Research on the forest ticket price formation mechanism based on three ecosystem service value pricing methods

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Abstract

Purpose – Currently, there is a conflict in developing countries between the requirements for the self-development of forestry and the insufficient investment in the forestry sector, and the forest ticket system is an innovative forestry management method to solve this contradiction. In the research on the forest ticket system, the study of its price formation mechanism is relatively important. The key issues of the forest ticket system are how to form the forest ticket price and whether the forest ticket pricing methods are reasonable. Solving these problems is the purpose of this study.

Design/methodology/approach – This study will use three methods, namely the forest ecosystem service value evaluation index method, the ecosystem service value based on per unit area evaluation method and the contingent valuation method, to study the forest ticket price formation mechanism, filling the gap in the current research on forest ticket pricing methods. It will analyze how these three pricing methods specifically price the forest ticket and evaluate whether these pricing methods are reasonable. This study will then summarize and comprehensively study the forest ticket price formation mechanism and provide policy recommendations for decision-making departments.

Findings – The contingent valuation method and the forest ecosystem service value evaluation index method should be mainly used and given priority in the forest ticket pricing process. When the forest ticket is mainly issued for local residents' willingness to compensate for the forestry ecological value, the contingent valuation method should be mainly considered; when the forest ticket is mainly issued for compensating for the ecological value of local used forest land, the forest ecosystem service value evaluation index method should be mainly considered. The ecosystem service value based on per unit area evaluation method does not need to be the focus.

Originality/value – Compared with existing research studies, which focus more on the forest ticket system itself and the definition of forest ticket, this study mainly focuses on the forest ticket price formation mechanism, emphasizing how to form the forest ticket price and whether the forest ticket pricing methods are reasonable, which has a certain degree of innovation and research value and can partially fill the gap in related fields. At the same time, this study has certain help for the enrichment of the forest ticket system and the extension of related research studies.

Keywords Ecosystem service value, Forest ticket price formation mechanism, Forest ticket pricing methods

Paper type Research paper

1. Introduction

1.1 Background

To address the issue of insufficient investment in the forestry sector and in accordance with the requirements of improving the compensation system for ecological protection, under the premise of strict control of the total amount of forest land acquisition and drawing on the

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experience of land ticket, Chongqing has pioneered the exploration of the "compensation first, occupation later" and "occupation and compensation balance" of the ecological value of forest land and trees, and implemented the forest ticket system for the expropriation of forest land for commercial development, with multiple supporting measures developed. The forest ticket system is the first market-based ecological compensation mechanism that can promote intensive use of forest land and accelerate the appreciation of natural capital. The previous system of paying vegetation restoration fees for the use of forest land could only compensate for the attached items on the forest land, while the forest ticket system can compensate for the ecological value of forest land and trees.

In developing countries, the situation of insufficient funding in the forestry sector always conflicts with the requirement of achieving self-development in the forestry industry. For example, according to *China forestry and grassland statistical yearbook*, China's total investment in forestry and grassland in 2021 was 416.998 billion yuan, of which the central financial fund was 116.189 billion yuan, and the local financial fund was 118.191 billion yuan, totaling 234.380 billion yuan, accounting for 56.21% of the total investment in forestry and grassland. This indicates that funding for the forestry sector in China needs significant government financial support, similarly in other developing countries. At the same time, there are problems with low efficiency in forestry funding and overall forestry investment in developing countries, and the low utilization efficiency of forestry investment funds further leads to a decline in the input-output efficiency of forestry. This is not only due to the particularity of forestry, but also closely related to the low marketization of the forestry industry and the low efficiency of forestry resource allocation. In addition, the current economic structure of the forestry industry in developing countries is highly centralized in the primary and secondary industries, with serious problems of low-end industry. As a result, there is a contradiction between the requirements for the self-development of forestry and the insufficient investment in most of developing countries, and the forest ticket system is an innovative forestry management method to solve this contradiction.

The definition of forest ticket used in this study is mainly based on the definition of the forest ticket system proposed by Chongqing Forestry Administration: the forest ticket is a ticketed and commercialized concept. In order to achieve the balance between occupation and compensation of the ecological value of forest land, for projects that occupy forest land and aim to make a profit, the ecological value of the corresponding forest land and trees must be compensated. In order to facilitate accounting and trading, the forest ticket is a ticket of the ecological value of forest land and trees that can be traded on the market. Specifically, the forest ticket refers to the ecological value of forest land and trees that meet the relevant standards, have passed the audit and acceptance, and can be publicly traded in the market based on voluntary participation.

The forest ticket system, which is formed mainly by forest tickets, is not only an important means to achieve forest ecological benefit compensation but also one of the forestry economic innovation mechanisms to promote forestry financing and solve the problem of insufficient funding in the forestry sector, and it can effectively solve related conflicts and contradictions.

1.2 Research questions and objective

The forest ticket is a ticket of the ecological value of forest land and trees that can be traded on the market, and is an important means to achieve forest ecological benefit compensation. The research on the forest ticket price formation mechanism mainly includes pricing methods, calculation principles and price formation process of the forest ticket. Therefore, the key issues of the forest ticket price formation mechanism are: firstly, how to form a reasonable forest ticket price and what pricing methods should be used to form the forest ticket price;

secondly, whether the pricing methods used to form the forest ticket price are reasonable and which one of them should ultimately be used for forest ticket pricing.

As a result, the research questions of this study mainly include two aspects: firstly, how to form the forest ticket price; secondly, whether the forest ticket pricing methods are reasonable. And the research objective of the forest ticket price formation mechanism is to solve these two problems, and through the resolution of these problems to further recognize and understand the forest ticket system. At the same time, policy recommendations are proposed to achieve forest ecological benefit compensation and solve the difficulties faced by forestry development such as forest financing problems through the forest ticket system.

To achieve the research objective, this study first reviewed existing literature on related issues and defined the question of forest ticket price formation mechanism. At the same time, corresponding theoretical foundation was selected to solve which forest ticket pricing methods should be used. On this basis, three pricing methods, namely the forest ecosystem service value evaluation index method, the ecosystem service value based on per unit area evaluation method and the contingent valuation method, were used for forest ticket pricing. Through empirical research, the forest ticket prices formed by these three pricing methods were obtained. Finally, based on the results of empirical research, the suitable forest ticket pricing method was selected to address the two questions of how to form the forest ticket price and whether the forest ticket pricing methods are reasonable. Relevant policy recommendations were also proposed.

1.3 Research contribution

1.3.1 Academic contributions. Firstly, research on the forest ticket price formation mechanism can to some extent promote the improvement and development of research related to the forest ticket system. This study focuses on the forest ticket price formation mechanism, which can partially fill the gap in this field that is still less involved in existing research, and is a supplement to related research on the forest ticket system. Secondly, research on the forest ticket price formation mechanism helps to understand the essential relationship between the forest ecosystem and its service value, and thus plays a certain role in promoting research on forest ecological benefit compensation system. Finally, the study of the forest ticket price formation mechanism also belongs to the study of the public good price formation mechanism, which can partially resolve the corresponding problems of the public good price formation mechanism, thus providing theoretical reference for related research on public goods.

1.3.2 Practical contributions. Research on the forest ticket price formation mechanism can effectively promote the efficient and high-quality development of forestry economic activities, further activate forest land resources, promote the enthusiasm of forest residents, increase their income and efficiently boost the scale, order and efficiency of forestry economic activities. Also, research on the forest ticket price formation mechanism can solve the forestry financing problem to a certain extent, promote the market-oriented development of forestry factors, broaden the financing channels of forestry and improve the efficiency of forestry resource allocation. More importantly, research on the forest ticket price formation mechanism can help to design appropriate trading systems for the forest ticket system, and fully introducing market mechanisms into the forestry production field, to some extent changing the serious problem of low-end forestry industry in developing countries, which is excessively centralized in the primary and secondary industries in terms of quantity. In addition, research on the forest ticket price formation mechanism can help accelerate carbon neutrality process and achieve peak carbon emissions and carbon neutrality as soon as possible.

2. Literature review

2.1 Research status of the forest ticket system

The prototype of forest ticket can be traced back to the forest usufruct trading system. The forest usufruct is an identification document for forest land ownership, types and quantities of forest ecological services, and forest ecological product usage rights. It introduces market mechanisms into forest ecological services and realize the marketization mode of forest ecological services through security trading methods. The forest usufruct trading system is composed of the forest usufruct, regulated users, exchanges and government support outside the exchange (Zhang, 2003, 2005). Based on the forest usufruct trading system, Zhang and related research teams optimized the system in 2012 and named it the forest ticket trading system, proposing the concept of the forest ticket for the first time.

Currently, existing research on the forest ticket system mainly focuses on the definition of the forest ticket system. Tian (2013, 2015) believes that the forest ticket system is a new institutional design borrowed from the land ticket system and is an efficient use of land resources that cannot be utilized by the land ticket system. By borrowing the definition of land ticket and based on the concept of the forestland red line, Tian defined the forest ticket system as follows: similar to the land ticket, farmers relinquish the right to use idle land and re-cultivate it as forestland, the newly added forestland area is then converted into construction land index and openly traded to obtain a certain amount of financial compensation. Tian's design of the forest ticket system can be called the first definition of forest ticket.

