

REVIEW ARTICLE

Progress and prospects of research on forest eco-efficiency compensation

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ABSTRACT

Forest ecological benefit compensation plays a promoting role in improving the enthusiasm of forest ecological builders and maintainers, maintaining the legitimate economic interests of forest owners, and coordinating the fairness between the “clear water and green mountains” protectors and the “gold and silver mountains” beneficiaries. Comprehensive combed the domestic forest ecological benefit compensation mechanism, including the compensation scope, compensation subject, compensation object, the research progress of compensation standard, summarized the forest ecosystem benefits measurement, including physical appraisal method, the value evaluation method, energy analysis method and the characteristics and application research progress of ecological model method. This paper discusses the research status and existing problems of the calculation basis of compensation standard, the origin, research emphasis and progress of forest ecological service payment abroad in recent years, and the mechanism of forest ecological service payment in many countries. Finally, some suggestions are put forward to improve the compensation mechanism of forest ecological benefits in China. On the one hand, it is necessary to broaden the source of funds through various ways of marketization and scientifically evaluate the forest ecological benefits. On the other hand, the compensation standard should be established scientifically and reasonably to achieve different compensation levels or compensation intervals.

Keywords: Forest Ecological Benefit Compensation; Differentiation; Compensation Standard

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1. Introduction

As an important part of the unified ecological organism of mountains, rivers, forests, fields, lakes, grass and sand, forests play an irreplaceable role in mitigating climate change, controlling soil erosion and land degradation and protecting biodiversity. Under the background of harmonious coexistence between human beings and nature, China has implemented forest classification management measures to meet the needs of human wood products on the one hand, and diversified ecological needs; on the other hand, so as to ensure the ecological barrier function of forests. With the continuous expansion of the construction of ecological public welfare forest, if the ecological benefits of the forest cannot be transformed into economic benefits, it will lead to the failure of the main operators, and affect the sustainable development of ecological public welfare forest construction. Ecological compensation is one of the main means to promote ecological environmental governance and sustainable development in the world. At the end of the 1990s, some Latin American countries implemented the payment for ecosys-

tem services (PES) program, which pays the eco-service protectors to encourage them to protect the ecological environment, and achieved good results. Many countries have since followed suit^[1]. Monetization of forest ecological benefits, on the one hand, it can stimulate people's awareness of forest protection and reduce the loss of forest ecosystem functions and biodiversity; on the other hand, the externalities of forest resources can be gradually and standardized into the market pricing of commodities^[2].

Under the background of ecological civilization construction, forest ecological benefit compensation mechanism can coordinate the relationship between ecological benefit and economic benefit. Forest ecological benefit compensation is in line with the top-level design planning of ecological civilization construction and the promotion of green development ideas. It can improve the enthusiasm of forest ecological builders and maintainers, maintain the legitimate economic interests of forest owners, and promote the rapid development of forest ecological construction. Ecological compensation is of great significance to coordinate the fairness between the protectors of "clear water and green mountains" and the beneficiaries of "gold and silver mountains", and to realize the "win-win" of forestry economic development and forest ecological protection. In 1981, "Decision of the Central Committee of the Communist Party of China and the State Council on Several Issues Concerning the Protection of Forests and the Development of Forestry" was issued, which clearly required the establishment of forest ecological benefit compensation system and the establishment of "forestry fund" and "green fee"^[3]. After that, the forest ecological benefit compensation system gradually improved. The State Council clearly pointed out the need to establish a forest ecological benefit compensation system in the "Notice on the Key Points of Economic System Reform in 1992" issued by the National Economic System Reform Commission. and paid use of forest resources should be carried out to provide official guidance for the promotion of forest ecological benefit compensation. In 1998, China promul-

gated the Forest Law of the People's Republic of China (referred to as the Forest Law), The legal basis of forest ecological benefit compensation fund is determined, and it is pointed out that forest ecological benefit compensation fund is used to provide ecological benefit of shelterbelt and forest resources, forest trees construction, care, protection and management, which is a great breakthrough in the practice of ecological compensation in China.

Forest ecological benefit compensation is one of the categories of ecological benefit compensation. It takes forest as the compensation accounting object, and solves the externalities of forest ecological benefit caused by market mechanism failure by encouraging people to maintain and preserve forest ecosystem services through economic hand^[4]. At present, there are three methods of forest ecological compensation: forest ecological compensation, forest resource ecological compensation and forest ecological benefit compensation. The first two express the same meaning. The meaning of forest ecological compensation and forest ecological benefit compensation is slightly different, with ecological compensation emphasizing financial responsibility for the consequences of actions that cause damage to the ecological environment, while forest ecological benefit compensation emphasizes compensation for those who bear costs beyond the scope of their obligations in the process of providing eco-efficiency as a public good to society. Comparatively speaking, forest ecological compensation is a broad concept, including not only the compensation for forest ecological environment, but also the protection of forest ecological environment investment and protection behavior compensation. For example, the input to forestry construction and protection in the project of returning farmland to forest, the "Three North" shelterbelt project and the natural forest protection project in China includes the costs of forest cultivation, forest operation, management and maintenance, and compensation for the loss caused by the opportunity cost of forest protection caused by the prohibition and restriction of logging. As well as social insurance subsidies for forest enterprises and subsidies for laid-off workers^[5]. Forest ecological benefit compensation is the

economic compensation for the forest ecological benefit which cannot be traded in the market. In the field of forestry in China, such compensation is a kind of economic compensation rather than economic responsibility, so the capital investment of state-owned forestry enterprises in the national forestry ecological engineering cannot be counted as forest ecological benefit compensation^[6]. Of course, the connotation of forest ecological benefit compensation is constantly improved and changed in the in-depth study and practice of forestry development at home and abroad. In the current study of forest ecological benefit compensation and forest ecological compensation, most scholars do not make a clear distinction between the two, that is, forest ecological benefit compensation is also known as forest ecological compensation, and this study is also not distinguished, unified as forest ecological benefit compensation.

