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Article

Research on the Innovative Operation Mode of Cross-Strait Forestry Cooperative Enterprises Empowered by the Forest Stamp System--Taking the Transformation of Ecological Product Value as an Example

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Abstract: This study takes the forest ticket system as an entry point to explore its enabling mechanism for ecological product value transformation. A multi-dimensional ecological product value accounting system is constructed, and the SBM-Malmquist model is used to measure the efficiency of ecological product value transformation by combining the 2020-2024 panel data of S City, F Province. The impact of the forest ticket system was assessed based on the double difference model, and the robustness was verified using the placebo test. The results showed that: (1) forest ecological products in the study area have water conservation (70.18%) and carbon sequestration and oxygen release (17.09%) as their core functions, and the spatial distribution of their value is dominated by natural factors, with the strongest explanatory power of the interaction between precipitation and average annual temperature ($q=0.83$); (2) the efficiency of the transformation of the value of ecological products shows a fluctuating upward trend, and technological progress is the key driving force for the improvement of efficiency and the efficiency value reaches 1.43 in 2023; (3) the forest ticket system has a significant positive effect on the transformation efficiency of ecological product value, and the efficiency is improved by 8.1%-8.2% on average after the implementation in key ecological functional areas, which verifies its effectiveness as an institutional innovation tool.

Keywords: forest ticket system; ecological product value; SBM-Malmquist; double difference model; placebo test

1. Introduction

Forests are the backbone of terrestrial ecosystems and a vital resource, serving as a critical ecological safeguard for the survival and development of all humanity. The rich and diverse forest resources have also made significant historical contributions to the development of Chinese civilization over the past 5,000 years. In the face of new historical trends such as addressing climate change and pursuing green development, the vigorous promotion of ecological civilization construction will also bring new opportunities for cross-strait forestry cooperation and development [1-2]. In future development, people on both sides of the strait will need to build a sound forest system to create better ecological conditions for ongoing development [3]. Among these, the development of collective forest areas holds significant importance for achieving common prosperity across the strait regions [4]. However, following the clarification of property rights in collective forest lands, issues such as forest fragmentation, low operational efficiency, and difficulties in financing have gradually emerged, constraining the realization of scaled-up forestry operations and value appreciation [5-7]. Therefore, to advance the “three-rights separation” reform of collective forest land, liberalize collective forest land management rights, and promote large-scale intensive forest land management, the state and local governments have successively introduced relevant policies and regulations [8-10]. Under this situation, state-owned forestry enterprises and institutions, as well as collective economic organizations and members from both sides of the Taiwan Strait, can adopt the issuance of forest bonds as a new model for shareholding cooperative forest management [11-12].

Forest bonds refer to equity certificates issued by state-owned forestry enterprises and institutions and village collective economic organizations and their members based on their investment shares when jointly investing in afforestation or cooperatively managing existing forest stands [13]. In the management and operation process, the issuance of forest bonds follows the principles of voluntary investment and equal negotiation, with the forestry authorities responsible for the supervision and management of forest bonds in the corresponding regions [14-15]. Literature [16] indicates that promoting the securitization of forest resources is an effective measure to address core issues in forestry development, and the introduction of the forest bond system has innovated the forest resource trading market, yielding promising expected benefits in practice. Literature [17] also emphasizes that the forest bond system is an innovative management approach to resolve the contradiction between forestry development and insufficient investment, while also exploring scientific pricing mechanisms for forest bonds, thereby providing valuable policy recommendations for relevant decision-making authorities. Literature [18] studied the evolutionary game theory relationships among multiple stakeholders under the forest ticket system, pointing out that only by maintaining high knowledge levels and high participation willingness over the long term can the forest ticket system maximize the conversion of forest resources into economic development advantages. Literature [19] uses a binary logit model to analyze local farmers' willingness to participate in the forest voucher system and its influencing factors, finding that under the constraints of an incomplete information environment, expected benefits, social capital, government publicity, and individual household characteristics significantly influence farmers' willingness to participate in forest voucher system transactions. It can be observed that as a product of using new forestry management mechanisms as the entry point for forest reform, its emergence has promoted specialized forestry operations, improved forest land utilization rates, and enhanced economic benefits. This shareholding cooperative operation model has facilitated forestry efficiency gains, increased village finances, and boosted forest farmers' incomes. However, the challenges and obstacles it faces require further addressing.

This paper firstly analyzes the operation and management mechanism of the forest ticket system and explores its optimization effect on the cross-strait forestry cooperation mode. Taking S city of F province as a typical area, the paper constructs an ecological product value accounting system with 13 functions including carbon sequestration, oxygen release, water conservation, etc., and quantifies the amount of regional ecological product value and its spatial distribution characteristics. Based on the SBM-Malmquist model, the spatial and temporal evolution of the transformation efficiency of ecological product value is measured. The double difference model is used to empirically test the effect of forest ticket system on the transformation efficiency of ecological product value.

2. Research on the Transformation of the Value of Ecological Products Based on the Forest Ticket System

In the context of global climate change and ecological civilization construction, the transformation of ecological product value has become a key path to promote regional sustainable development. As the main body of terrestrial ecosystems, forestry is not only the core link in the transformation of ecological benefits into economic benefits, but also an important hand in deepening the reform of the collective forest right system and promoting cross-strait forestry cooperation. However, in the traditional cross-strait forestry cooperation, there are common problems such as ambiguous definition of property rights, imbalance of benefit distribution mechanism, and limited financing channels, which restrict the effective release of the value of ecological products. In this context, the forest ticket system, as an innovative property right system arrangement, provides an institutional carrier for cracking the above dilemmas and a practical path for transforming the value of ecological products by constructing a cooperation model of common resources, shared rights and interests, and shared risks.

2.1. Forest Ticket System Based on Cross-Strait Forestry Cooperation

2.1.1. Basic Process of Forest Stamp Issuance

The operation and management mechanism of forest stamps is designed around the core objective of “safeguarding the rights and interests of cross-strait cooperation subjects and promoting the transformation of ecological product values”, and its issuance process is shown in Figure 1. The first step is to establish a vehicle for the issuance of forest stamps; the second step is to calculate the number of forest stamps to be issued; the third step is to register the status of forest stamp holders; and the third step is to hold a ceremony for the first issuance of forest stamps.