The second definition of forest ticket was proposed by Sanming Forestry Administration (2019), referring to equity or share certificates issued based on investment proportions by state-owned forestry enterprises or institutions and village collective economic organizations with their members for afforestation or cooperative operation of existing forest land, with trading, pledge and cashing functions. Subsequently, Sanming Forestry Administration (2020) further divided the forest ticket into equity and debt categories. The definition of the equity forest ticket is similar to the above definition, referring to equity certificates with income rights issued by state-owned forestry enterprises or institutions and other corporate entities or individuals who invest in afforestation or cooperative operation of existing forest land and whose cooperation rights are proportionally valued. The debt forest ticket refers to debt certificates issued by the forest right collection and storage guarantee agency to the winning bidder in an open auction of standing trees at the bid price.

In addition, Huinong District of Shizuishan has also established the forest ticket system and summarized it as a new model of "exchange forest for energy" and "exchange forest for carbon". "Exchange forest for energy" refers to locking the value of forest resources and the operator's income through the forest ticket system, initiating the mechanism of exchange and purchase between industrial energy consumption and forest, thus ensuring forest land income and easing the pressure of energy conservation and consumption reduction. "Exchange forest for carbon" is on the basis of "exchange forest for energy", refers to locking the value of forest ticket through the carbon emission reduction of forest resources, promoting carbon sequestration economic forest trading and relying on the carbon sequestration trading platform to increase the financing mode of forestry and guide social capital participation (Di and Li, 2021).

And the definition of forest ticket used in this study has been mentioned above: the forest ticket is a ticketed and commercialized concept. In order to achieve the balance between occupation and compensation of the ecological value of forest land, for projects that occupy forest land and aim to make a profit, the ecological value of the corresponding forest land and trees must be compensated. In order to facilitate accounting and trading, the forest ticket is a ticket of the ecological value of forest land and trees that can be traded on the market. Specifically, the forest ticket refers to the ecological value of forest land and trees that meet the relevant standards, have passed the audit and acceptance and can be publicly traded in the market based on voluntary participation.

The deficiencies in the definition of forest ticket and the design of the forest ticket system in existing research mainly lie in: First, the design of other forest ticket research mainly focuses on construction land replacement, reform of collective forest tenure, etc., only considering the social benefits that the forest ticket system can bring, without considering the ecological benefits that the forest ticket system can bring, let alone the forest ecological benefit compensation. Second, the main goals of other forest ticket research are only to promote the development of forestry industry and increase the income of forest farmers, neglecting the requirement that the main goal of the forest ticket system should also include its impact on the ecological environment. Third, other forest ticket research analyzes the impact of the system from a micro perspective, and there are few macroscopic analyses and designs. Fourth and most importantly, other forest ticket research has almost no study on the forest ticket price formation mechanism and forest ticket pricing methods.

2.2 Research status of the forest ecological benefit compensation

This research on the forest ticket price formation mechanism is of great significance in recognizing the forest ecosystem service value and creating innovative forest ecological benefit compensation system. Therefore, a comprehensive review of the research status of the forest ecological benefit compensation is also reasonable and necessary.

Forest ecological benefit refers to the ecological and social benefit that forests provide to people by leveraging their own functions. These beneficial services and welfare are provided by forests through their ecological structure, processes and functions for human beings. Forest ecological benefit compensation refers to the compensation for forestry ecological environment, the behavior of protecting the ecological environment and the objects with important ecological value. It is the process by which the government provides economic compensation to forestry production and management operators to promote forestry development, and is also an important method for adjusting the interest relationship of ecological environment protection. It is of great significance to ensure the sustainable supply of forest ecosystem services. The fundamental purpose of implementing the forest ecological benefit compensation system is to improve or maintain the high environmental quality of forest ecosystem. As forest ecological benefit has strong externalities, its compensation must be achieved through internalizing externalities.

The research on the forest ecological benefit compensation around the world is mainly divided into three stages: the first stage is in the formation background that is the rapid decline of forest ecological function under high-intensity forest resource exploitation (Olson and Dinerstein, 1998), thus gradually shifting from emphasizing the economic benefit of forest to emphasizing its ecological benefit (Vauhkonen and Ruotsalainen, 2017); the second stage is the mature stage of research in the field of forest ecological benefit compensation, mainly focusing on identifying relevant parties for ecological compensation (Wunder, 2015), constructing a reasonable ecological compensation standard system (Huang *et al.*, 2011), the compensation model combining market and government (Pirard, 2012) and emphasizing the balance of ecological compensation mechanisms (Pagiola *et al.*, 2005); the third stage focuses more on exploring the relationship between forest ecological benefit compensation and poverty eradication (Markova-Nenova and Watzold, 2017), some studies suggest that ecological compensation can narrow the wealth gap (Wang and Maclaren, 2012), while others suggest that the main purpose of forest ecological benefit compensation should be to protect forest resources (Pascual *et al.*, 2014).

However, there are still some problems with forest ecological benefit compensation system, including incomplete legal basis, incomplete supporting systems, fewer financing channels, unreasonable determined standards and single compensation methods. Regarding how to reform forest ecological benefit compensation system, the existing research has proposed methods such as developing and improving relevant laws and regulations, establishing flexible and diverse compensation methods, clarifying the responsibility for funding from all parties, introducing the market into forest ecological benefit compensation, expanding financing channels for ecological benefit compensation and constructing a forest ecosystem service value evaluation system.

The existing experience in solving these problems is as follows. As a developed country with abundant forest resources, Australia's forest ecological benefit compensation mechanism includes government transfer payments and market-based compensation, including the federal government's emission reduction fund and local trust funds. The United States developed a forest ecosystem service market to address compensation funding issues and focuses on managing non-timber forest products. Brazil mainly compensates for forest ecological benefit through ecological value-added taxes and legal trade rights for forest products.

Research on the forest ticket system and the forest ticket price formation mechanism can provide some reference at the micro level for solving problems such as the lack of funding and financing channels for forest ecological benefit compensation, unreasonable standards and single compensation methods. With flexibility and diversity, this study provides market-based solutions and innovative methods for forest ecological benefit compensation, which can avoid the slow development of the forestry industry due to an imperfect forest ecological benefit compensation system to some extent.

2.3 Research status of the theory of ecosystem service value

Ecosystem service refers to the life-supporting product and service obtained directly or indirectly through the structure, processes and functions of ecosystem. The ecosystem service value evaluation is an important basis for ecological environmental protection, ecological functional zoning, environmental economic accounting and ecological compensation decision-making. This evaluation is of great significance for the scientific management of ecosystem and can help identify problems that arise during the evolution. It also can comprehensively show the current status and trends of ecosystem, thereby improving the scientificity of ecosystem management and providing effective ecological information for relevant departments and the public. Therefore, it is necessary to scientifically evaluate the ecosystem service value.

The issue of ecosystem service value initially gained widespread attention in the academic community in the early 1990s. Research on wetland ecosystems, global environmental systems, biodiversity and other topics laid the theoretical foundation for this issue. The related academic papers published by Costanza *et al.* (1997) and the Millennium Ecosystem Assessment project sponsored by the United Nations (2005) further pushed the research on ecosystem service value to a new height and gradually made it a key focus in related research fields. Since then, the academic community has conducted extensive research on the ecosystem service value of different types and scales, and has achieved valuable research results in methodological research and evaluation techniques.

Evaluating the ecosystem service value provides a theoretical basis and scientific foundation for establishing ecological compensation standards, and promotes the development of related research on ecological environmental management. The evaluation method of ecosystem service value usually uses the ecological parameter model based on remote sensing monitoring or the ecosystem service value equivalent method based on expert knowledge. Xie *et al.* (2003) localized the ecosystem service value equivalent method using expert knowledge and achieved better application results. This method has been positively adopted by the academic community due to its good comparability of evaluation results and standardized operational guidelines.

The forest ticket system is a method of forest ecological benefit compensation, and the formation of its price must rely on the quantification of its ecological value. To quantify its value, the theory of ecosystem service value must be used to price the forest ticket. Evaluating the ecosystem service value of the forest ticket is helpful for realizing forest ecological benefit compensation through the forest ticket system and providing the price formation mechanism for the design of forest ticket.

3. Research methods

Three ecosystem service value pricing methods were selected: the forest ecosystem service value evaluation index method (FESVIM), the ecosystem service value based on per unit area evaluation method (ESVPM) and the contingent valuation method (CVM). The reasons for choosing these three methods are as follows: firstly, these three forest ticket pricing methods are relatively mature and have been widely used in previous studies; secondly, these three methods have certain representativeness, the FESVIM comes from the standard specification of forestry industry, the ESVPM comes from outstanding research achievements in academic circles, and the CVM can reflect the general public's willingness to compensate for the forestry ecological environment; thirdly, this study can ensure that relatively complete data can be obtained using these three methods.

3.1 The forest ecosystem service value evaluation index method

The FESVIM calculates the value of various benefits that humans obtain from the forest ecosystem and determines the forest ecosystem service value contained within them. The sum of these values represents the total forest ecosystem service value. In this research, all the forest ecosystem service values contained within the forest ticket system are selected and calculated, and the results are used to determine the price of forest ticket.