2. Research and practice progress of forest ecological compensation in China

The compensation for forest ecological benefits started late in China. In the process of development, although there are some difficulties and problems in legal protection, system design, technology implementation and market operation, some achievements have been made gradually. The research of forest ecological benefit compensation mainly focuses on compensation mechanism, calculation of compensation benefit and compensation standard.

2.1 Compensation mechanism for forest ecological benefits

2.1.1 Scope of compensation

In China's current forestry planning, forest ecological benefit compensation model is the main indicator of ecological public welfare forest compensation. In addition, it also includes continuous compensation left over from several major forestry ecological projects, including the forest land for ecological projects such as returning farmland to forests and natural forest protection that have expired since 2004^[7]. The scope of ecological public

welfare forests shall be delimited by the state and local governments, namely national public welfare forest and local public welfare forest. After the reform of collective forest ownership system, public welfare forests not only include those owned by the state and collective, but also those owned by individuals. To solve the problem of ownership of public welfare forest is helpful to clarify the object range of compensation. Some scholars consider adding other forest species into the range of forest benefit ecological compensation, including commercial forest^[8]. In fact, commercial forest belongs to the range of forest ecological benefit compensation in specific forestry engineering projects, mainly to compensate for the loss of grain yield caused by the abandonment of farmland in the process of forestry construction. In terms of the benefit of commercial forest and public welfare forest place develop, Zhang^[6] discussed in detail the determination of forest ecological benefit compensation ranges from the perspective of classified forest management. He thinks that the different value of public welfare forest and commercial forest is decided by classified management. Commercial forest can realize its value under the market operation mechanism, but public welfare forest cannot, which is the basis of establishing the ecological compensation system of public welfare forest. Therefore, the ecological value of commercial forest should not be compensated. I agree with this point of view, although the commercial forest has temporary ecological value when it is not cut down, the forest ecological benefit has a longer time scale and is characterized by long-term stability, so the ecological value of the commercial forest should not be compensated except for forestry engineering projects.

2.1.2 Compensation subject

In current domestic practice, the main body of compensation is government compensation. Referring to foreign compensation mechanisms, Cao *et al.*^[9] believe that relying solely on government compensation will lead to many problems, such as management mechanism, long effectiveness and supervision problems, etc. A more ideal situation is to introduce a market compensation mechanism and

give full play to the principle of “the destroyer is responsible for recovery” and “the person receiving the benefit is responsible for compensation”. Tong^[10] pointed out that we can learn the mature experience from foreign countries in market compensation for forest ecological benefits, the feasibility of trying to expand the scope of compensation subjects. For example, compensation subjects could include infringers on forest resources. However, the forest ecological benefit compensation system in China is mainly based on related laws such as Forest Law, and the forest ecological benefit compensation system has not been included in the punishment of forest resource infringers. Based on the external reasons of forest ecological benefits, many scholars also believe that the beneficiaries of forest ecological benefits should be gradually included in the compensation subject. Li *et al.*^[11] investigated whether people were willing to pay for ecological compensation from the perspective of social trust, and concluded that most urban residents were willing to pay for forest ecological services, which was related to the awareness of forest importance and ecological compensation policy perceived by the research objects of ecological environment, suggesting that forest ecology be adopted tourism preference and inclusion of personal credit system will gradually improve the acceptance of forest ecological compensation. Jiang *et al.*^[12] investigated the willingness of people in the lower reaches of Hun River to compensate for forest ecological benefits, and concluded that most downstream residents were willing to compensate for the value of water conservation played by the forest, but it was also related to their own income and other factors.

2.1.3 Compensate the object

Compensation objects refer to the people who make contributions to protect forest resources from logging and destruction^[13]. At present, the object of forest ecological benefit compensation in China is mainly the subject of forest right, including forest management unit, forester and forester. Tong^[10] proposed that the object of compensation should include local residents who suffer ecological damage due to the destruction of forest resources. As the case before, this part of the population is very small.

