu Z, Peng Z, Yang L, Chen X (2018) An Improved Shapley Value Method for a Green Supply Chain Income Distribution Mechanism. Int J Env Res Pub He. http://dx.doi.org/10.3390/ijerph15091976

Yi Y, Köhlin G, Xu J (2014) Property rights, tenure security and forest investment incentives: evidence from China's collective forest tenure reform. Environ Dev Econ 19:48–73. https://doi.org/10.1017/s1355770x13000272

Zhang H, Kuuluvainen J, Yang HQ, Xie Y, Liu C (2017a) The effect of off-farm employment on forestland transfers in China: a simultaneous-equation tobit model estimation. Sustain 9:1645–58. https://doi.org/10.3390/su9091645

Zhang H, Kuuluvainen J, Ning YL, Liao WM, Liu C (2017b)Institutional regime,off-farm employment, and the interaction effect: what are the determinants of households' forestland transfer in China? Sustain 9:1885–1899. https://doi.org/10.3390/su9101885

Zhang X, Bao H, Skitmore M (2015) The land hoarding and land inspector dilemma in China: An evolutionary game theoretic perspective. Habitat Int 46:187–195. http://dx.doi.org/10. 1016/j.habitatint.2014.12.002

Zhou L, Zhang YQ, Dai GC, Zhang S (2016) Access to microloans for households with forest property collateral in China. Small-Scale For 15:291–301. https://doi.org/10.1007/s11842-016-9323-4

Zhu Z, Xu Z, Shen Y, Huang C (2018) How forestland size affects household profits from timber harvests: A case-study in China`s Southern collective forest area. Land Use Policy 1–9. https://doi.org/10.1016/j.landusepol.2018.04.055

Zhu Z, Xu Z, Shen Y, Huang C, Zhang Y (2019) How off-farm work drives the intensity of rural households' investment in forest management: The case from Zhejiang, China. For Policy Econ 98:30–43. https://doi.org/10.1016/j.forpol.2018.04.006