The index system mainly includes four major service systems: supporting services, regulating services, provisioning services and cultural services, and nine categories of 18 evaluation indexes, such as soil conservation, nutrient retention of trees, water conservation, carbon sequestration and oxygen release, air purification, forest protection, biodiversity, forest product supply and forest health care, are included within these four service systems. The specific descriptions of these indexes are as follows.

(1) Supporting services

Supporting services refer to a series of services, including soil formation, nutrient cycling and primary production, that are essential for the production of all other forest ecosystem services. These services include two categories of indexes: soil conservation and nutrient retention of trees. Soil conservation mainly includes two specific functions: soil reinforcement and fertility holding. Nutrient retention of trees mainly includes three specific functions: nitrogen retention, phosphorus retention and potassium retention. These functions are all included in the ecological value of forest land and trees involved in the forest ticket system. Therefore, in this research, when forming the forest ticket price through the FESVIM, the service value of the five specific functions in the supporting service category is considered.

(2) Regulating services

Regulating services refer to the benefits that humans obtain from the forest ecosystem in regulating climate, disease, water resources and other elements. These benefits include four categories of indexes: water conservation, carbon sequestration and oxygen release, air purification and forest protection. Water conservation mainly includes two specific functions: regulating water quantity and purifying water quality. Carbon sequestration and oxygen release mainly includes two specific functions: carbon sequestration and oxygen release. Air purification mainly includes three specific functions: providing negative ions, absorbing gas pollution and dust retention. Forest protection mainly includes two specific functions: wind prevention and sand fixation and farmland protection. These functions are all included in the ecological value of forest land and trees involved in the forest ticket system. Therefore, in this research, when forming the forest ticket price through the FESVIM, the service value of the nine specific functions in the regulating service category is considered.

(3) Provisioning services

Provisioning services refer to the various products that humans obtain from the forest ecosystem, such as food, freshwater, fuelwood, biochemicals and genetic resources. These services include two categories of indexes: biodiversity and forest product supply. Biodiversity mainly includes one specific function, which is the conservation of species resources. Forest product supply mainly includes two specific functions: timber product supply and non-timber product supply. For the forest ticket system only focuses on the ecological value of forest land and trees, the two specific functions under the forest product supply are not included. Therefore, in this research, when forming the forest ticket price through the FESVIM, only the service value of the conservation of species resources in the provisioning service category is considered.

(4) Cultural services

Cultural services refer to the intangible benefits that humans obtain from the forest ecosystem, such as spirituality, religion, recreation and ecotourism, aesthetics, inspiration, education, attachment to homeland and cultural heritage. These benefits include one category of indexes: forest health care. In this research, when forming the forest ticket price through the FESVIM, the service value of forest health care in the cultural service category is considered.

In summary, in the index system, only two specific functions are not included in the ecological value of forest land and trees involved in the forest ticket system, which are timber product supply and non-timber product supply. Therefore, when using the FESVIM to form the forest ticket price, the price equals to the total service value, which is sum of the service value of the other 16 evaluation indexes' specific functions.

3.2 The ecosystem service value based on per unit area evaluation method

The ESVPM is the research method that calculates the forest ecosystem service value per unit area via the standard equivalent. In this research, the forest ecosystem service value per unit area calculated by this method is used to determine the price of forest ticket.

A standard ecosystem service value equivalent factor (referred to as the standard equivalent) refers to the economic value of the national average natural grain yield of one hectare of farmland per year (Xie *et al.*, 2003). Following Xie *et al.*'s (2003, 2015) processing method, this study uses the output value of the grain production per unit area of farmland as the ecosystem service value of a standard equivalent factor. The economic value of grain yield in the farmland ecosystem is mainly calculated based on the three major crops of rice, wheat and corn. The formula for calculating this value is:

$$D = S_r \times F_r + S_w \times F_w + S_c \times F_c \tag{3-1}$$

In formula (3-1), D represents the ecosystem service value of a standard equivalent factor (yuan/hm^2), S_r, S_w and S_c respectively represent the percentage of the planting area of rice, wheat and corn in the total planting area of the three crops for the current year (%), F_r, F_w and F_c respectively represent the national average production value per unit area of rice, wheat and corn for the current year (yuan/hm^2). The standard equivalent value for the current year can be calculated using the relevant data and formula (3-1).

At the same time, Xie *et al.* (2015) obtained the equivalent table of ecosystem service value per unit area by calculation, which includes the forest ecosystem service value equivalent part (Table 1). By combining Table 1 with the calculated standard equivalent value for the current year, the forest ecosystem service value per unit area can be further acquired.

According to the equivalent table, the total service value of the coniferous forest ecosystem is 17.53 standard equivalents, the total service value of the theropencedrymion ecosystem is 23.09 standard equivalents, the total service value of the broad-leaved forest ecosystem is 22.95 standard equivalents, and the total service value of the shrubbery ecosystem is 15.22 standard equivalents.

The ESVPM ultimately calculates the ecological service value per unit area of different forest ecosystems, which represents the ecological value of forest land and trees of different forest ecosystems. Therefore, the forest ticket price is equal to the ecological service value per unit area calculated by this method.

3.3 The contingent valuation method

The CVM is the most widely used and influential typical stated preference value evaluation method among non-market value evaluation methods. This method applies the principle of utility maximization, using questionnaire surveys to reveal consumers' preferences for a particular public good and their maximum willingness to pay for an improvement in the situation or their minimum willingness to accept compensation for a deterioration in the situation, then used to evaluate the economic value of the public good. The CVM is a unique method for evaluating both use and non-use values of public goods in econometrics, and is currently one of the most widely used simulated market methods. It can overcome the limitations of a lack of actual markets and substitute markets for exchanging goods by providing hypothetical markets for pricing public goods.

Forest ecosystem services		Classification of forest ecosystems			
		Coniferous forest	Theropencedrymion	Broad-leaved forest	Shrubbery
Provisioning services	Food production	0.22	0.31	0.29	0.19
	Material production	0.52	0.71	0.66	0.43
	Water supply	0.27	0.37	0.34	0.22
Regulating services	Gas regulation	1.70	2.35	2.17	1.41
	Climate regulation	5.07	7.03	6.50	4.23
	Environmental purification	1.49	1.99	1.93	1.28
	Water regulation	3.34	3.51	4.74	3.35
Supporting services	Soil conservation	2.06	2.86	2.65	1.72
	Nutrient cycle maintenance	0.16	0.22	0.20	0.13
	Biodiversity	1.88	2.60	2.41	1.57
Cultural services	Aesthetic landscape	0.82	1.14	1.06	0.69

Source(s): Table courtesy of Xie *et al.* (2015)

Table 1. Equivalent table of forest ecosystem service value per unit area

This study provides a hypothetical market for respondents using a questionnaire survey, thereby evaluates the ecological value of forest ticket to price the forest ticket. The questionnaire survey consists of three parts: (1), the first part investigates the respondents' personal information, including age, gender, education level, per capita annual income and other issues; (2), the second part investigates the respondents' understanding of the forestry ecological environment, including whether they follow news and information related to the forestry ecological environment, the severity of the damage to forestry ecological environment, the impact of damage to the forestry ecological environment on respondents, whether they consider the protection of the forestry ecological environment or economic development to be more important and other issues; (3), the third part investigates the respondents' willingness to compensate for the forestry ecological environment, including whether they are willing to pay forestry ecological compensation for environmental improvement, the amount they are willing to pay annually, the appropriate annual amount of compulsory forestry ecological compensation and other issues.

Two questions in the third part of the survey questionnaire are related to the forest ticket price formation through the CVM. The first question is the maximum amount respondents are willing to pay annually for environmental improvement, and the second question is the appropriate annual amount of compulsory forestry ecological compensation they consider. By counting the valid data from respondents' answers to these two questions, this research can respectively calculate the average annual willingness-to-pay price and the average annual compulsory forestry ecological compensation. After obtaining the results of the two aspects separately, this study converts them into the ecological value payment willingness per unit area of forestland and the compulsory forestry ecological compensation per unit area of forestland by using conversion from the population to the forest area. The forest ticket price is equal to the ecological value payment willingness per unit area or the compulsory forestry ecological compensation per unit area.

4. Empirical research

4.1 The forest ecosystem service value evaluation index method pricing

This research screened a total of 16 evaluation indexes from nine categories in the index system. In the empirical research on the FESVIM pricing, the forest ticket system in Chongqing is taken as an example. The total forest ecosystem service value in the forest ticket system is calculated based on the ecosystem service value of each specific function of the evaluation indexes.

The relevant data required for forest ecosystem service value evaluation in this section mainly comes from yearbook materials such as *Chongqing Statistical Yearbook*, *China Forestry and Grassland Yearbook*, *China Forestry and Grassland Statistical Yearbook*, *China Water Statistical Yearbook*, as well as other publicly available materials such as the China Agricultural Information Network of Ministry of Agriculture and Rural Affairs (http://www.agri.cn/). In addition, some indexes are set based on the recommended usage prices of the standard specification of Chinese forestry industry, while some indexes are set based on relevant research, and some indexes are set based on data and materials from the Chongqing forest ticket system and related research projects.

(1) Supporting services

Supporting services include two categories of indexes: soil conservation and nutrient retention of trees, with a total of five specific functions.