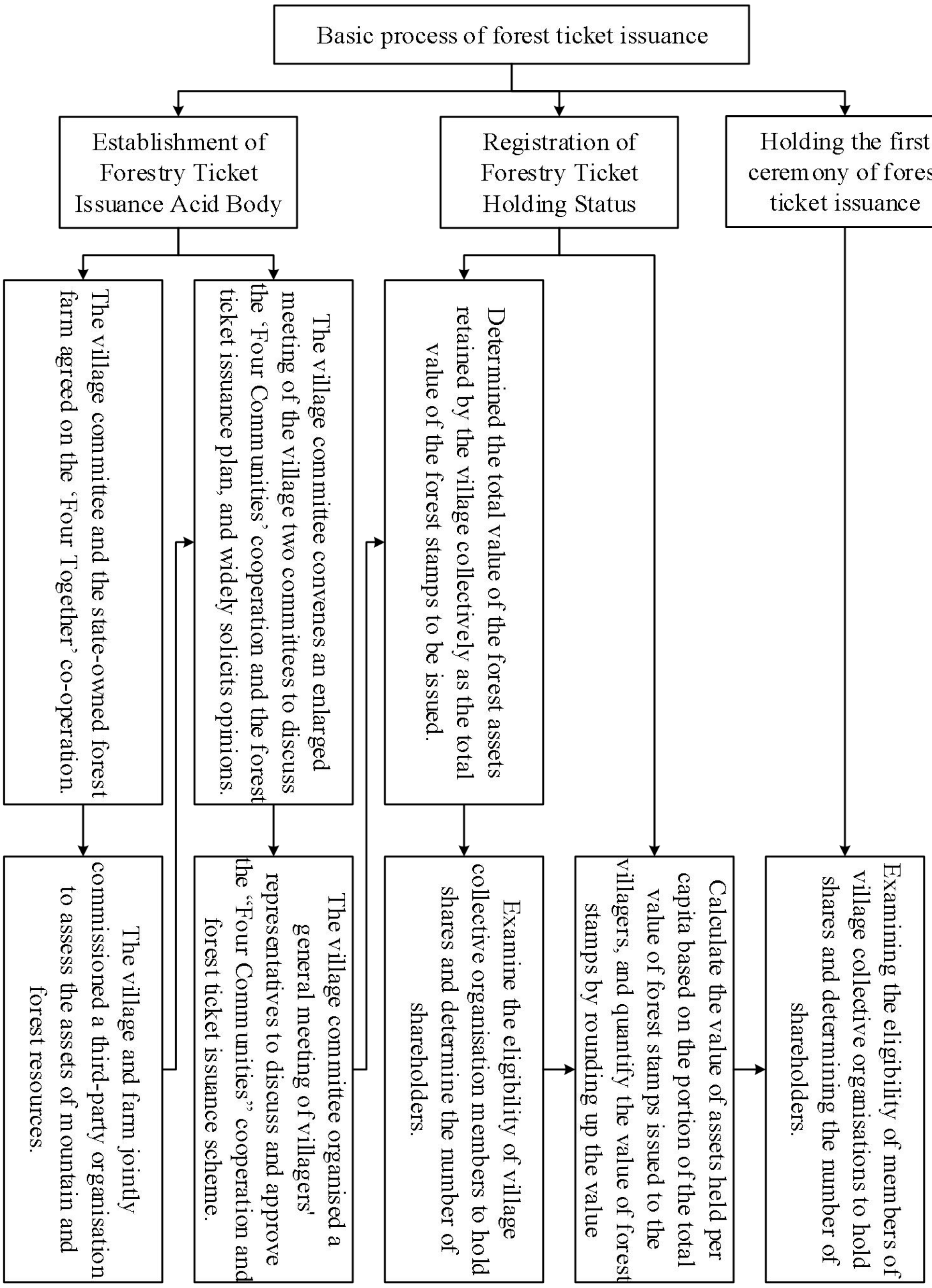

Figure 1. The process of issuing forest tickets.

2.1.2. Forestry Ticket Operational Management

First, the forest stamps issued shall be in real-name form, uniformly numbered, and jointly signed by the State-owned forest farms and village committees of both parties to the cooperation, indicating the time of issuance, i.e., the time of commencement of the cooperative operation. The village committee registers the issued forest stamps with real names, establishes an account, implements a register management system, and establishes a mechanism for reporting and registering changes in the holders of circulation transactions and pledges, as well as dynamic management.

Secondly, forest stamps are categorized into corporate shares of the village committee and individual shares of the villagers according to the different holders, and can circulate freely in the market. Villagers are allowed to list their forest tickets in the Rural Property Rights Trading Center, which has set a floor price and ceiling price to prevent excessive speculation from disrupting the normal market order.

Third, the state-owned forest farms to the unit issued by the forest ticket for the bottom, according to the annual single interest of 3% acquisition.

Through the innovation of process design and operation mechanism, the forest ticket system not only solves the pain points of traditional cross-strait forestry cooperation such as ambiguous definition of property rights, unequal distribution of benefits, and poor financing channels, but also builds a new model of cooperation with common resources, shared rights and interests, and risk-sharing, which provides a systemic carrier and a practical path for the transformation of ecological product value.

2.2. Methods of Accounting for the Value of Ecological Products

The functional value approach, based on theories related to ecological economics, is about the role of both the functional quantity of ecosystem services and the unit price of the functional quantity.