At present, there is a common understanding that we should give full play to the function of market compensation, gradually expand the scope of compensation subject and object, and make better use of forest ecological benefit compensation. In terms of how to carry out market-oriented compensation, scholars propose that the compensation path can be broadened through some ways, including developing carbon sink trading items, forest biodiversity trade, forest ecotourism, increasing the added value of forests^[9], underforest economy^[14], ecological compensation tax and other economic means. These methods are supported by sound market mechanisms. At present, only the carbon sink market mechanism is relatively perfect in China, while the practice and exploration of other ways are still lacking. The satisfaction of forest ecological benefit compensation object is also a research hotspot. Scholars have discussed how to adopt effective compensation methods to improve the object's willingness to protect and maintain forest ecological benefit and improve the livelihood of forest builders. Currently, a new compensation idea is trans-regional compensation^[15], which can coordinate the imbalance of economic and ecological benefits between the economically developed regions and the regions with developed forest resources, and establish an effective compensation relationship between the protection subjects and the beneficiaries through the role of the government^[16], which is helpful to break through the predicament of trans-regional forest ecological benefits compensation. For example, in December 2020, Hainan Province issued the Implementation plan of horizontal ecological protection compensation for upstream and downstream river basins in Hainan Province. In June 2021, Chongqing Municipal Bureau of Planning and Natural Resources and Sichuan Provincial Department of Natural Resources jointly issued the Implementation opinions on promoting the construction of Shuangcheng Economic Circle in Chengdu-Chongqing region and jointly carrying out ecological restoration of territorial space.

The extension and expansion of the subject and object of compensation requires the improve-

ment and promotion of mechanisms. The undertaker of forest ecological benefit compensation should be the beneficiary of all aspects. But in practice, compensation funds cannot be obtained according to the principle of “who benefits and who compensates”. The current government-led compensation mechanism is the main reason to limit the diversification of compensation sources, which is also related to the long-term “free-riding mentality” of the Chinese public. In terms of our country’s forest resource management subject and management mode, the role of governments cannot be missing. However, the transition from the government-led compensation mode to the active participation of the public needs a process, and also needs the support of sound market supporting mechanisms and laws and regulations, and gradually guides the enthusiasm of public participation through market mechanisms.

2.2 Measure forest ecological benefit

On the one hand, calculating forest ecosystem benefits can show the ecological benefits played by forest ecosystem numerically, on the other hand, it can be converted and measured with other ecosystems. The result can be used as the basis to determine the compensation standard of forest ecological benefit. Most scholars believe that forest ecological value should be evaluated scientifically from the source, so the positive external value of forest should be calculated as compensation amount. In general, forest ecological benefit measurement methods can be roughly divided into object quality evaluation method, value evaluation method, energy analysis method and ecological model method^[17,18]. The first three are based on market theory and are able to express the value of ecological services directly in monetary terms, while the ecological model is to simulate forest ecological process and calculates forest ecological benefit based on ecological law.

2.2.1 Ecological modeling

The ecological model method calculates the ecosystem service value by establishing the model and revises and calculates the ecological parameters of the model. The disadvantage is that the calculation process is complex and the technical barrier is

strong. However, the investigation factors such as remote sensing and geographic information can be added to make the simulation results more dynamic and accurate. For example, Zhou *et al.*^[19] adopted ecological model method combined with system dynamic thinking to develop an estimation equation for forest eco-efficiency compensation for Yunnan forests in terms of both the economic and ecological value of the forest trees. There are more and more in-depth studies using this method in China and abroad.

2.2.2 Material quality evaluation method

The method of matter quality evaluation evaluates the value of various services provided by forest ecosystem from the perspective of biomass. The material quality evaluation method can be subdivided into functional value method and equivalent factor method. Most of the domestic researches on the functional value method refer to the specifications for assessment forest ecosystem services released in 2008^[20], which uses a formula to calculate the amount of material value in combination with the survey factors and corresponding ecological parameters of the forest inventory data. The advantage of this method is that the calculation process has direct basis and can compare different ecological service values^[21]. The disadvantage is that it is difficult to take into account the stand age, stand density and site conditions, resulting in differences in ecological parameters, and if the correction coefficient is added, the calculation process becomes more complicated and its reliability is difficult to evaluate.

Equivalent factor method is to use quantifiable standards to construct the equivalent value of forest ecosystem services, and to obtain the forest ecological value through the conversion of parameters such as area. It was first used by Costanza *et al.*^[22]. Xie *et al.*^[23] improved the equivalence factor method and developed a dynamic assessment method for the value of terrestrial ecosystem services in China, which provides guidance for Chinese scholars to study the equivalence factor method. The advantages of this method are simple conversion, less data required, fast calculation, suitable for large area value calculation. The disadvantage is that it is

difficult to reflect the impact of parameters such as forest storage site quality on ecological value when converting according to area.

Another advantage of the method is that it can evaluate the density and quality of forest ecosystem services so as to provide a basis for differentiated ecological compensation. Jiang *et al.*^[12] adopted the functional value method to convert the area of different tree species in the Hun River basin and the “ecological service value per unit area of different forest types” to the value of forest ecological water conservation. Combining the equivalent factor method and the ecological-economic differential rent theory, Shuxing Hu^[24] calculate the value of different types of ecological services and the compensation standard price by using the forest resource abundance index and the comprehensive index of economic development combined by the accumulation and coverage rate. Some scholars have also made a combination of measurement methods, absorbing the advantages of different approaches, and establish a calculation method with low technical barriers and strong operability. Tang *et al.*^[25] combined two methods of the material quality method, absorbing the advantages of equivalent factor method and functional value method, and established a forest ecological value accounting method based on standard sample plot equivalent value. Feng^[26] combined the functional value method with the ecological model method, using remote sensing data extraction factors and forest survey data to calculate the forest ecological service values of Chongqing in 2000 and 2009 respectively.