① Soil conservation

$$U_a = U_{a1} + U_{a2} = \frac{AC_a(X_2 - X_1)}{\rho} + A(X_2 - X_1)\left(\frac{N_aC_{a1}}{R_{a1}} + \frac{P_aC_{a1}}{R_{a2}} + \frac{K_aC_{a2}}{R_{a3}} + M_aC_{a3}\right) \quad (4\text{-}1)$$

Soil conservation mainly includes two specific functions: soil reinforcement and fertility holding. In formula (4-1), the total soil conservation service value U_a is composed of the soil reinforcement service value U_{a1} and the fertility holding service value U_{a2}. Among the variables related to the soil reinforcement service value U_{a1}, the cost of excavating and transporting one cubic meter of soil $C_a = 12.6$ yuan/m^3, the soil erosion modulus of the forest land $X_1 = 0.973$ t/(hm^2·a), the soil erosion modulus of the non-forest land $X_2 = 1.259$ t/(hm^2·a), the soil bulk density of the forest land $\rho = 1161.1$ t/m^3. Among the variables related to the fertility holding service value U_{a2}, the average nitrogen content of the forest soil $N_a = 0.55\%$, the average phosphorus content of the forest soil $P_a = 0.12\%$, the average potassium content of the forest soil $K_a = 1.50\%$, the average organic matter content of the forest soil $M_a = 3.88\%$; the nitrogen content of ammonium phosphate fertilizer $R_{a1} = 14.0\%$, the phosphorus content of ammonium phosphate fertilizer $R_{a2} = 15.01\%$, the potassium content of potassium chloride fertilizer $R_{a3} = 50\%$; the annual average unit price of ammonium phosphate fertilizer $C_{a1} = 2400$ yuan/t, the annual average unit price of potassium chloride fertilizer $C_{a2} = 2200$ yuan/t, the annual average unit price of organic matter $C_{a3} = 320$ yuan/t. The total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total soil conservation service value per year in Chongqing forest ecosystem $U_a = 281$ million yuan, and the annual soil conservation service value per unit area of forestland in Chongqing $u_a = U_a/A = 54.88$ yuan/hm^2.

② Nutrient retention of trees

$$U_b = U_{b1} + U_{b2} + U_{b3} = AB\left(\frac{N_bC_{b1}}{R_{b1}} + \frac{P_bC_{b1}}{R_{b2}} + \frac{K_bC_{b2}}{R_{b3}}\right) \quad (4\text{-}2)$$

Nutrient retention of trees mainly includes three specific functions: nitrogen retention, phosphorus retention and potassium retention. In formula (4-2), the total nutrient retention of trees service value U_b is composed of the nitrogen retention service value U_{b1}, the phosphorus retention service value U_{b2} and the potassium retention service value U_{b3}. Among all variables, the average nitrogen content of the forest trees $N_b = 1.5\%$, the average phosphorus content of the forest trees $P_b = 0.25\%$, the average potassium content of the forest trees $K_b = 0.4\%$; the nitrogen content of ammonium phosphate fertilizer $R_{b1} = 14.0\%$, the phosphorus content of ammonium phosphate fertilizer $R_{b2} = 15.01\%$, the potassium content of potassium chloride fertilizer $R_{b3} = 50\%$; the annual average unit price of ammonium phosphate fertilizer $C_{b1} = 2400$ yuan/t, the annual average unit price of potassium chloride fertilizer $C_{b2} = 2200$ yuan/t; the annual forest stands net productivity $B = 11.98$ t/(hm^2·a), the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total nutrient retention of trees service value per year in Chongqing forest ecosystem $U_b = 19.277$ billion yuan, and the annual nutrient retention of trees service value per unit area of forestland in Chongqing $u_b = U_b/A = 3770.30$ yuan/hm^2.

(2) Regulating services

Regulating services include four categories of indexes: water conservation, carbon sequestration and oxygen release, air purification and forest protection, with a total of nine specific functions.

① Water conservation

$$U_c = U_{c1} + U_{c2} = 10C_cA(P - E - C) + 10KA(P - E - C) \quad (4\text{-}3)$$

Water conservation mainly includes two specific functions: regulating water quantity and purifying water quality. In formula (4-3), the total water conservation service value U_c is composed of the regulating water quantity service value U_{c1} and the purifying water quality service value U_{c2}. Among all variables, the reservoir construction unit storage investment $C_c = 6.1107$ yuan/t, the purification cost of water $K = 2.09$ yuan/t; the precipitation in Chongqing in 2021 $P = 1287$ mm, the evapotranspiration of forest stands $E = 735.5$ mm, the surface runoff $C = 271.7$ mm, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total water conservation service value per year in Chongqing forest ecosystem $U_c = 117.316$ billion yuan, and the annual water conservation service value per unit area of forestland in Chongqing $u_c = U_c/A = 22945.56$ yuan/hm^2.

② Carbon sequestration and oxygen release

$$U_d = U_{d1} + U_{d2} = AC_{d1}(1.63R_{d1}B + F) + 1.19AC_{d2}B \quad (4\text{-}4)$$

Carbon sequestration and oxygen release mainly includes two specific functions: carbon sequestration and oxygen release. In formula (4-4), the total carbon sequestration and oxygen release service value U_d is composed of the carbon sequestration service value U_{d1} and the oxygen release service value U_{d2}. Among all variables, the annual carbon sequestration amount of forest soil per unit area $F = 1.647$ t/($hm^2 \cdot a$), the price of carbon sequestration $C_{d1} = 1200$ yuan/t, the price of oxygen $C_{d2} = 1000$ yuan/t, the carbon content in CO_2 $R_{d1} = 27\%$; the annual forest stands net productivity $B = 11.98$ t/($hm^2 \cdot a$), the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total carbon sequestration and oxygen release service value per year in Chongqing forest ecosystem $U_d = 115.342$ billion yuan, and the annual carbon sequestration and oxygen release service value per unit area of forestland in Chongqing $u_d = U_d/A = 22559.48$ yuan/hm^2.

③ Air purification

Air purification mainly includes three specific functions: providing negative ions, absorbing gas pollution and dust retention.

$$U_{e1} = 5.256 \times 10^{15} \times AHK_{e1}(Q_{e1} - 600)/L \quad (4\text{-}5)$$

In formula (4-5), among the variables related to the providing negative ions service value U_{e1}, the negative ion production cost $K_{e1} = 5.8185$ yuan/10^{18} ions, the concentration of negative ions in the forest $Q_{e1} = 10000$ ions/cm^3, the average lifespan of negative ions in the forest area $L = 20$ min, the average height of forest in Chongqing in 2021 $H = 45$ m, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2. Therefore, the total providing negative ions service value per year in Chongqing forest ecosystem $U_{e1} = 3.307$ billion yuan, and the annual providing negative ions service value per unit area of forestland in Chongqing $u_{e1} = U_{e1}/A = 646.81$ yuan/hm^2.

$$U_{e2} = A(K_{e21}Q_{e21} + K_{e22}Q_{e22} + K_{e23}Q_{e23}) \quad (4\text{-}6)$$

In formula (4-6), among the variables related to the absorbing gas pollution service value U_{e2}, sulfur dioxide treatment cost $K_{e21} = 1.20$ yuan/kg, fluoride treatment cost $K_{e22} = 0.69$ yuan/kg, nitrogen oxides treatment cost $K_{e23} = 0.63$ yuan/kg; the annual absorption of sulfur dioxide per unit area of forest $Q_{e21} = 126.55$ kg/hm^2, the annual absorption of fluoride per unit area of forest $Q_{e22} = 2.60$ kg/hm^2, the annual absorption of nitrogen oxides per unit area of forest $Q_{e23} = 5.35$ kg/hm^2; the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2. Therefore, the total absorbing gas pollution service value per year in Chongqing forest ecosystem $U_{e2} = 803$ million yuan, and the annual absorbing gas pollution service value per unit area of forestland in Chongqing $u_{e2} = U_{e2}/A = 157.02$ yuan/hm^2.

$$U_{e3} = AK_{e3}Q_{e3} \quad (4\text{-}7)$$

In formula (4-7), among the variables related to the dust retention service value U_{e3}, the dust reduction and cleaning cost $K_{e3} = 0.15$ yuan/kg, the annual dust retention per unit area of forest $Q_{e3} = 16811.86$ kg/hm^2, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2. Therefore, the total dust retention service value per year in Chongqing forest ecosystem $U_{e3} = 12.893$ billion yuan, and the annual dust retention service value per unit area of forestland in Chongqing $u_{e3} = U_{e3}/A = 2521.78$ yuan/hm^2.

$$U_e = U_{e1} + U_{e2} + U_{e3} \quad (4\text{-}8)$$

In formula (4-8), the total air purification service value U_e is composed of the providing negative ions service value U_{e1}, the absorbing gas pollution service value U_{e2} and the dust retention service value U_{e3}. Therefore, the total air purification service value per year in Chongqing forest ecosystem $U_e = U_{e1} + U_{e2} + U_{e3} = 17.003$ billion yuan, and the annual air purification service value per unit area of forestland in Chongqing $u_e = U_e/A = 3325.61$ yuan/hm^2.