(1) Soil fixation

$$U_{\text{Solidified soil}} = G_{\text{Solidified soil}} * C_{\pm} / \rho \tag{1}$$

where $G_{\text{Solidified soil}}$ is the amount of solidified soil in $t \cdot a^{-1}$ for the assessment stand year; A represents stand area $\left(hm^2\right)$; X_2 represents the modulus of soil erosion on unforested land $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; X_1 is the modulus of soil erosion on forested land of the measured stand $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; $U_{\text{Solidified soil}}$ represents the annual solid soil value of the assessed stand (yuan $\cdot a^{-1}$); $G_{\text{Solidified soil}}$ represents the annual soil consolidation of the assessed stand $\left(t \cdot a^{-1}\right)$; $C_{\pm}$ represents the cost of excavating and transporting earthwork per unit volume (yuan $\cdot m^{-3}$); ρ stands for soil bulk density $\left(g \cdot cm^{-3}\right)$.

(2) Fertilizer preservation

$$G_N = A * N * (X_2 - X_1) * F \tag{2}$$

$$G_P = A * P * (X_2 - X_1) * F \tag{3}$$

$$G_K = A * K * (X_2 - X_1) * F \tag{4}$$

$$G_{\text{Organic matter}} = A * M * (X_2 - X_1) * F \tag{5}$$

$$U_{\text{Fertiliser}} = G_N * \frac{C_1}{R_1} + G_P * \frac{C_1}{R_2} + G_K * \frac{C_2}{R_3} + G_{\text{Organic matter}} * C_3 \tag{6}$$

where G_N , G_P , G_K , and $G_{\text{Organic matter}}$ are respectively the nitrogen $\left(N\right)$, phosphorus $\left(P\right)$, potassium $\left(K\right)$ and organic matter $\left(t \cdot a^{-1}\right)$; X_2 is the soil erosion modulus of non-forested land $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; X_1 is the measured soil erosion modulus of forest land $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; A is the stand area $\left(hm^2\right)$; F is the correction factor; where $U_{\text{Fertiliser}}$ is the annual fertilizer conservation value of the stand (yuan $\cdot a^{-1}$); G_N Reducing nitrogen loss for stand soil consolidation $\left(t \cdot a^{-1}\right)$; C_1 is the cost price of diammonium phosphate (yuan $\cdot t^{-1}$); R_1 is the nitrogen content of diammonium phosphate fertilizer (%); G_P reduces phosphorus loss for stand soil consolidation $\left(t \cdot a^{-1}\right)$; R_2 is the phosphorus content of diammonium phosphate fertilizer, %; G_K reduces potassium loss for stand soil consolidation $\left(t \cdot a^{-1}\right)$; C_2 is the price of potassium chloride fertilizer (yuan $\cdot t^{-1}$); R_3 is the potassium content of potassium chloride fertilizer (%); $G_{\text{Organic matter}}$ Reducing the loss of organic matter for soil consolidation $\left(t \cdot a^{-1}\right)$; C_3 is the price of organic matter (yuan $\cdot t^{-1}$).

(3) Nutrient fixation of forest trees

$$G_{\text{Nitrogen}} = A * N_{\text{Nutrition}} * B_{\text{Year}} * F \tag{7}$$

$$G_{\text{Phosphorus}} = A * P_{\text{Nutrition}} * B_{\text{Year}} * F \tag{8}$$

$$G_{\text{Potassium}} = A * K_{\text{Nutrition}} * B_{\text{Year}} * F \tag{9}$$

$$U = G * C_1 \ (C_2) \tag{10}$$

where G_{Nitrogen} , $G_{\text{Phosphorus}}$ and $G_{\text{Potassium}}$ are the annual nitrogen, phosphorus and potassium fixation of the stand $\left(t \cdot a^{-1}\right)$; A is the stand area $\left(hm^2\right)$; $N_{\text{Nutrition}}$, $P_{\text{Nutrition}}$ and $K_{\text{Nutrition}}$ are the measured contents (%) of nitrogen, phosphorus and potassium in forest trees. B_{Year} is the measured value of the net productivity of the stand $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; F is the correction factor; U is the evaluation fixation value of nitrogen, phosphorus and potassium, G is the fixed amount of nitrogen, phosphorus and potassium respectively, and C_1 is the price of diammonium phosphate fertilizer (yuan $\cdot t^{-1}$); C_2 is the price of potassium chloride fertilizer (yuan $\cdot t^{-1}$).

(4) Adjust the amount of water

$$G_{\text{Tone}} = 10A * \left(P_{\text{Water}} - E - C\right) * F; U_{\text{Tone}} = G_{\text{Tone}} * C_{\text{Reservoirs}} \tag{11}$$

where G_{Tone} is the amount of water regulated by the stand $\left(m^3 \cdot a^{-1}\right)$; P_{Water} is the measured precipitation outside the forest $\left(mm \cdot a^{-1}\right)$; E is the measured evapotranspiration of the stand $\left(mm \cdot a^{-1}\right)$; C is the measured surface rapid runoff of the forest stand $\left(mm \cdot a^{-1}\right)$; A is the stand area $\left(hm^2\right)$; F represents the correction factor. U_{Tone} is the annual adjusted water value of the stand (yuan $\cdot a^{-1}$); G_{Tone} is the annual regulated water volume of the stand $\left(m^3 \cdot a^{-1}\right)$; $C_{\text{Reservoirs}}$ is the market price of water resources (yuan $\cdot m^{-3}$).

(5) Purify water quality

$$G_{\text{Net}} = 10A * \left(P_{\text{Water}} - E - C\right) * F; U_{\text{Net}} = G_{\text{Net}} * K_{\text{Water}} \tag{12}$$

where G_{Net} is the annual purified water quality of the stand $\left(m^3 \cdot a^{-1}\right)$, and U_{Net} is the value of the purified water of the stand (yuan $\cdot a^{-1}$); G_{Net} to evaluate the annual quality of purified water in the stand $\left(m^3 \cdot a^{-1}\right)$; K_{Water} is the cost of water purification, unit: yuan $\cdot a^{-1}$.