2.2.3 Value evaluation method

The value assessment method mainly evaluates the value provided by forest ecosystem from the perspective of monetary value. Value evaluation method is a widely used method, according to different types of market, which can be divided into direct market method, alternative market method and simulated market value method^[27]. Each method can be subdivided into several calculation methods, direct market method can be subdivided into market value method, expense method, human capital method and machine cost method. Alternative market method can be divided into alternative

cost method, restoration and protection cost method, shadow engineering method, shadow price method and travel cost method. Simulated market value method can be divided into conditional value method and selective experiment method^[28]. Direct market method and alternative market method are more widely used and studied than simulated market value method. The characteristic of value evaluation method is that it does not need much theoretical foundation of forest ecology, and can be calculated from the perspective of cost or market price of physical quantity, etc. However, due to the different function and focus of forest ecological value evaluated by researchers, there are great differences in the value calculated by different people. This method has the advantage of high economic efficiency. the disadvantage of which is that it mostly reflects the ideal market price for ecosystem services, and there may be repeated calculation when the calculation results of different values of forest ecology are superimposed.

Many scholars have measured and explored the value of different aspects of forest ecology in different scales including province, city, county and forest farm. Kong^[29] used the alternative cost method to calculate the industrial opportunity cost of ecological construction and environmental protection costs. Sheng *et al.*^[30] used shadow engineering method to calculate the ecological benefits of forest precipitation interception and precipitation stored by ecosystem, and proposed the compensation standard of unit area of regional differentiation. Zhang *et al.*^[31] used shadow engineering method to calculate the ecological benefits of forest in Hohhot from two aspects of economic value and ecological value. Li^[32] calculated the ecological benefits of different aspects of forests by using market value method, travel cost method and other methods, after integrating all the benefits, the ecological compensation standard is measured. Bao *et al.*^[33] used the market value method to calculate ecological compensation value according to ecological location quotient and dominant ecological value, and recommended compensation based on 10% of the total benefit of the forest. Lv *et al.*^[34] divided the forest into different age groups and used different

methods to measure the ecological benefits of forests in different age groups, and then calculated compensation amount according to different ownership. Wu *et al.*^[35] measured the four main ecosystem service values of *Pinus massoniana* at subcompartment scale, including carbon sequestration, water conservation, soil and fertilizer conservation, and biodiversity, and calculated the forest ecological benefit compensation standard of this tree species, so as to realize the value calculation of a single tree species in a small range. Li^[36] calculated the value of forest carbon sequestration by combining the calculated forest carbon storage with the carbon price and forest tree price using the value evaluation method. Finally, the calculation result of ecological compensation standard is obtained. Zheng *et al.*^[37] measured forest landscape recreation value and the employment value by using simulated market value method alternative market method.

In general, different methods of calculating forest ecological value are applicable to different aspects. The value of carbon fixation and oxygen release and water conservation focuses on the alternative market approach. Market value method or alternative market method can be used for soil fixation and fertilizer preservation. Landscape recreation value is applicable to the simulation of market value method. The controversy in the study of valuation method is that some scholars directly superimpose the calculation results of various ecological benefits of forests, resulting in much larger measurements than the actual benefit. Therefore, Wu *et al.*^[35] proposed that carbon fixation and oxygen release, water conservation, soil and fertilizer conservation and biodiversity are the main types of forest ecosystem services. To avoid double counting, oxygen release services and biodiversity services are excluded from the total service value. Zhang^[28] pointed out that after the calculation of forest ecological benefits, the benefits should be integrated and modified through analytic hierarchy process or compensation coefficient method, which is conducive to the objective evaluation of compensation standards.

2.2.4 Energy analysis method

Energy analysis method is based on energy theory and system ecology, which converts different kinds of energy into a unified standard solar value to measure and analyze, using economic value to measure the value of ecological services^[38]. Energy analysis method reflects the solar energy consumed by forest ecosystems in the same way as other systems and is able to relate forest ecosystems to the level of economic development. The disadvantage is that it does not reflect the types of services provided by forest ecosystems that other systems cannot provide. Therefore, the application of this method in estimating the value of forest ecosystem services is relatively rare.

To sum up, forest ecological function includes carbon fixation, water conservation, wind-breaking and sand-fixation, and the functional emphases of calculating benefit compensation vary from scholar to scholar. Because each forest ecological benefit theory foundation is different, the scientificity and accuracy of the results obtained by directly adding the values of various ecological functions by means of value quantity evaluation method is still debatable.

2.3 Determining the compensation standards

Determining the compensation standard is the key and difficult point in forest ecological compensation research. The compensation standard of forest ecological benefit is different with different ways. At present, ecological compensation of public welfare forest in China is dominated by the government. Compensation is determined according to the level of forest tenure. Due to different sources of compensation funds for national and local public welfare forests, there will be different compensation standards^[39]. This is related to the degree of economic development of the local and the development of local forestry. In the process of studying the compensation standard, most scholars have mentioned the problem that the compensation standard is too low^[40,41]. In view of the problem that most scholars pointed out that the compensation standard is too low, Chen *et al.*^[42] suggested that the increase of compensation standard can be adjusted and increased gradually in accordance with the average

growth rate of GDP in a cycle of 5 years. The low compensation standard is mainly caused by a single source of funds. The low compensation standard is the main reason for most scholars to re-estimate forest ecological benefits. The way to determine the compensation standard of forest ecological benefit can be summed up as measuring according to the ecological value of input cost or opportunity cost. According to the input cost is usually the lowest standard, according to the ecological value is the highest standard, the compensation standard generated in the actual compensation process should be between the highest standard and the lowest standard. The current compensation fund for forest ecological benefits only includes that the cost of forest management and protection is far lower than the forest ecological benefits. To improve the compensation standard, we need to reform the ecological compensation mechanism and actively expand the source of funds.