④ Forest protection

$$U_f = U_{f1} + U_{f2} = U_{f1} + AQ_{f2}C_{f2} \quad (4\text{-}9)$$

Forest protection mainly includes two specific functions: wind prevention and sand fixation, and farmland protection. In formula (4-9), the total forest protection service value U_f is composed of the wind prevention and sand fixation service value U_{f1} and the farmland protection service value U_{f2}. Among all variables, the wind prevention and sand fixation benefit in Chongqing $U_{f1} = 0.3$ million yuan, the average crop yield per unit area increased due to the presence of forest $Q_{f2} = 857.08$ kg/hm^2, the average price of crops in Chongqing in 2021 $C_{f2} = 2.188$ yuan/kg, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total forest protection service value per year in Chongqing forest ecosystem $U_f = 9.588$ billion yuan, and the annual forest protection service value per unit area of forestland in Chongqing $u_f = U_f/A = 1875.35$ yuan/hm^2.

(3) Provisioning services

Provisioning services only include one category of indexes: biodiversity, with a total of one specific function which is conservation of species resources.

$$U_g = AS_g \quad (4\text{-}10)$$

In formula (4-10), the total biodiversity service value is U_g, the annual opportunity cost of species loss per unit area $S_g = 14106.94$ yuan/hm^2, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total biodiversity service value per year in Chongqing forest ecosystem $U_g = 72.126$ billion yuan, and the annual biodiversity service value per unit area of forestland in Chongqing $u_g = U_g/A = 14106.94$ yuan/hm^2.

(4) Cultural services

Cultural services only include one category of indexes: forest health care, with a total of one specific function which is forest health care.

$$U_h = 0.8U_t \tag{4-11}$$

In formula (4-11), the total forest health care service value is U_h, the tourism revenue from all forest parks and nature reserves in Chongqing in 2021 $U_t = 38$ billion yuan, the total forestland area in Chongqing in 2021 $A = 5.1128$ million hm^2.

Therefore, the total forest health care service value per year in Chongqing forest ecosystem $U_h = 30.4$ billion yuan, and the annual forest health care service value per unit area of forestland in Chongqing $u_h = U_h/A = 5945.86$ yuan/hm^2.

In summary, the total forest ecosystem service value per year in Chongqing $U = U_a + U_b + \ldots + U_h = 381.333$ billion yuan, the annual total forest ecosystem service value per unit area of forestland in Chongqing $u = u_a + u_b + \ldots + u_h = 74583.98$ yuan/hm^2. Therefore, formed according to the FESVIM, the forest ticket price is 74583.98 yuan/hm^2.

The forest ticket price formed using the FESVIM essentially considers the size of the service value covered by the forest ticket, thus using this method to price the forest ticket is reasonable, and this method plays a significant role in measuring the forest ecosystem service value and realizing the forest ecological benefit compensation function of the forest ticket. The main purpose of forest ticket system involved in this research is to compensate for the corresponding ecological value of the used forest land and achieve a balance between forestland ecological value occupation and compensation. Consequently, when pricing the forest ticket involved in forest ticket system, this method should be emphasized.

4.2 The ecosystem service value based on per unit area evaluation method pricing

Based on the relevant research of Xie *et al.* and the equivalent table of forest ecosystem service value per unit area, this study collected the relevant data from the past decade (2013–2022), and calculated the standard ecosystem service value equivalent factor (referred to as the standard equivalent) for these years using the ESVPM. Then, this study used the standard equivalent as the basis to calculate the service value of four types of forest ecosystems: the coniferous forest ecosystem, the theropencedrymion ecosystem, the broad-leaved forest ecosystem and the shrubbery ecosystem. Finally, this study formed the forest ticket price on the basis of the above results.

To calculate the standard ecosystem service value equivalent factor, it is necessary to first calculate the output value of the grain production per unit area of farmland in the agricultural ecosystem, which is mainly based on the data of the planting area of the three major crops of rice, wheat and corn, the percentage of the planting area of the three crops, and the national average production value per unit area of the three crops. The relevant data collected by this study from 2013 to 2022 are shown in Table 2.

Using the data from 2019 as an example: the rice planting area was 29693.5 thousand hm^2, the wheat planting area was 23727.7 thousand hm^2, the corn planting area was 41284.1 thousand hm^2 and the total planting area of the three major crops was 94705.3 thousand hm^2. Consequently, the percentage of the rice planting area $S_r = 31.35\%$, the percentage of the wheat planting area $S_w = 25.05\%$, the percentage of the corn planting area $S_c = 43.59\%$. At the same time, the national average production value per unit area of rice $F_r = 18933.0$ yuan/hm^2, the national average production value per unit area of wheat $F_w = 15660.0$ yuan/hm^2, the national average production value per unit area of corn $F_c = 13933.5$ yuan/hm^2.

Therefore, based on the above data and formula (3-1), a standard ecosystem service value equivalent factor, namely the standard equivalent in 2019 $D = 15933.6$ yuan/hm^2. According to the equivalent table, the total service value of the coniferous forest ecosystem is 17.53 standard equivalents, amounts to 279315.7 yuan/hm^2; the total service value of the

Table 2. The planting area, the percentage of the planting area and the national average production value per unit area of rice, wheat and corn in China from 2013 to 2022

Year	Rice			Wheat			Corn		
	Planting area (1000 hm^2)	Percentage (%)	Average value per unit area (yuan/hm^2)	Planting area (1000 hm^2)	Percentage (%)	Average value per unit area (yuan/hm^2)	Planting area (1000 hm^2)	Percentage (%)	Average value per unit area (yuan/hm^2)
2022	29450.0	30.66	21674.2	23520.0	24.49	17517.4	43070.0	44.85	19247.7
2021	29921.2	30.91	21691.5	23567.1	24.34	17314.7	43324.2	44.75	18738.8
2020	30075.5	31.75	19421.8	23380.0	24.68	16051.0	41264.3	43.56	14993.1
2019	29693.5	31.35	18933.0	23727.7	25.05	15660.0	41284.1	43.59	13933.5
2018	30189.5	31.26	19342.5	24266.2	25.12	12802.5	42130.1	43.62	13222.5
2017	30747.2	31.49	20140.5	24508.0	25.10	15205.5	42399.0	43.42	12760.5
2016	30745.9	30.86	20157.0	24694.0	24.79	13956.0	44177.6	44.35	11488.5
2015	30215.7	32.67	20662.5	24141.4	26.11	15025.5	38119.3	41.22	14242.5
2014	30309.9	33.12	20721.0	24069.4	26.30	15795.0	37123.4	40.57	17185.5
2013	30311.7	33.40	19588.5	24117.3	26.58	13528.5	36318.4	40.02	16344.0

Source(s): Table courtesy of the National Bureau of Statistics of China http://www.stats.gov.cn/

theropencedrymion ecosystem is 23.09 standard equivalents, amounts to 367906.4 yuan/hm^2; the total service value of the broad-leaved forest ecosystem is 22.95 standard equivalents, amounts to 365675.7 yuan/hm^2; the total service value of the shrubbery ecosystem is 15.22 standard equivalents, amounts to 242509.1 yuan/hm^2.

Similarly, the standard equivalents and their average value for China's ecosystems from 2013 to 2022, as well as the service values and their average value for the four forest ecosystems are shown in Table 3.

To ensure the rationality of pricing results and avoid the situation where the forest ticket price is higher due to higher data in a certain year, this study uses the average value of the forest ecosystem service value obtained by the ESVPM in the past decade (2013–2022) to price the forest ticket. Therefore, the standard equivalent D is taken as the average value of 16818.5 yuan/hm^2, and the resulting forest ticket prices are as follows: the coniferous forest ecosystem forest ticket price is 294828.1 yuan/hm^2, the theropencedrymion ecosystem forest ticket price is 388338.9 yuan/hm^2, the broad-leaved forest ecosystem forest ticket price is 385984.3 yuan/hm^2, the shrubbery ecosystem forest ticket price is 255977.4 yuan/hm^2.

By comparing the forest ticket price formed by the ESVPM and the FESVIM, it can be found that the results obtained by using the former method are higher. For individuals or organizations who need to purchase the forest ticket, if only the forest ecosystem service value obtained by this method is used as the basis for pricing forest tickets, although the pricing results can reasonably reflect the total ecological value contained in the forest ecosystem, the results displayed are too high for these buyers themselves, and they may find it difficult to agree to purchase the forest ticket at such prices, which may cause certain resistance.

Therefore, only from the perspective of data, it is reasonable to design the forest ticket system based on the forest ticket price formed by this method, but its operability in reality must be considered. At the same time, both the ESVPM and the FESVIM are direct measures of the forest ecosystem service value. Compared with the latter method, the forest ticket price formed by the ESVPM is obviously higher in numerical value, so it is difficult to use this price to form the forest ticket price instead of the price obtained by the FESVIM when allocating and using the forest ticket.