(6) Carbon sequestration

$$G_{\text{Carbon}} = G_{\text{Carbon sequestration by vegetation}} + G_{\text{Soil carbon sequestration}} \tag{13}$$

$$G_{\text{Carbon sequestration by vegetation}} = 1.63 R_{\text{Carbon}} * A * B_{\text{Year}} * F \tag{14}$$

$$U_{\text{Carbon}} = G_{\text{Carbon}} * C_{\text{Carbon}} \tag{15}$$

where C_{Carbon} is the annual carbon sequestration of the stand ecosystem, unit: $t \cdot a^{-1}$; $G_{\text{Carbon sequestration by vegetation}}$ is the annual carbon sequestration of the stand $\left(t \cdot a^{-1}\right)$; $G_{\text{Soil carbon sequestration}}$ is the annual soil carbon sequestration corresponding to the stand $\left(t \cdot a^{-1}\right)$; R_{Carbon} is the carbon content in carbon dioxide, which is 27.27%; A is the stand area $\left(hm^2\right)$; B_{Year} is the measured value of the net productivity of the stand $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; F is the correction factor; U_{Carbon}

is the annual carbon sequestration value of the stand (yuan $\cdot a^{-1}$); G_{Carbon} is the potential annual carbon sequestration of the stand ecosystem $\left(t \cdot a^{-1}\right)$; C_{Carbon} is the carbon sequestration price (yuan $\cdot t^{-1}$).

(7) Oxygen release

$$G_{\text{Oxygen}} = 1.19A * B_{\text{Year}} * F; U_{\text{Oxygen}} = G_{\text{Oxygen}} * C_{\text{Oxygen}} \tag{16}$$

where G_{Oxygen} is the annual oxygen release of the stand $\left(t \cdot a^{-1}\right)$; A is the stand area $\left(hm^2\right)$; B_{Year} is the measured value of the net productivity of the stand $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; F is the correction factor for forest ecosystem services; U_{Oxygen} is the annual oxygen release value of the forest (yuan $\cdot a^{-1}$); G_{Oxygen} is the annual oxygen release of the stand $\left(t \cdot a^{-1}\right)$; C_{Oxygen} is the price of oxygen (yuan $\cdot a^{-1}$).

(8) Provide negative ions

$$U_{\text{Negative Ion}} = 5.256 * 10^{15} * A * H * F * K_{\text{Negative Ion}} * (Q_{\text{Negative Ion}} - 600) / L \tag{17}$$

where $U_{\text{Negative Ion}}$ provides the value of negative ions for the stand year (yuan $\cdot a^{-1}$); A is the stand area $\left(hm^2\right)$; H is the measured value of stand height $\left(m\right)$; F is the correction factor; $K_{\text{Negative Ion}}$ is the cost of generating negative ions (yuan·pcs^{-1}); $Q_{\text{Negative Ion}}$ is the measured value of the negative ion concentration of the stand (pcs· $\cdot cm^{-3}$); L is the anion lifetime $\left(\min\right)$.

(9) Dust retention

$$U_{\text{Stagnant dust}} = (G_{TSP} - G_{PM_{10}} - G_{PM_{2.5}}) * K_{TSP} + U_{PM_{10}} + U_{PM_{2.5}} \tag{18}$$

where $U_{\text{Stagnant dust}}$ is the potential dust retention value of the forest stand year (yuan $\cdot a^{-1}$); G_{TSP} is the potential amount of TSP in the forest stand year $\left(t \cdot a^{-1}\right)$; $G_{PM_{10}}$ and $G_{PM_{2.5}}$ are the amounts of PM_{10} and $PM_{2.5}$ respectively (yuan $\cdot kg^{-1}$); K_{TSP} is the dust cleaning fee (yuan $\cdot kg^{-1}$); $U_{PM_{10}}$ and $U_{PM_{2.5}}$ are the values of the corresponding suspended solids (yuan $\cdot a^{-1}$) respectively.

(10) Absorption of gaseous pollutants

$$U_{\text{CO2}} = G_{\text{CO2}} * K_{\text{CO2}} \tag{19}$$

$$U_{\text{Fluoride}} = G_{\text{Fluoride}} * K_{\text{Fluoride}} \tag{20}$$

$$U_{\text{Nitrogen oxides}} = G_{\text{Nitrogen oxides}} * K_{\text{Nitrogen oxides}} \tag{21}$$

where U_{CO2}, U_{Fluoride}, and $U_{\text{Nitrogen oxides}}$ are the values of annual CO2, fluoride, and NOx uptake by the forest stand (yuan $\cdot a^{-1}$), respectively; and G_{CO2}, G_{Fluoride} and $G_{\text{Nitrogen oxides}}$ are the annual uptake of the corresponding pollutants by the forest stand $\left(t \cdot a^{-1}\right)$; K_{CO2}, K_{Fluoride} and $K_{\text{Nitrogen oxides}}$ are the treatment costs of the corresponding pollutants, respectively (yuan $\cdot kg^{-1}$).

(11) Wind and sand control

$$\begin{aligned} G_{\text{Wind and sand control}} &= A_{\text{Wind and sand control}} * (Y_2 - Y_1) * F; U_{\text{Wind and sand control}} \\ &= K_{\text{Wind and sand control}} * G_{\text{Wind and sand control}} \end{aligned} \tag{22}$$

where $G_{\text{Wind and sand control}}$ is the amount of wind and sand fixation in the stand $\left(t \cdot a^{-1}\right)$; $A_{\text{Wind and sand control}}$ is the area of windbreak and sand-fixing forest $\left(hm^2\right)$; Y_2 is the wind erosion modulus of the woodland $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; Y_1 is the wind erosion modulus of woodland $\left(t \cdot hm^{-2} \cdot a^{-1}\right)$; F is the correction coefficient of forest ecosystem; $U_{\text{Wind and sand control}}$ is the value of windbreak and sand fixation in the stand (yuan $\cdot a^{-1}$); $K_{\text{Wind and sand control}}$ is the cost of sand fixation (yuan $\cdot t^{-1}$); $G_{\text{Wind and sand control}}$ is the quality of windbreak and sand fixation in the stand $\left(t \cdot a^{-1}\right)$.