The current compensation is a means of government regulation. How to determine the compensation standard of the combination, realize the reasonable distribution of compensation methods in each region, ensure the fairness and rationality of compensation are very important in forest ecological benefit compensation practice. Public welfare forest area according to the area in compensation, which is associated with the past our country forest resources management goal and also related to forest ecological value conversion unit. Using area of statistics and conversion is the is the consensus and habit of scholars in the study of forest ecological benefits and compensation practice. This also facilitate forest and other ecosystem value measure and conversion. In addition, the use of unit area to measure forest ecological benefits can also promote and compare the expansion of forest ecological value on the area scale. In the past, forestry management pursued the growth of forest resource area, but the increase of area does not necessarily promote the improvement of forest resource quality, nor does it directly lead to the increase of forest ecological value. How to implement the different compensation standard among different regions and how to implement the different compensation from

the quality and location of tree species in a small area are the focus and difficulty of the research.

As to which indexes should be referred to carry out the actual compensation work, most scholars believe that the compensation standard is based on the ecological benefits of the forest as an objective basis. Wen^[43] believes that compensation standards should not be fixed according to area, but should be made based on forest ecological quality, and advocates that the carbon sequestration capacity of forest ecological functions should be measured according to the annual increment of forest storage as the basis of ecological tax calculation. Some scholars also believe that compensation should be made for forestland by referring to the existing geological quantity^[44], or based on forest stock measurement to calculate compensation^[45]. Compensation shall be made according to the transaction price of forestry carbon sink and adjustment shall be made according to the fluctuation of carbon sink. Compensation based on the forest carbon sequestration price will not affect the operation of the forestry market, and at the same time achieve the purpose of improving forest carbon sink^[46]. The compensation method of forest carbon sink is gradually recognized by the public^[47], and the public is gradually accepting this method and willing to buy carbon sink for forest ecological benefit compensation. Public willingness is mainly related to individual risk preference^[48]. Li^[49] believed that differential compensation standard should be calculated, and factors such as tree species' stand age and stand quality in ecological location should be taken into account. Other scholars pointed out that compensation standards should reflect high quality and favorable price and establish a classification and classification compensation mechanism to guarantee the enthusiasm of foresters in forest maintenance^[50]. Chen *et al.*^[51] constructed a compensation coefficient model of ecological public welfare forest in Zhuzhou city of Hunan province based on indicators such as ecological public welfare forest ownership, the governance level, protection level, stand quality and ecological service function of ecological public welfare forest, and calculated the compensation coefficient, reflecting the differential compen-

sation. Some scholars have also established a public welfare forest ecological compensation standard influencing factors measurement model. Huang^[52] Chen *et al.*^[53] established a measurement model between the compensation standard of public welfare forest and per capita disposable income, stock volume, log price of various tree species and protection grade, forming a standard system of classification calculation and compensation. Liao^[54] established a regression analysis model of differentiated forest ecological benefit compensation standard for public welfare forest of Hunan Forest parks. The compensation standard has a strong linear relationship with stock volume, log price, protection level, per capita income and other factors, suggesting hierarchical compensation to reflect the principle of high quality. The development of forest ecological function is a long and slow process, and it is time-consuming and laborious to calculate its benefit in the short term. Originally, it is more scientific to carry out statistics and calculate compensation standard in a fixed period. As the amount of compensation standard and whether the compensation is reasonable are directly related to the satisfaction of the compensation object, some scholars have gradually begun to explore the research on the intention of compensation and investigate the satisfaction of foresters on compensation and the factors affecting the satisfaction^[55]. Many studies have shown that income level and education level of foresters are important factors affecting the satisfaction of forest ecological compensation^[56]. The lack of attention to the construction of public welfare forest is one of the reasons leading to the poor effect of forest ecological compensation. The younger and more educated farmers are more likely to agree with differentiated compensation for public welfare forests^[57]. Therefore, it is necessary to further strengthen the popularization and publicity of forest ecological cognition for compensation objects, so that compensation objects gradually accept differentiated compensation.

Investigation into the willingness of compensation object, in general, help to promote the rationality of the forest ecological benefit compensation system. When formulating the forest ecologi-

cal benefit compensation standard, on the one hand, it is necessary to consider the compensation satisfaction of forest and governments' willingness to pay the principal. On the other hand, it is necessary to refer to the relevant factors such as forest quality and ecological benefit, and the level of local economic development, and appropriately adopt reasonable incentive mechanism and competition mechanism, and set up a reasonable level of forest ecological benefit compensation standard, which will promote the scientific formulation of forest ecological compensation standard.