However, the ESVPM also has certain advantages. The calculation of this method is the most convenient among all the pricing methods adopted in this study. It only requires the total planting area of the three major crops of rice, wheat and corn and the national average

Year	Standard equivalent (yuan/hm^2)	Coniferous forest (yuan/hm^2)	Theropencedrymion (yuan/hm^2)	Broad-leaved forest (yuan/hm^2)	Shrubbery (yuan/hm^2)
2022	19568.0	343027.2	451825.3	449085.8	297825.1
2021	19304.7	338411.6	445745.8	443043.1	293817.7
2020	16660.4	292057.1	384689.0	382356.5	253571.5
2019	15933.6	279315.7	367906.4	365675.7	242509.1
2018	15029.9	263473.9	347040.1	344935.9	228754.9
2017	15697.8	275181.8	362461.4	360263.7	238920.0
2016	14775.6	259016.4	341168.7	339100.2	224884.7
2015	16544.6	290026.4	382014.2	379698.0	251808.4
2014	17990.9	315379.7	415408.8	412890.1	273820.8
2013	16679.5	292391.3	385129.2	382794.1	253861.7
Average value	16818.5	294828.1	388338.9	385984.3	255977.4

Source(s): Authors' own work

Table 3. The ecosystem service value per unit area and forest ecosystem service value in China from 2013 to 2022

production value per unit area of these three crops to calculate the ecosystem service value per unit area of four different forest ecosystems, namely the coniferous forest ecosystem, the theropencedrymion ecosystem, the broad-leaved forest ecosystem and the shrubbery ecosystem. As a result, its pricing results can be calculated quickly in a short period of time. For this reason, the ESVPM can be used as a reference for the forest ticket price formation to a certain extent when the time is limited. Simultaneously, this method can measure the service value of different forest ecosystems, so this method should be considered when considering differentiated pricing of the forest ticket for different forest ecosystems.

4.3 The contingent valuation method pricing

The CVM is random sampling with a certain representativeness. According to the CVM, this study designed a relevant survey questionnaire to evaluate the ecological value of forest ecosystem to price the forest ticket. Considering the availability and accuracy of data, the targeted groups for the survey are randomly selected respondents from across the whole country.

The questionnaire survey of this study consists of three parts: (1), the first part investigates the respondents' personal information, including age, gender, education level, per capita annual income and other issues; (2), the second part investigates the respondents' understanding of the forestry ecological environment, including whether they follow news and information related to the forestry ecological environment, the severity of the damage to forestry ecological environment, the impact of damage to the forestry ecological environment on respondents, whether they consider the protection of the forestry ecological environment or economic development to be more important and other issues; (3), the third part investigates the respondents' willingness to compensate for the forestry ecological environment, including whether they are willing to pay forestry ecological compensation for environmental improvement, the amount they are willing to pay annually, the appropriate annual amount of compulsory forestry ecological compensation and other issues. To ensure the accuracy of the survey results, this study planned to distribute 200 questionnaires. Considering the issues of response rate and validity of the questionnaire survey, the study ultimately distributed 240 electronic questionnaires through the online platform. Finally, a total of 213 questionnaires were collected, with a response rate of 88.75%.

In the first part of the questionnaire, the results of the survey on personal information of the respondents, including their age, gender, education level and per capita annual income, can ensure the randomness of the respondents' selection. Limited to the length of the paper, this part of the data and results are not reflected in the main text.

After excluding data from respondents unwilling to pay forestry ecological compensation for environmental improvement, a total of 169 respondents are willing to pay, including 128 who are willing to pay forestry ecological compensation for environmental improvement, accounting for 75.74% and 41 who consider it is both acceptable to pay forestry ecological compensation or not, accounting for 24.26%. The price distribution of their willingness to pay is shown in Table 4.

The division of the price range of willingness to pay is based on the literature support of the related research of the CVM. The willingness to pay mainly concentrates on the values of 50–200, 201–500 and 501–1,000. The number of people willing to pay 501–1,000 yuan per year is the highest, accounting for 24.26% of the total, followed by respondents willing to pay 50–200 yuan and 201–500 yuan per year, accounting for 22.49 and 17.75% respectively.

To avoid invalid questionnaires and reduce errors, this study excluded respondents with willingness to pay greater than 2,000 yuan per year when calculating the average willingness-to-pay price. Therefore, the proportion of effective calculated data is 80.47%.

The average value of willingness to pay $E(WTP)$ can be calculated through the mathematical expectation formula (4-12) of the discrete variable WTP:

$$E = E(WTP) = \sum_{i=1}^{n} A_i P_i \tag{4-12}$$

In formula (4-12), A_i is the willingness-to-pay price, P_i is the probability of respondents choosing that price, and n is the number of willingness-to-pay prices. Based on the effective data, $E(WTP) = 656.26$, which means that respondents are willing to pay 656.26 yuan per year for forestry ecological compensation for environmental improvement.

To avoid the influence of extreme values on the average value, this study uses the median of willingness-to-pay price to review the data. The median of willingness-to-pay price is 500 yuan, which means that respondents are willing to pay 500 yuan per year for forestry ecological compensation for environmental improvement, so the average willingness-to-pay price is 1.31 times the median of willingness-to-pay price, which is within a reasonable range.

After obtaining the average willingness-to-pay price, the annual ecological value payment willingness per unit area of forestland can be calculated by converting the population to forest land area. Then, the forest ticket can be priced based on the ecological value payment willingness per unit area of forestland. The respondents to the survey questionnaire for this study come from all over the country, so the data from *China Statistical Yearbook* is used to calculate the value of forest ticket. At the end of 2021, the total population of China was 1.4126 billion, and the total area of forestland in the country was 2.841 million km^2, amounts to 284.1 million hm^2. Consequently, the annual ecological value payment willingness per unit area of forestland WTP is calculated as 3263.05 yuan/hm^2 based on the average willingness-to-pay price, and it is calculated as 2486.10 yuan/hm^2 based on the median of willingness-to-pay price.

Considering the inherent meaning and operating mechanism of the CVM, and the nature of forest ticket, this study ultimately uses the calculation result of the average willingness-to-pay price 3263.05 yuan/hm^2 as the forest ticket willingness-to-pay price, which means that the ecological value payment willingness per unit area of forestland is 3263.05 yuan/hm^2.

In the questionnaire, in addition to asking about the amount that respondents are willing to pay forestry ecological compensation for environmental improvement, this study also asked about the appropriate annual amount of compulsory forestry ecological compensation by the government they consider. The results of this question are shown in Table 5.

The division of the price range of compulsory compensation is based on the literature support of the related research of the CVM. The highest number of respondents believe that the annual compulsory forestry ecological compensation by the government should be between 50 and 200 yuan, accounting for 35.68% of the total. Over half of the respondents

Table 4. The price distribution of willingness to pay per year

Willingness to pay per year (yuan)	Number of people	Relative frequency (%)	Cumulative frequency (%)
Less than 50	9	5.33	5.33
50–200	38	22.49	27.81
201–500	30	17.75	45.56
501–1,000	41	24.26	69.82
1001–2,000	18	10.65	80.47
2001–5,000	18	10.65	91.12
Greater than 5,000	15	8.88	100.00

Source(s): Authors' own work

believe that the annual compulsory compensation should be 200 yuan or less, while over three-quarters believe it should be 1,000 yuan or less.

To avoid invalid questionnaires and reduce errors, this study also excluded respondents who believe that the compulsory compensation should be greater than 2,000 yuan per year when calculating the average compulsory compensation price. Therefore, the proportion of effective calculated data is 83.57%.

The average compulsory compensation price can also be calculated through the method that obtained the average value of willingness to pay $E(WTP)$, denoted as $E(CC)$:

$$E = E(CC) = \sum_{i=1}^{n} A_i P_i \tag{4-13}$$

In formula (4-13), A_i is the compulsory compensation price, P_i is the probability of respondents choosing that price, n is the number of compulsory compensation prices. Based on the effective data, $E(CC) = 411.44$, indicating that respondents believe the annual compulsory forestry ecological compensation by the government should be 411.44 yuan.

However, when using the median of compulsory compensation price to review the data, this study found that the median of compulsory compensation price is 200 yuan, so the average compulsory compensation price is 2.06 times the median of compulsory compensation price, which is a relatively high result.

Considering the practical factors, the willingness-to-pay price must be higher than the compulsory compensation price. If the compulsory compensation price is in the same way with the willingness-to-pay price, only those respondents whose compulsory compensation is more than 2,000 yuan are excluded, the pricing result of the compulsory compensation price cannot reflect these practical factors. At the same time, in order to avoid the influence of extreme values on the average value, this study continued to exclude respondents who believe that the compulsory compensation should be between 1,001 and 2,000 yuan per year, and the proportion of effective calculated data then decreases further to 78.87%. Recalculating the average compulsory compensation price can obtain that $E(CC') = 322.84$, at this time the median of compulsory compensation price remains at 200 yuan, and the average compulsory compensation price is now 1.61 times the median of compulsory compensation price, which is within a reasonable range, so there is no need to exclude the respondents again.

After obtaining the average compulsory compensation price, the annual compulsory forestry ecological compensation per unit area of forestland can also be calculated by converting the population to forest land area. This study continued to use data from *China Statistical Yearbook* of 2021 to calculate the result. If only respondents who believe that the compulsory compensation should be greater than 2,000 yuan per year are excluded, the

Compulsory compensation per year (yuan)	Number of people	Relative frequency (%)	Cumulative frequency (%)
Less than 50	31	14.55	14.55
50–200	76	35.68	50.23
201–500	26	12.21	62.44
501–1,000	35	16.43	78.87
1,001–2,000	10	4.69	83.57
2,001–5,000	11	5.16	88.73
Greater than 5,000	24	11.27	100.00

Source(s): Authors' own work

Table 5. The price distribution of compulsory compensation per year

compulsory forestry ecological compensation is calculated as 2045.76 yuan/hm^2; if respondents who believe that the compulsory compensation should be greater than 1,000 yuan per year are excluded, the compulsory forestry ecological compensation is calculated as 1605.22 yuan/hm^2; using the median of compulsory compensation price, the compulsory forestry ecological compensation is calculated as 994.44 yuan/hm^2.