(12) Farmland protection

$$U_{\text{Farmland protection}} = K_a * V_a * m_a * A_{\text{Agriculture}} \tag{23}$$

where $U_{\text{Farmland protection}}$ is the value of farmland protection function (yuan $\cdot a^{-1}$); K_a is $1hm^2$ farmland protection area $19hm^2$; V_a is the price of crops and pastures (yuan $\cdot kg^{-1}$); m_a is the average increase in the yield of crops and pastures $\left(kg \cdot hm^{-2} \cdot a^{-1}\right)$; $A_{\text{Agriculture}}$ is the area of farmland shelterbelts $\left(hm^2\right)$.

(13) Conservation of species resources

$$U_{\text{Raw}} = \left(1 + \sum_{m=1}^{x} E_m * 0.1 + \sum_{n=1}^{y} B_n * 0.1 + \sum_{r=1}^{z} O_r * 0.1\right) * S_{\text{Raw}} * A \tag{24}$$

where S_{Raw} is the annual conservation value of species resources in the stand (yuan $\cdot a^{-1}$); E_m is the rare and endangered index of m species in the stand; B_n is the endemic species index of n in the stand; O_r is the age index of ancient trees of species r in the stand; x is to calculate the number of rare and endangered species; y is to calculate the number of endemic species; r is to calculate the number of ancient tree species; S_{Raw} is the conservation value of species resources per unit area (yuan $\cdot hm^{-2} \cdot a^{-1}$); A is the stand area $\left(hm^2\right)$.

(14) Supply of forest products

$$U_{\text{Wood products}} = \sum_{i=1}^{n} (A_i * S_i * U_i)\ (i = 1, 2, ..., n) \tag{25}$$

where $U_{\text{Wood products}}$ is the annual value of wood products in the region (yuan $\cdot a^{-1}$); A_i is the area of the first i species of timber products $\left(hm^2\right)$; S_i is the volume per unit area of wood products in i $\left(m^3 \cdot hm^{-2} \cdot a^{-1}\right)$; U_i is the market price of the first i wood product (yuan $\cdot m^{-3}$).

Non-timber products

$$U_{\text{Non-wood products}} = \sum_{j=1}^{n} (A_j * V_j * P_j)\ (j = 1, 2, ..., n) \tag{26}$$

where $U_{\text{Non-wood products}}$ is the annual value of wood products in the region (yuan $\cdot a^{-1}$); A_j is the area of the first j wood product $\left(hm^2\right)$; S_j is the volume per unit area of wood products in j $\left(kg \cdot hm^{-2} \cdot a^{-1}\right)$; U_j is the market price of the first j timber product (yuan $\cdot kg^{-1}$).

(15) Forest health care

$$U_r = 0.8U_k \tag{27}$$

Where U_r is the annual forest recreation value in the region, unit: yuan $\cdot a^{-1}$; U_k is the output value of recreation and medical industry combined with ecology in each province, region and municipality directly under the central government, including the tourism industry, and the output value driven by directly or indirectly, unit: yuan $\cdot a^{-1}$; the parameter 0.8 is the ratio of locally owned nature tourism industry to 80% of the national output value.

3. Measurement of the Transformation Efficiency of Ecological Product Value Based on SBM-Malmquist

3.1. Overview of the Study Area

In this study, S city of F province was selected as the study area.S city is located in the central and western part of F province, divided into 6 county units, with subtropical monsoon climate, average annual precipitation of 1688mm, humid climate, mountainous hills as the main topography, and red and yellow soil as the main soils with high fertility, which possesses superior conditions for the development of forest ecosystems. As a national collective forest right system reform pioneer area, S city forest resource endowment is outstanding, in 2024, the forest coverage rate of 78.7%, woodland area of 28.45 million mu, live wood storage capacity of 210 million cubic meters, forest ecosystem service function is remarkable.

In recent years, S City, relying on the location advantages, actively explore cross-strait forestry cooperation new model. 2020, the local pilot forest ticket system, through the state-owned forest farms and village collectives jointly financed the operation of forest land, to promote the assetization of forestry resources, capitalization, for the study of the forest ticket system empowered cross-strait forestry cooperation and the transformation of ecological value of the product to provide a typical sample.

3.2. Construction of the Indicator System

Based on both input and output aspects, the indicator system is constructed as shown in Table 1. The input indicator is the value of forest ecological products. It is expressed by the value of carbon sequestration and oxygen release, the value of water conservation, the value of reducing sedimentation and siltation, and the value of climate regulation. The InVEST model and IUEMS were used to calculate the functional volume, and the shadow value method was combined to account for the value volume. Output indicators are expressed in terms of the regional economy, i.e., the output value of the primary, secondary and tertiary industries, and the status of industrial output value can comprehensively reflect the level of changes in the local economy.

Table 1. Index System for the Transformation of Ecological Product Value.

Indicator type	First-level indicator	Secondary indicator
Input indicator	The value of forest ecological products	Carbon sequestration and oxygen release value(Billion yuan)
		Water conservation value(Ten thousand Yuan)
		Sediment reduction value(Ten thousand Yuan)
		Climate regulation value(Ten thousand Yuan)
Output indicator	Regional economy	Output value of primary industry(Ten thousand yuan)
		Output value of secondary industry(Ten thousand yuan)
		Output value of tertiary industry(Ten thousand yuan)

3.3. Descriptive Analysis of Input-Output Indicators

The results of the descriptive statistics for the input-output indicators are shown in Table 2 for a total of six districts, with each district providing a sample size of one for each indicator for each year, covering the period 2020-2024.

Table 2. Descriptive statistical results of input-output indicators.