3. Research and practice progress of forest ecological benefit compensation abroad

The formulation of ecological benefit compensation by foreign scholars is slightly different from that in China, and PES is the most widely used in foreign literature. The central idea of PES is that the value of ecosystem services should be compensated by the beneficiaries. The purpose of PES is similar to that of forest ecological compensation, which also corrects market dysfunction by internalizing environmental externalities into market prices. Foreign PES studies started early. In 1997, Daily^[58] first explicitly proposed the concept of ecosystem service functions, laying a foundation for PES research and practice. Subsequently, the relevant concepts, classification framework and evaluation of ecosystem service function value of ecosystem compensation services have become hot topics and cutting-edge issues. Since then, there have been hundreds of PES programs around the world, which mainly covers four aspects of ecosystem services: biodiversity conservation, watershed services, carbon storage and landscape beautification. Some countries have long implemented policies and projects related to forest protection, which, although not directly specified as payment for forest ecological services, actually play a similar role. In addition to the forest engineering projects compensated by the government and public financial subsidies, the foreign forest ecological service payment system is partly the supervision and compensation of forest ecology by public welfare organizations, such as the

European Union LIFE (The Financial Instrument for the Environment). The environmental finance facility of LIFE has numerous projects responsible for and funding forest restoration in the European Union. In addition, there is a large part of market-driven compensation for forest ecological benefits, including carbon sequestration trading and costs generated by forest ecotourism. There are some countries such as river downstream to the upstream of the compensation for afforestation to interest-free loans or exemption system, this section should not belong to the forest ecological benefit compensation of direct, but should belong to the preferential policies of forest ecological benefit compensation. Scope and object are different depending on the source of the money, after all, different sources of compensation funds have different focus, not the source of government and market. Gold is mixed and compensated.

3.1 Forest ecological service payment under the government compensation mechanism

Government compensation is generally for large-scale restoration or maintenance of forest ecology, such as afforestation and management, which is similar to cost compensation. Costa Rica's PSA program (Pago de Servicios Ambientales) pioneered the global implementation of PES payments for ecological services^[59]. In 1996, Costa Rica's newly revised Forest Law approved the PSA, which initially included three aspects of financial compensation: Forest protection, reforestation and forest management. It evolved into 16 modes of compensation including biodiversity, water services and pasture regeneration by 2014. Among them, forest protection and reforestation are still the two main modes. The main source of compensation funds is financial funds provided by the government, mainly from fuel tax, and water service fees^[60]. In the PSA compensation program implemented in Costa Rica, any private forest owners with property rights can voluntarily participate in the PSA program based on land ownership. Private forest owners can receive compensation and tax-exempt incentives by signing paid contracts and purchasing environmental service certificates with the benefi-

ciaries of forest ecological benefits and the third party FONAFIFO (The National Forestry Financing Fund). In addition to Costa Rica, some countries, including Vietnam and Morocco, have secured a portion of their sources of payment for forest ecological services through transfer payments and mandatory taxes^[61].

The British Forestry Commission established the forest subsidy system in 2003 and revised it in 2008, providing six kinds of subsidies including forest planning, forest evaluation, forest renewal, forest improvement, afforestation subsidy and forest management. Different subsidies are based on the area, with different standards. Subsidies are mainly provided to residents who provide forest ecological services and those who manage forests^[62]. Before 2014, forest ecological services in the United States were mainly paid by government subsidies. The policy of the United States is similar to that of China, which compensates the farmers who carry out afforestation projects in the original farmland according to the extent of forestland. The private forest area of the United States is huge, accounting for 60% of the country's forestland. The government mainly provides financial subsidies for the artificial afforestation of private forests, and compensates them through "afforestation tax incentive plan" and "forestry encouragement plan" funds. Many EU countries also rely mainly on government funds for compensation. The German government's compensation funds come from federal finance and state finance, in addition, some of them come from the EU. Germany's special protected forests account for about 1/3 of the forest area^[63], all of which are invested and specially managed by the government. The compensatory content of private forest includes afforestation allowance, raise allowance, forest land soil ameliorates to wait. As long as the forest is under sustainable development and management, subsidies are provided. The basic criteria include the cost of forest protection, expenditure on means of production and expenditure on conversion of forest forms. Compensation amount basically can reach 85%–95% of farmers' losses in 2000 Germany through the continuous ecological tax after the reform, continue to fuel, electricity added tax^[64] in

forest ecological management account, safeguard the market funds of the stability of the private forest compensation channels, at the same time to improve the public environmental awareness and improve the quality of forest environment has a promoting effect. In addition, the German state of Baden-Wurttemberg has introduced a forest maintenance tax, which specifies the amount to be paid for forest destruction, namely 0.6 euros per square meter, expanding the source of funds for compensation. The Australian government on the forest compensation scope including state-owned forest, forest reserves, in the state of natural forest and private natural forest^[65], compensation in the form of a direct compensation, municipal fees, tax incentives and in-kind donations, as well as the implementation of the pay for river basin upstream deforestation, compensation to the local forestry department to improve the forest environment.

Japan is the first country in Asia to implement forest ecological compensation. Compensation for forest ecological benefits in Japan includes forestry subsidy, preferential loan for forestry and tax preference^[66]. Government funding sources include central and local finance, and the main compensation scope is to protect the forest, similar to China's public welfare forest, but the compensation object is limited to private forest owners. Some local governments set up water source tax to deposit into "forest environment preservation fund"^[67] and collect it from downstream residents and legal persons in the form of transfer payment. Kochi Prefecture, for example, will receive 10,000 yen per person per year in 2020 for forest environmental protection, forest management and tending and management of severely degraded forests.