Considering the inherent meaning and operating mechanism of the CVM, and the nature of forest ticket, this study ultimately uses the calculation result of the average compulsory compensation price 1605.22 yuan/hm^2, which excluded respondents who believe that the compulsory compensation should be greater than 1,000 yuan per year, as the forest ticket compulsory compensation price, which means that the compulsory forestry ecological compensation per unit area of forestland is 1605.22 yuan/hm^2.

In this section, the research ultimately formed five different forest ticket prices: the average willingness-to-pay price 3263.05 yuan/hm^2, the median of willingness-to-pay price 2486.10 yuan/hm^2, the first average compulsory compensation price 2045.76 yuan/hm^2, the second average compulsory compensation price 1605.22 yuan/hm^2, the median of compulsory compensation price 994.44 yuan/hm^2. Finally, this study adopted the average willingness-to-pay price 3263.05 yuan/hm^2 as the forest ticket willingness-to-pay pricing result, and the second average compulsory compensation price 1605.22 yuan/hm^2 as the forest ticket compulsory compensation pricing result.

Compared with the forest ticket prices formed by other pricing methods, the pricing result of the CVM is lower in numerical value, making it more easily accepted by the public. Whether the forest ticket willingness-to-pay price or the forest ticket compulsory compensation price, the numerical value is relatively friendly to the purchasers of forest ticket, and do not cause them to have a psychological resistance to the price, which is more conducive to the promotion of the forest ticket system in various places and is of great help to the implementation of the forest ticket system. Meanwhile, the forest ticket price formed by the CVM is based on the data of the surveyed respondents. Since the economic status of the respondents and the purchasers of forest ticket is closer than that of the issuers and purchasers of forest ticket, the purchasers of forest ticket also consider the price to be more reasonable compared to the prices set by the forest ticket issuing department through other methods, which is conducive to the acceptance of forest ticket by purchasers.

However, the forest ticket price formed by the CVM has a certain degree of subjectivity, and its ability to reflect the forest ecosystem service value is slightly insufficient. The respondents' economic status is similar to that of the purchasers of forest ticket, so respondents' willingness to pay for environmental improvement and the appropriate amount of compulsory forestry ecological compensation they consider will be lower, resulting in that the formed forest ticket price is much lower than the actual amount of forest ecological benefit compensation should be collected. As a result, compared to the forest ticket prices calculated using other methods, the forest ticket price formed by the CVM is deficient in realizing the forest ecological benefit compensation function of the forest ticket and may even lead to the overuse of forest resources by the purchasers of forest ticket.

In summary, the CVM cannot be the only reference method for the forest ticket price formation, but can still play an important supplementary role in the forest ticket price formation.

5. Research conclusions and policy recommendations

5.1 Research conclusions

Through theoretical exploration and empirical research, this study provides answers to two core issues that need to be solved concerning the forest ticket price formation mechanism. These two issues are also the two key issues in the research on the forest ticket system, namely, how to form the forest ticket price and whether the forest ticket pricing methods are reasonable.

To address the issue of how to form the forest ticket price, this study selected three ecosystem service value pricing methods, namely, the forest ecosystem service value evaluation index method (FESVIM), the ecosystem service value based on per unit area evaluation method (ESVPM), and the contingent valuation method (CVM). This study first explained and analyzed the characteristics and operational mechanisms of these three pricing methods, and collected the necessary data in detail for these methods. Based on the data collected, this study conducted empirical research on each of the three pricing methods in line with their inherent properties, and finally calculated the different forest ticket prices using each method. The forest ticket prices calculated through empirical research can be summarized as follows:

(1) The forest ticket price formed according to the FESVIM is 74583.98 yuan/hm^2;

(2) The forest ticket price formed according to the ESVPM is 294828.1 yuan/hm^2 for the coniferous forest ecosystem, 388338.9 yuan/hm^2 for the theropencedrymion ecosystem, 385984.3 yuan/hm^2 for the broad-leaved forest ecosystem, and 255977.4 yuan/hm^2 for the shrubbery ecosystem;

(3) The forest ticket price formed according to the CVM is 3263.05 yuan/hm^2 as the willingness-to-pay pricing result, and 1605.22 yuan/hm^2 as the compulsory compensation pricing result.

After solving the first core issue, this study discussed and explained whether the forest ticket pricing methods are reasonable.

Firstly, regarding the ESVPM pricing, this method forms a standard ecosystem service value equivalent factor on the basis of calculating the economic value of the national average natural grain yield of one hectare of farmland per year, then calculates the ecological service value per unit area of different forest ecosystems over the years by means of the equivalent table of forest ecosystem service value per unit area, finally the forest ticket price is equal to the average value of forest ecosystem service value per unit area calculated by this method. The advantage of the ESVPM is that the process is relatively convenient, and does not require complex calculations to obtain the pricing result. Moreover, it can derive different pricing results for different forest ecosystems. However, after comparing the pricing result obtained through this method with that obtained through the FESVIM, it is clear that the pricing result of the ESVPM is significantly higher in numerical value. Given that both the two methods directly measure the forest ecosystem service value, the FESVIM is more reasonable, and should be referenced more in the forest ticket price formation. As for the ESVPM, its pricing result can only serve as a certain reference for the forest ticket price formation. Nevertheless, since the ESVPM can measure the service value of different forest ecosystems, it should be taken into account when considering differentiated pricing of the forest ticket for different forest ecosystems.

Regarding the CVM pricing, relevant data was collected through two questions related to the forest ticket price formation in the survey questionnaire issued by this study, then the respondents' average annual willingness-to-pay price and the average annual compulsory forestry ecological compensation were calculated from two perspectives respectively. These two results were then converted into the ecological value payment willingness per unit area of forestland and the compulsory forestry ecological compensation per unit area of forestland to form the forest ticket price. The advantage of the CVM pricing is that the forest ticket price formed by this method is more easily accepted by local residents, so that there is less resistance encountered in promoting and implementing the forest ticket system. However, the

CVM also has some shortcomings, mainly reflected in the subjectivity of the price formed by this method and the slightly insufficient ability to reflect the forest ecosystem service value. The CVM is used to price the forest ticket from the perspective of consumers, and on the nature of public goods the forest ticket price formation should mainly consider pricing from the perspective of providers. Therefore, the CVM cannot be the only reference method for the forest ticket price formation, but can still play an important supplementary role in the forest ticket price formation.

Lastly, regarding the FESVIM pricing, the service value of 16 evaluation indexes' specific functions under the forest ecosystem service value evaluation index system was calculated separately, and then the service value of these specific functions was summed up to calculate the total forest ecosystem service value, forming the forest ticket price. The FESVIM is the most detailed of all the pricing methods adopted in this study, thus the pricing result obtained using this method can reasonably reflect the total ecological value contained in forest land and trees. Compared with the ESVPM, although the calculation process of the FESVIM is more complicated, the total forest ecosystem service value calculated using this method is closer to reality. At the same time, the FESVIM refers to the standard specification of Chinese forestry industry, which prices the forest ticket from the perspective of providers. Based on the nature and requirements of public goods, the price formation is calculated according to the industry standard has higher priority compared to using other methods. The main purpose of the forest ticket is to compensate for the corresponding ecological value of the used forest land and achieve a balance between forestland ecological value occupation and compensation. Therefore, the relevant department of forest ticket formulation should mainly consider the FESVIM for forest ticket pricing.

In conclusion, the reasonableness of the three pricing methods used in this study for forest ticket price formation is summarized as follows. The ESVPM should mainly be used as a reference during the forest ticket pricing process, and this method does not need to be the focus, but when considering differentiated pricing of the forest ticket for different forest ecosystems, this method should be considered. The CVM and the FESVIM should be mainly used and given priority in the forest ticket pricing process, but their priority is slightly different. When pricing public goods, as the provider is the dominant party, calculation according to the industry standard has higher priority compared to using other methods. As a result, the priority of the FESVIM is higher than the CVM, this method should be considered primarily. But consumer willingness can to some extent affect the formulation or adjustment of industry standard, so the important supplementary role of the CVM in the forest ticket price formation cannot be ignored.

5.2 Policy recommendations

Through the specific analysis and empirical research of the forest ticket price formation mechanism, this study proposes four policy recommendations for the forestry-related department in developing countries to solve the contradiction between the requirements for the self-development of forestry and the insufficient investment.

First, local forest resources should be surveyed regularly, and the FESVIM should be used to calculate the total forest ecosystem service value as the forest ticket price. The data involved in the FESVIM changes regularly, and the final total forest ecosystem service value will also change, this requires forestry-related departments to conduct regular and frequent surveys of local forest resources to update the data in a timely manner, and observe changes in the total service value of local forest ecosystem, so as to develop relevant forestry policies based on the reasons for changes in service value. At the same time, in most of developing countries, people's understanding of forest ecosystem service value needs to be improved, regularly using the FESVIM to calculate the forest ticket price can enhance the overall understanding of forestry and related industries, and stimulate the enthusiasm of various social entities for afforestation and forest protection.