Indicator	Mean value	Standard deviation	Sample size
The value of forest ecological products	2568363	936574	30
Physical capital input	10382.48	9375.35	30

3.4. Model Construction

The super-efficient SBM model is a further optimization of the traditional DEA model, i.e., slack variables are taken into account. The specific setup of the model is as follows:

$$\begin{cases} \min \rho = \dfrac{1-\dfrac{1}{m}\sum_{i=1}^{m}\dfrac{S_i^-}{x_{ik}}}{1+\dfrac{1}{s}\sum_{r=1}^{s}\dfrac{S_r^+}{y_{rk}}} \\ s.t.\ \sum_{j=1}^{m} x_{ij}\lambda_j - S_i^- = x_{ik}\ (i=1,2,\ldots,m) \\ \sum_{j=1}^{m} y_{tj}\lambda_j + S_t^+ = y_{tk}\ (t=1,2,\ldots,s) \end{cases} \tag{28}$$

(28) where ρ is the relative efficiency value of the decision unit, $\rho < 1$ indicates that the decision unit is at a certain distance from the production frontier and there is a loss of efficiency, and $\rho \geq 1$ is relatively efficient; x_{ik}, x_{ij} denote the elements in the input matrix, y_{ik}, y_{ij} denote the elements in the output matrix; m and S are the number of input and output indicators, respectively; S_i^- and S_t^+ are the slack variables for the inputs and outputs, respectively; and λ_j is the weight variable, $\lambda_j \geq 0$, $j = 1,2,\ldots,n(j \neq k)$; $S_i^- \geq 0$, $S_t^+ \geq 0$.

Malmquist index model is to explore the value of dynamic changes in the efficiency of the study area from the beginning of the study period to the end of the study period, which is used as a measure of the characteristics and trends of the dynamic changes in the level of inputs and outputs of the study area in different time periods. MaxDEA software was used for the calculation and the specific model setup is as follows:

$$\begin{aligned} M\left(x^{t+1}, y^{t+1}; x^t, y^t\right) &= Tech \times Effch = Tech \times Pech \times \text{Sech} \\ &= \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \\ &= \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \end{aligned} \tag{29}$$

(29) In Eq. (29), the conversion efficiency, i.e., $M\left(x^{t+1}, y^{t+1}; x^t, y^t\right)$, denotes the degree of change in the production efficiency of a decision unit in the study area over the period t to $t+1$, and x^t and y^t

denote the period of t in the study area respectively. each input and output variable, $D^m\left(x^t, y^t\right)(m = t, t+1)$ denotes the distance between the production frontier and the actual output of the study area in the period m, and Tech, Effch, Pech, and Sech denote the efficiency of technological progress, the index of change in technological efficiency, the efficiency of pure technology, and the efficiency of scale, respectively.

4. Research on the Transformation Efficiency of Ecological Product Value under the Empowerment of Forest Ticket System

4.1. Eco-Product Valuation

4.1.1. Physical Versus Value Volume Analysis

According to the accounting formula and relevant data, the physical volume and value of forest ecological products are calculated as shown in Table 3. Among them, the value of water conservation accounts for the highest proportion, reaching 70.18%, followed by the value of carbon sequestration and oxygen release, accounting for 17.09%. This indicates that the forest ecosystem in the study area takes water supply and carbon sink as its core functions, which is consistent with the ecological orientation of "water conservation and soil fixation" in the red soil area, and reflects the superiority of the ecological benefits of forestry in S city.

Table 3. Analysis of Physical Quantity and value Quantity.

Type	Accounting indicator	Physical quantity/10^4t·a^{-1}	Value quantity /10^8yuan·a^{-1}	Average value per unit area /10^4yuan·hm^{-2}·a^{-1}	The proportion of the total value/%
Carbon sequestration and oxygen release value	Forest vegetation absorbs CO_2	6535.36	40.25	0.03	17.09
	Forest vegetation releases CO_2	4244.24	482.69	0.65	
	Forest vegetation fixes CO_2	3550.21	14.93	0.06	
Water conservation value	Conserve water sources	183.49×10^4	1253.63	1.78	70.18
	Purify water quality	37.27×10^4	52.52	0.14	
Sediment reduction value	Wind prevention and sand fixation	3865.27	30.56	0.18	5.25
Climate regulation value	Absorb SO_2	26.36	15.32	0.12	7.48
	Absorb NO_x	11.53	9.35	0.08	
	Retained dust	69.37	7.39	0.09	

4.1.2. Value of Ecological Products in Different Stand Types

According to the accounting results of the physical volume and value of forest ecological products in the study area, the physical volume and value of forest ecological products corresponding to different forest stand types and forest age types were counted and calculated using the ARCGIS zoning statistics tool and the statistical function of EXCEL table, and the calculation results are shown in Table 4. The value of ecological products of different forest stand types differed significantly, and the total value of tree forests was the highest, reaching 1181.43×10^4yuan·a^{-1}, mainly due to their outstanding water-holding function (772.76×10^4yuan·a^{-1}). Although shrub forests have a higher value of carbon sequestration and oxygen release, they have a weaker function of preventing wind and fixing sand due to a single tree species and less understorey vegetation.

Table 4. Ecological Product Values of Different Forest Stand Types.

Forest stand type	Dominant tree species	Tree species area/10^4hm^2	Ecological product value/10^4yuan·a^{-1}				
			Carbon sequestration and oxygen release value	Water conservation value	Sediment reduction value	Climate regulation value	Total
Arbor tree forest	Cypress orientalis	9.35	9.48	255.35	2.04	3.94	280.16
	Birch species	18.52	59.24	201.45	0.84	2.15	282.20
	Larch tree	90.39	28.31	105.35	3.11	0.98	228.14
	Poplar tree species	78.62	19.06	95.23	7.93	1.62	202.46
	Pinus tabuliformis	45.18	20.48	115.38	5.36	2.07	188.47
Economic forest	Economic forest	95.75	9.03	19.42	1.03	1.35	126.58
Shrubland	Shrubs	122.63	80.28	194.67	0.35	0.88	398.81
Scattered forest land	Scattered forest land	7.35	6.24	0.94	0.11	1.37	16.01
Ungrown forest	Ungrown forest	60.18	9.21	7.42	0.63	0.45	77.89

4.1.3. Analysis of Physical and Value Volume Drivers

The data were brought into the geodetector model run with the value of forest ecological products as the dependent variable, and annual precipitation, average annual temperature, elevation, slope, soil organic matter, total soil nitrogen, GDP per capita, population density, and nighttime lighting index (numbered X1~X9, respectively) as the independent variables. The q-values of different detector factor interactions are shown in Table 5, where "*" indicates two-factor enhancement and "**" indicates nonlinear enhancement. The explanatory power of any two detectors interacting on forest ecological products was greater than that of a single factor, showing a two-factor and nonlinear enhancement trend, and there was no independent acting factor. Except for soil organic matter and nighttime light index, which were mainly nonlinearly increasing, the interactions of other factors were all two-way enhancement effects. The strongest explanatory power was found in the interaction between precipitation and annual average temperature, with a q-value of 0.83. Although the single factor of soil organic matter and nighttime light index was small, the q-value of the interaction with other factors was significantly increased, which further indicated that the factors affecting the spatial distribution of the value of forest ecological products were relatively complex, affected by the dominant single factor, and also affected by the joint influence of natural and natural factors, and natural and anthropogenic factors. From the q value of the explanatory power of different detection factors and their interactions, the influence of natural factors is greater than that of anthropogenic factors.