3.2 Forest ecological service payment under market mechanism

An important source of forest ecosystem service payment under the market mechanism is carbon sink trading. Some countries and regions have formed the mature mechanism of carbon trading market, the typical of which is the European Union Emissions Trading Scheme. It involves the industry's carbon emissions trading, though not specifi-

cally for forest ecological system of the trading system, but the forest carbon sinks services provider and the beneficiary can through woods fixed to the trading system, the absorption and conversion of CO₂ volume trading, so as to improve the income of forest households. In many countries, forest ecological service payment is not a single mode of government or market compensation, but a combination of the two modes, but the dominant mode is different. Costa Rica, for example, in addition to government compensation, also has funds from international loans and donations, private donations, and bilateral institutions, including loans from the World Bank and global environmental fund (GEF) donations^[68]. In addition, Costa Rica's eco-payments are funded by carbon charges. Carbon charges include protected areas and private forests, but some funds are limited in scope. For example, water service charges can only be used for watershed forests that play a role in water conservation, and carbon funds can only be used for reforestation. Costa Rica's Forest Law also refers to users of forest landscapes as sources of payment, but since there is no mandatory requirement, many users do not actually pay.

Under the market mechanism, different countries have various ways to ensure the source of compensation funds. The United States uses forest park entrance fees and hunting fees as the source of compensation funds^[69]. Meanwhile, the forest ecological insurance system and market-oriented protection mechanism are introduced to allow enterprises to participate in forest ecological benefit compensation projects. The Australian clean energy regulator has set up an emission reduction fund with the carbon credit market as the main body. Enterprises that emit excess CO₂ will be included in the compensation body and all forest managers will be compensated. In addition, The State of New South Wales in Australia has also implemented a watershed compensation model, in which irrigators pay for the ecological and environmental functional service value of afforestation in the upper reaches of the watershed. In order to balance the lack of externalities of forest ecological benefits, Germany adopts the strategy of "horizontal transfer payment".

Through the interstate financial balance fund, whereby the richer regions transfer ecological compensation to the poorer regions through the interstate fiscal balance fund, or the downstream regions assume the responsibility of compensation to the upstream regions. Brazil mainly implements ecological value-added tax and legal storage policy. Ecological value-added tax is the part of sales tax collected by the government returned to the states, and its proportion is determined by the proportion of protected areas in the area of the state and the protection level. Legal reserves policy refers to the farmers lack of forest coverage provisions can be purchased from forest coverage enough farmers index^[69]. Canada stipulates that the entrance fee of forest parks is paid to the local forestry department according to a certain percentage^[70]. Sweden has implemented forest ownership vesting in the form of an ecological tax to incentivize private forest owners to contribute to forest eco-efficiency compensation. Colombia uses ecological services taxes from electricity and industrial water to compensate for forest ecological benefits^[28]. Finland piloted a scheme for forest owners to participate in landscape and recreation value trade (LRVT), in which forest management associations or regional forest centers act as third parties to obtain funds from tourists or tourism businesses and assess the amount of compensation^[71].

Foreign market-oriented compensation policies are relatively diversified, among which transfer payment mode plays a better role in reflecting the fairness of compensation. However, it is very important to formulate policies scientifically. How to coordinate and monitor the contradictions and interests of both sides of the transfer should not be ignored, for example, whether the transfer purchase between insufficient forest coverage rate and sufficient owners will have adverse effects on the overall ecological benefits of the forest. The effect of these policies is still worth further evaluation.

3.3 Scientific design of compensation standards

In countries with more perfect forest compensation policy mechanisms, such as Mexico and

Costa Rica, in addition to implementing PES policies mandated by the government and encouraged by the market, compensation standards for forest ecological benefits in some countries tend to take into account the interests of both regions and people^[72]. The emphasis of forest ecological compensation abroad is private forest, especially in the United States, so the rationality of private forest compensation standard will affect the enthusiasm of private forest owners to participate in forest ecological compensation. Costa Rica offers differentiated financial incentives based on the type of ecosystem and natural endowments of forest land, and the compensation is adjusted annually according to the impact of inflation. The United States adopts a non-uniform compensation standard in the implementation of PES projects. Competition mechanism is introduced to determine the compensation standard suitable for local natural economic conditions. The initial price of carbon trading credit in Australia is 23 Australian dollars per unit of carbon credit, and the later price is based on the auction price of carbon credit as a floating price. In the implementation of forest benefit ecological compensation in Britain, the compensation standard of broadleaved forest is nearly twice as much as that of coniferous forest. Finland pays attention to the compensation of tree species differences, and the compensation period of broadleaved forest is twice as much as that of coniferous forest.

Due to the introduction of more market compensation mechanisms, foreign forest ecological benefit compensation mechanisms have diversified sources of funds and high public participation. However, many scholars have paid attention to the implementation effects of PES, mainly including the following aspects: (1) the quantity and quality of ecosystem services provided by PES; (2) measuring the direct and indirect effects of PES on participants; (3) the impact of PES projects on social equity. Some scholars used the classification evaluation system to analyze the characteristics of dozens of domestic and foreign PES cases, evaluate the performance of PES plan on the ground, and test whether PES is successful according to whether it makes positive contributions to local livelihood and

well-being^[73]. Some scholars also analyzed the effectiveness of forest ecological service payment programs, including the quantitative analysis of farm rental costs and compensation results, as well as the significant impact on forester enthusiasm, forest harvesting rate and coverage rate^[74]. In the studies on the influence of PES on participants, foreign scholars pay more attention to whether the public is willing, the length of the contract, the payment method, the willingness and acceptance of the compensated, whether the compensation standard meets the willingness of forest conservators to receive compensation and the purchase motivation^[75-77], etc. One of the key points is the research on ecological compensation intention of private ownership forests and corporate forests^[78].