Second, survey questionnaires should be distributed regularly to local residents, and the CVM should be used to investigate their average annual willingness-to-pay price and average annual compulsory forestry ecological compensation, in order to determine the forest ticket price. The questionnaires distributed in this study could not fully reflect the average payment willingness of residents in a certain area, but questionnaires distributed by forestry-related departments to local residents can better reflect the situation of local residents. For different countries, the average income of residents and their understanding of the forestry ecological environment vary greatly. Therefore, different surveys of residents' willingness to pay for forestry ecological compensation in various countries are conducive to transnational related research and can promote international development of the forest ticket system.

Third, forestry-related departments in various countries should increase the exploration and understanding of the forest ticket system to solve the problem of forest ecological benefit compensation and forestry financing. The forest ticket system can maintain a dynamic balance of ecological resources, ensure the continuous increase of ecological value and the continuous improvement of the ecological environment, and effectively innovate the forest ecological benefit compensation system from these aspects. In addition, the forest ticket system can also attract more capital investment into the forestry field, improve the development level of the forestry sector and further promote the forestry industry's market-oriented development, thus solving the existing problems in forestry financing.

Fourth, forestry-related departments in various countries should promote interdisciplinary research, organize experts and project teams in different disciplines related to the forest ticket system to conduct research on the forest ticket comprehensive pricing scheme. The formulation of the forest ticket comprehensive pricing scheme requires knowledge reserves from multiple disciplines, and involves interdisciplinary research. If the forest ticket comprehensive pricing scheme is treated as a single-discipline project or task, it is difficult to arrive at reasonable results, but under the promotion of the forestry-related department, it is easier to organize and form interdisciplinary research among different disciplines.

References

Costanza, R., d'Arge, R., Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P. and Belt, M. (1997), "The value of the world's ecosystem services and natural capital", *Nature*, Vol. 387 No. 6630, pp. 253-260.

Di, Y.D. and Li, W. (2021), "The reform of mountain and forest rights promotes the development of the forest industry through 'multi-legged walking'", Shizuishan Daily, 10-28(007).

Huang, S.L., Chen, Y.H., Kuo, F.Y. and Wang, S.H. (2011), "Emergy-based evaluation of peri-urban ecosystem services", *Ecological Complexity*, Vol. 8 No. 1, pp. 38-50.

Markova-Nenova, N. and Watzold, F. (2017), "PES for the poor? Preferences of potential buyers of forest ecosystem services for including distributive goals in the design of payments for conserving the dry spiny forest in Madagascar", *Forest Policy and Economics*, Vol. 80, pp. 71-79.

Millennium Ecosystem Assessment (2005), *Ecosystems and Human Wellbeing: Biodiversity Synthesis*, World Resources Institute, Washington, D.C.

Olson, D.M. and Dinerstein, E. (1998), "The global 200: a representation approach to conserving the earth's most biologically valuable ecoregions", *Conservation Biology*, Vol. 12 No. 3, pp. 502-515.

Pagiola, S., Arcenas, A. and Platais, G. (2005), "Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America", *World Development*, Vol. 33 No. 2, pp. 237-253.

Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E. and Muradian, R. (2014), "Social equity matters in payments for ecosystem services", *Bioscience*, Vol. 64 No. 11, pp. 1027-1036.

Pirard, R. (2012), "Market-based instruments for biodiversity and ecosystem services: a lexicon", *Environmental Science and Policy*, Vols 19-20, pp. 59-68.

Sanming Forestry Administration (2019), "Sanming forest ticket management measures (Trial)".

Sanming Forestry Administration (2020), "Sanming forest ticket management measures (Trial Version 2)".

Tian, F.Q. (2013), "Woodland total control and occupation and retrieval: the forest ticket system analysis", *Journal of Northwest Forestry University*, Vol. 28 No. 06, pp. 237-243+259.

Tian, F.Q. (2015), "Study on forest ticket system of idle land afforestation", *Journal of Fujian Forestry Science and Technology*, Vol. 42 No. 03, pp. 153-161.

Vauhkonen, J. and Ruotsalainen, R. (2017), "Assessing the provisioning potential of ecosystem services in a Scandinavian boreal forest: suitability and tradeoff analyses on grid-based wall-to-wall forest inventory data", *Forest Ecology and Management*, Vol. 389, pp. 272-284.

Wang, C. and Maclaren, V. (2012), "Evaluation of economic and social impacts of the sloping land conversion program: a case study in Dunhua County, China", *Forest Policy and Economics*, Vol. 14 No. 1, pp. 0-57.

Wunder, S. (2015), "Revisiting the concept of payments for environmental services", *Ecological Economics*, Vol. 117, pp. 234-243.

Xie, G.D., Lu, C.X., Leng, Y.F., Zheng, D. and Li, S.C. (2003), "Ecological assets valuation of the Tibetan plateau", *Journal of Natural Resources*, No. 02, pp. 189-196.

Xie, G.D., Zhang, C.X., Zhang, L.M., Chen, W.H. and Li, S.M. (2015), "Improvement of the evaluation method for ecosystem service value based on per unit area", *Journal of Natural Resources*, Vol. 30 No. 08, pp. 1243-1254.

Zhang, D.H. (2003), *A Research on the Marketization of Forest Ecological Services – on the Establishment, Validation and Deduction of the Exchange System Model of Forest Usufruct*, Beijing Forestry University, Beijing.

Zhang, D.H. (2005), "Key words in forestry economic development: basic point, visual angle & approach", *Forestry Economics*, No. 01, pp. 24-28.

Further reading

Costanza, R. (2007), "Ecosystem services: multiple classification systems are needed", *Biological Conservation*, Vol. 141 No. 2, pp. 350-352.

Costanza, R., Groot, R., Sutton, P., Ploeg, S., Anderson, S., Kubiszewski, I., Farber, S. and Turner, R. (2014), "Changes in the global value of ecosystem services", *Global Environmental Change*, Vol. 26, pp. 152-158.

Fan, S. and Peng, H.J. (2021), "Experiences and enlightenment of the market-based forest ecological compensation mechanism in Australia", *World Forestry Research*, Vol. 34 No. 03, pp. 112-116.

Fang, Q.S., Li, H.X. and Xie, Y. (2022), "Forest ticket practice: the way to realize the capitalization of collective forest resources", *Journal of Beijing Forestry University (Social Sciences)*, Vol. 21 No. 02, pp. 55-62.

Feng, Q.Y., Tong, Y.Y., Ke, S.F. and He, Y.J. (2021), "Comparison of forestry investment and financing among China, the United States of America and Japan and its inspiration", *World Forestry Research*, Vol. 34 No. 04, pp. 89-94.

Foster, J.B. (2007), "The financialization of capitalism", *Monthly Review*, Vol. 58 No. 11, pp. 1-12.

Gerald, A.E. (2005), *Financialization and the World Economy*, Edward Elgar, London.

Jin, X.D. (2018), *The Research on the Willingness to Pay for Urban Renewal in Old Residential Areas Based on Contingent Valuation Method*, Chongqing University.

Kevin, P.P. (1993), *Boiling Point*, Random House, New York.

Kevin, P.P. (1994), *Arrogant Capital: Washington, Wall Street, and the Frustration of American Politics*, Little, Brown, Boston.

Mao, Z. (2020), "Comparative study on forest ecological benefit compensation system", *Legality Vision*, No. 34, pp. 137-138.

Pattanayak, S.K., Wunder, S. and Ferraro, P.J. (2010), "Show me the money: do payments supply environmental services in developing countries?", *Review of Environmental Economics and Policy*, Vol. 4 No. 2, pp. 254-274.

Pearce, D.W. (1995), *Blueprint 4: Capturing Global Environmental Value(Blueprint Series)*, Earthscan, London, Vol. 4.

Randall, A. (1991), "The value of biodiversity", *Ambio*, Vol. 20 No. 2, pp. 64-68.

Song, C. (2021), *Radiating Benefit of Windbreak and Sand Fixation and Ecological Protection Compensation of Desert Ecosystem Nature Reserve —— a Case Study on the Baijitan Nature Reserve, Ningxia*, Beijing Forestry University, Beijing.

Sun, W.L., Chen, X.Q. and Zhao, R. (2015), "Comparative analysis of commercial forest financing models", *Forestry Economics*, Vol. 37 No. 12, pp. 126-129.

Turner, K. (1991), "Economics and wetland management", *Ambio*, Vol. 20 No. 2, pp. 59-63.

Wang, W.B. and Li, S. (2021), "Practices and exploration of forest ticket system reform in Sanming of Fujian province", *Forest Resources Management*, No. 04, pp. 17-22.

Xu, L.X., Guo, Q.J., Ai, X.R., Liu, X.Q., Xiang, Q. and Zhao, H.D. (2022), "Evaluation of ecosystem service value of forest scenic area", *Forestry and Ecological Sciences*, Vol. 37 No. 04, pp. 456-465.

Zhang, Y.X., Luo, H.L. and Wang, C. (2021), "Progress and trends of global carbon neutrality pledges", *Climate Change Research*, Vol. 17 No. 01, pp. 88-97.

Zhang, X.M., Zhang, Y. and Zhang, C.C. (2021), "Forest ticket system research —— based on the 'four in one' forestry cooperation model", *China Forestry Economics*, No. 03, pp. 26-30.

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