Figures

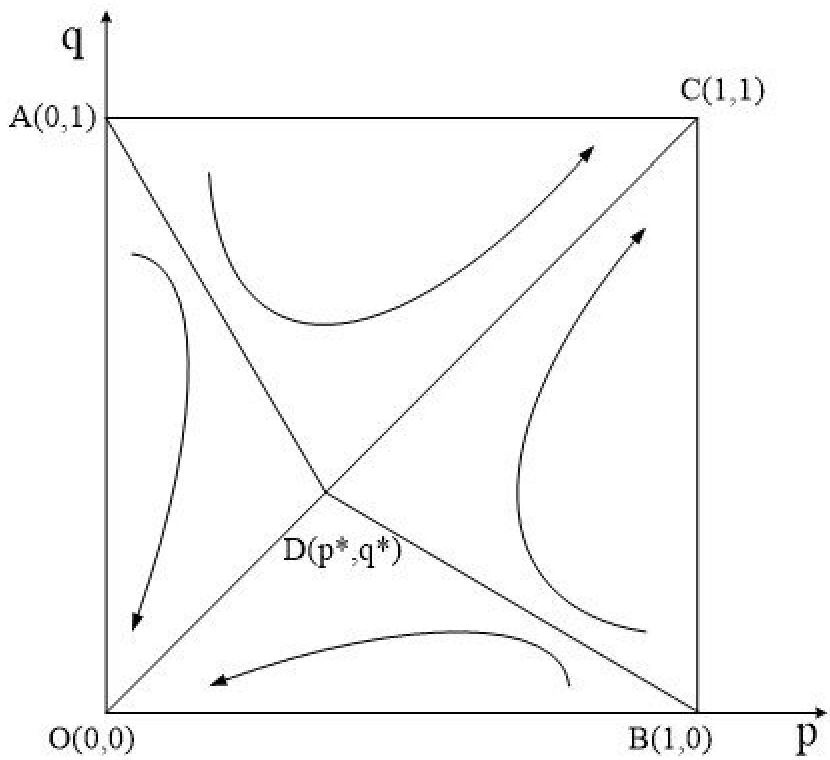

Figure 1

Phase diagram of the evolution game in the cooperation of forest rights transfer

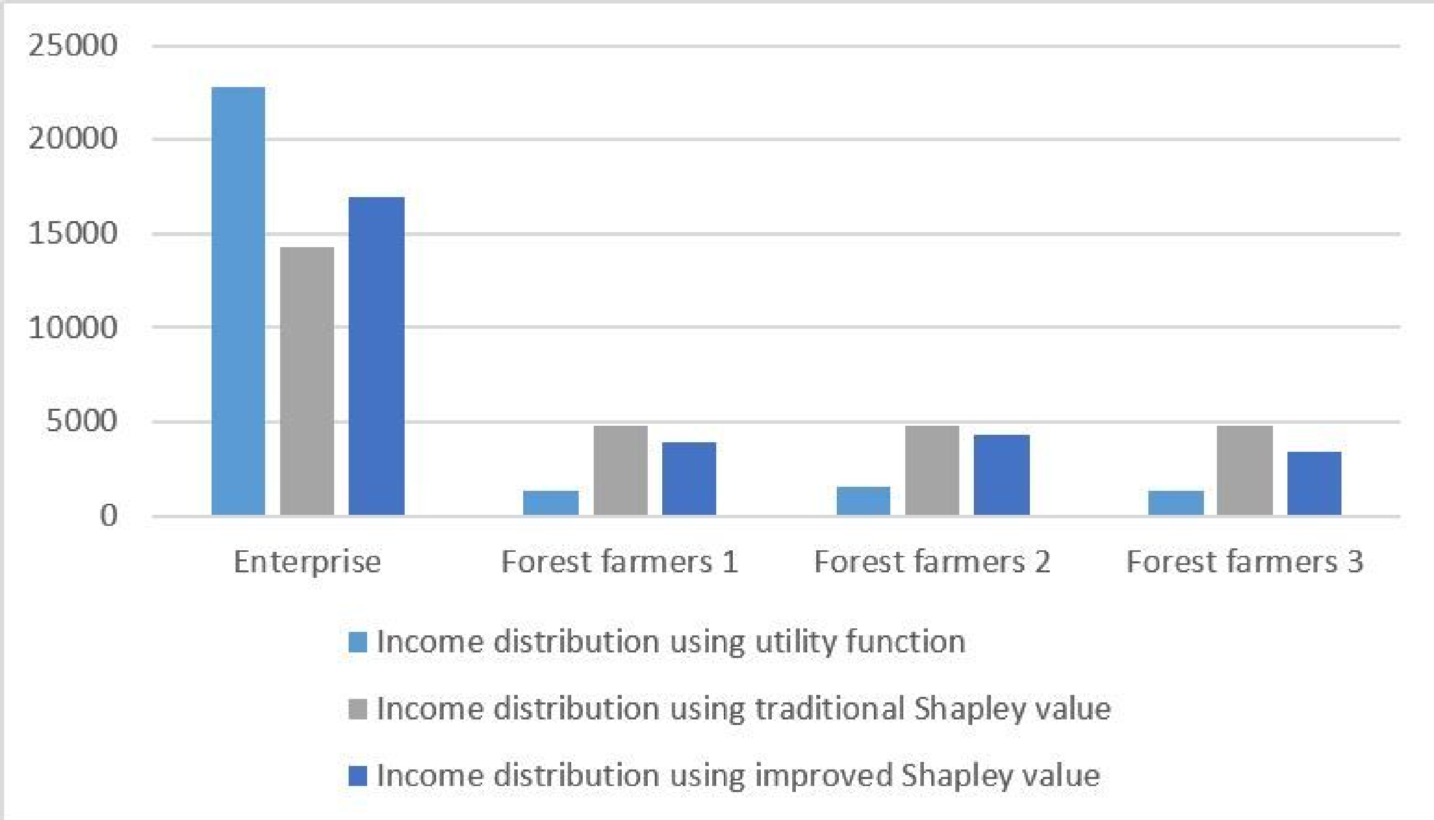

Figure 2

Comparison of income distribution results of forest rights transfer