Foreign PES in implementing the marketization compensation mechanism is more diverse, from the perspective of sources of compensation funds also has expanded the scope of the “payment for ecosystem services” includes not only the forest ecological product and the service provider’s positive incentive fees, including damage to forest ecological product use and negative penalty fee, more in line with the idea of ecosystem services to pay abroad PES projects focus more on evaluation and compensation from certain perspectives of forest ecosystem functions, such as carbon sinks, biodiversity, watershed services and other PES projects. Due to the high degree of marketization of private and corporate forests and the more diversified sources of funds from public welfare organizations and funds, there is a better environmental foundation for promoting the implementation of PES. Foreign PES field surveys and empirical studies are more frequent. Through different forms of evaluation methods, including dialogues with local governments and PES management decision-makers^[79,80], direct research and compensation for audiences^[81], design evaluation models combining qualitative and quantitative methods^[82], the impact of actual ecological compensation policies on local income and ecological environment is evaluated to objectively judge whether PES is effective.

4. Review and prospect

Due to the difference in forest management mode and ownership at home and abroad, there are many differences in the implementation and research of forest ecological benefit compensation mechanism. Some countries with rich experience in forest ecological compensation mechanism have gradually accumulated mature experience in introducing and evaluating market mechanism. Due to classified forest management objectives and government-led mode, public welfare forests are under strict protection in China, and their ecological value has not been marketized, resulting in a great restriction on the source of funds. At present, there are few attempts and explorations in domestic market compensation mechanism compared with foreign countries. The compensation of forest ecological benefit in our country has experienced the compensation of forest ecological project in the past to the development and change of public welfare forest compensation at present. At present, there are many market-based compensation methods that can be used for reference, and the more mature way is the integration of carbon sink market and ecological compensation mechanism. However, further exploration still depends on the promotion and practice of carbon trading market and forestry authorities. The forest classification management model implemented in China has ensured the forest cover rate and stand quality to a certain extent. On the basis of the existing forest resources, we continue to explore forest eco-efficiency management models and funding mechanisms for different management entities, give full play to the role of forest eco-efficiency compensation mechanisms, and continue to safeguard the livelihoods of forest eco-service providers to form a virtuous cycle. Forest ecological compensation can also be combined with poverty alleviation and poverty alleviation. Many poor areas are located in key areas of forest ecological function. By tapping jobs of ecological construction and protection, poor people with labor ability can participate in ecological engineering construction or become local forest rangers, custodian and other ecological protection personnel, thus realizing forest ecological compensation through

employment. Establish a cross-regional horizontal compensation mechanism and adaptation mechanism of watershed compensation according to local conditions, so as to guarantee the appeal of forest ecological benefit compensation rights and interests in underdeveloped areas, especially the forests owned by individuals after forest rights reform.

It is the key point in practice to calculate and determine compensation standard for the real value of existing forest resources. The compensation standard of forest ecological benefit is far lower than the evaluation result of forest ecosystem service value. Even if the evaluation result for forest ecosystem service value is used as the reference of forest ecological benefit compensation, it will be difficult to market and no one will pay the bill. Therefore, on the one hand, it is necessary to broaden the source of funds through marketization and other ways, and evaluate and analyze the forest ecological benefits scientifically from the preference of buyers and sellers, purchase motivation, protection awareness and other perspectives. The forest ecological benefits can be transformed into the economic benefits of the market. On the other hand, the fairness of compensation standard should be realized from the large scope of forest resources distribution, such as provincial and municipal level, and the scale of forest class and small class. The compensation standard should be more scientific whether it is state-owned forest, collective public welfare forest or private public welfare forest. In a large range, it is necessary to scientifically demonstrate the regional importance of ecological compensation and determine the compensation standard. Local forest ecological benefit compensation needs to be combined with the local economic development level to establish compensation standards. The compensation in the small forest enclosure should reflect the principle of high quality and favorable price and the principle of classification and classification compensation. The calculation of compensation standard should reflect the stability and continuity of forest ecological benefits in a certain period of time, and reflect the rationality of forestry's unique attributes and distribution standard. It is necessary to find a unit of measurement that

can reflect forest quality, quality grade, ecological location and other factors, and explore a compensation benefit measurement model based on local reality and compensation theory, so as to better meet the goal of forest ecological service function.

In terms of the source of compensation funds, we should gradually improve the public's awareness of forest ecological benefits and the participation of compensation, and expand the payment scope of forest ecological benefits compensation. By means of science popularization and research, the awareness of "who will develop and who will protect, and who will benefit and who will compensate" will gradually be deeply rooted in people's minds and the public's "free-riding" behavior on forest ecological benefits can gradually be eliminated. It can guide the carbon sink trading market, the biodiversity market, forest tax and other ways to expand the forest ecological benefit compensation model, explore a more relaxed and reasonable market mechanism under the guidance of the government, and form a good coupling mechanism of government compensation and market compensation.

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Conflict of interest

The authors declared no conflict of interest.

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