Table 5. q values for interaction of different probe factors.

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	0.45								
X2	0.83*	0.48							
X3	0.52*	0.73*	0.41						
X4	0.63*	0.70*	0.69*	0.37					
X5	0.61**	0.62**	0.58**	0.72**	0.12				
X6	0.47*	0.71*	0.63*	0.59*	0.59*	0.27			
X7	0.62*	0.58*	0.67*	0.60*	0.61**	0.46*	0.38		
X8	0.58*	0.66*	0.59*	0.58*	0.70**	0.59*	0.61*	0.31	
X9	0.60**	0.69**	0.56**	0.70**	0.68**	0.63**	0.47**	0.35**	0.07

4.2. Characterization of Changes in the Transformation Efficiency of Ecological Product Values

The comprehensive transformation efficiency of forest ecological product value in the study area is shown in Figure 2, showing fluctuating characteristics. In 2020, there was an obvious "trough period", which was caused by insufficient technical efficiency, indicating that there were shortcomings in the rational and efficient use of forest resources under the investment level of that year, and there would be a "peak period" in 2023, with an efficiency value of 1.43.

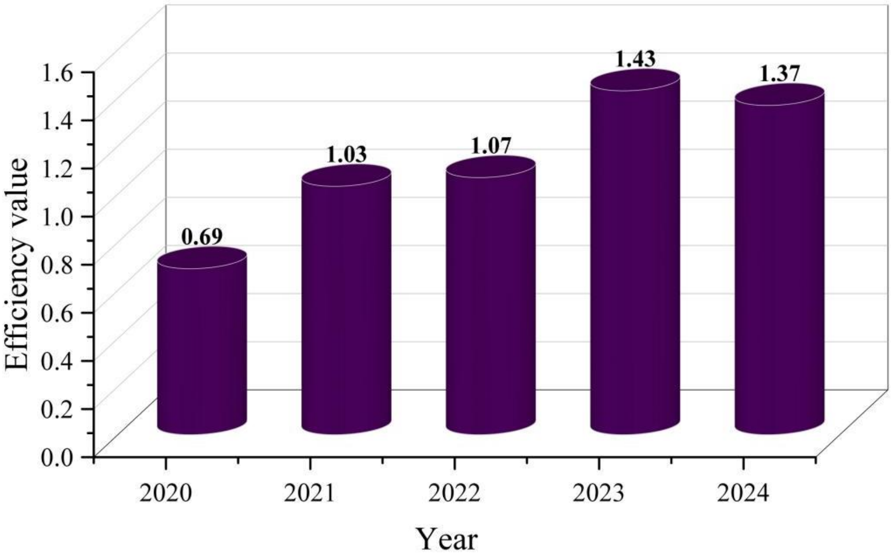

Figure 2. Comprehensive transformation efficiency of ecological product value.

The six regions were numbered as A1~A5, and the Malmquist index of forest ecological products and their decomposition results are shown in Table 6. During the study period, the comprehensive transformation efficiency of forest ecological product value in the six study areas showed significant stage characteristics. In 2020, due to the lack of technical efficiency, the CCE was generally low, among which A5 and A2 were only 0.594 and 0.617 due to the single resource structure and lagging management technology, which were in a depression of efficiency. Driven by policies in 2021, CCE in all regions has rebounded significantly. From 2022 to 2023, technological progress will become the core driving force for efficiency improvement. A3 and A6 have a CCE of 1.276 in 2023 and A6 leads the way with a CCE of 1.419 due to their stronger technical absorption capacity. In 2024, the CCE of all regions will continue to grow, and the CCE of A6 will be significantly higher than the average.

Table 6. Malmquist index and its decomposition results.

Region	Index	2020	2021	2022	2023	2024
A1	Pech	0.783	0.894	0.927	1.058	1.129
	Sech	0.892	0.918	0.955	0.982	1.031
	Tech	0.951	1.083	1.128	1.251	1.302
	CCE	0.673	0.832	0.954	1.283	1.467
A2	Pech	0.726	0.813	0.881	0.982	1.054
	Sech	0.851	0.882	0.924	0.965	1.011
	Tech	0.924	1.056	1.118	1.209	1.284
	CCE	0.617	0.852	0.974	1.183	1.347
A3	Pech	0.756	0.834	0.902	1.029	1.094
	Sech	0.872	0.928	0.938	0.974	1.042
	Tech	0.941	1.065	1.153	1.302	1.388
	CCE	0.693	0.883	1.042	1.276	1.492
A4	Pech	0.701	0.792	0.862	0.951	1.027
	Sech	0.823	0.855	0.894	0.943	0.993
	Tech	0.906	1.034	1.082	1.182	1.254
	CCE	0.635	0.813	0.938	1.127	1.246
A5	Pech	0.681	0.771	0.842	0.933	1.002
	Sech	0.802	0.837	0.871	0.929	0.972
	Tech	0.893	1.018	1.062	1.153	1.224
	CCE	0.594	0.781	0.902	1.063	1.205
A6	Pech	0.813	0.892	0.951	1.083	1.152
	Sech	0.902	0.934	0.963	1.002	1.054
	Tech	0.975	1.105	1.182	1.357	1.428
	CCE	0.783	0.982	1.125	1.419	1.534

4.3. Analysis of the Efficiency of Ecological Product Value Transformation under the Influence of the Forest Ticket System

4.3.1. Variable Selection

(1) Explained variable (Y): efficiency of forest ecological product value transformation.

(2) Core explanatory variable (D*T): counties and municipalities belonging to key ecological functional zones after the implementation of the forest ticket system, i.e., the interaction term.

(3) Control variables

1) Level of economic development (C1). Measured by per capita GDP unit in ten thousand yuan.

2) Degree of industrial advancedization (C2). Measured by the ratio of value added of tertiary industry to that of industry.

3) Population size (C3). Measured by the population of each city, district and county at the end of the year, in tens of thousands of people.

4) Urbanization level (C4). Measured by the ratio of urban population to total population.

5) Size of fixed asset investment (C5). Measured by investment in fixed assets, in ten thousand dollars.

The descriptive statistics of the main variables are shown in Table 7. The mean value of forest ecological product value transformation efficiency in the study period is 1.02, with a standard error of 0.18, and the overall efficiency is at a medium-high level with some fluctuations. Among the control variables, the mean value of per capita GDP was 85,300 yuan, the mean value of the ratio of tertiary industry to industrial added value was 1.21%, the mean value of population size was 498,700 people, and the mean value of urbanization rate was 54.62%. The mean value of fixed asset investment is 5.235 billion yuan, indicating that capital investment has a strong supporting role in the transformation of ecological products.

Table 7. Descriptive Statistics of Main Variables.

Variable type	Variable name	Observed value	Mean value	Standard error	Minimum value	Maximum value
Explained variable	The efficiency of value transformation of ecological products	30	1.02	0.18	0.65	1.52
Control variable	C1/Ten thousand yuan	30	8.53	1.12	5.02	12.08
	C2/%	30	1.21	1.21	0.28	1.76
	C3/Ten thousand people	30	49.87	49.87	14.65	79.20
	C4/%	30	54.62	54.62	9.81	69.80
	C5/Ten thousand yuan	30	52.35×10^4	52.35×10^4	15.21×10^4	80.60×10^4

4.3.2. Analysis of Test Results

This part assesses the impact of forest ticket system on the transformation efficiency of forest ecological product value by constructing a double difference model (DID), and the overall regression results are shown in Table 8. The forest ticket system has a significant positive effect on the efficiency of forest ecological product value transformation. The coefficients of the core explanatory variable D*T are 0.082 and 0.081 in models (1) and (2), respectively, and both pass the test at 1% and 5% significance levels. It shows that compared with non-key ecological functional zones, key functional zones improved the conversion efficiency of forest ecological products value by 8.1%-8.2% on average after the implementation of the forest ticket system, and this result is statistically significant. This positive effect verifies that the forest ticket system, as an institutional innovation tool, can effectively break through the institutional mechanism barriers of traditional forestry management and promote the improvement of the conversion efficiency of ecological product value. The overall fit of the model is good, with R2 of 0.781 and 0.772, respectively, and about 78% of the variance of the explanatory variables can be explained by the model, which verifies the reasonableness of the model setting. At the same time, the model controls for regional fixed effects and time fixed effects, effectively avoiding the interference of regional heterogeneity and time trends on the results and enhancing the reliability of the conclusions.

Table 8. Overall Regression Results.

	(1) Y	(2) Y
D*T	0.082*** (0.005)	0.081** (0.005)
C1		0.012* (0.005)
C2		0.003*** (0.000)
C3		0.002 (0.047)
C4		0.002 (0.001)
C5		-0.002 (0.004)
Constant	0.715*** (0.003)	0.702*** (0.045)
Regional effect	Yes	Yes
Time effect	Yes	Yes
Observations	30	30
R-squared	0.781	0.772

4.3.3. Placebo Test

In order to further test whether the conclusions are affected by other unobservable factors, this paper utilizes the Bootstrap method to randomly group the samples and conduct regression analysis on them after assigning them as treatment or reference groups, and repeats the randomized experiments for 1000 times. The placebo test results are shown in Figure 3, the t-value of the coefficient of the influence of the forest ticket system on the transformation efficiency of forest ecological products is approximately normally distributed, mostly concentrated near 0, indicating that in the randomized 1,000 times of experiments, the proportion of the regression coefficients of the forest ticket system on the transformation efficiency of forest ecological products that are significantly positive and significantly negative are both small, and they are small probability events, and the spurious treatment effect of the system does not exist, and it further illustrates that the robustness of the previous estimation results.

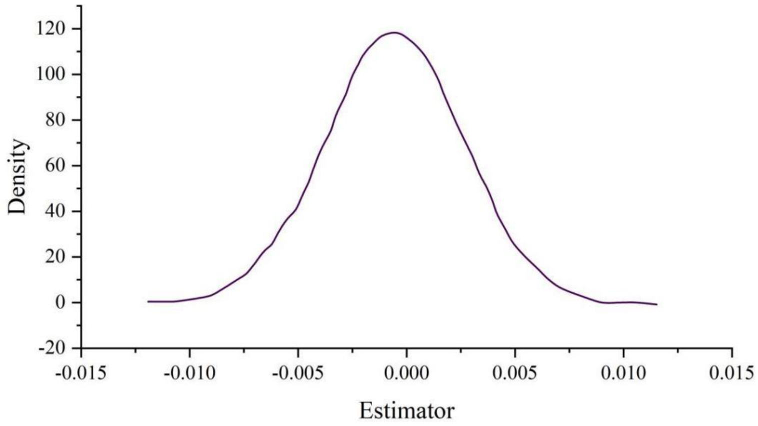

Figure 3. Placebo test results.

5. Conclusion

Through theoretical analysis, accounting analysis, efficiency measurement and empirical test, this paper draws the following main conclusions:

(1) The value of forest ecological products in the study area takes water conservation (70.18%) and carbon sequestration and oxygen release (17.09%) as its core functions, and its spatial distribution is jointly influenced by natural and human factors, but the natural factors have stronger explanatory power. The interaction between precipitation and annual average temperature has the strongest explanatory power, with a q-value of 0.83.

(2) The conversion efficiency of ecological product value shows a fluctuating upward trend, and technological progress is the core driver of efficiency improvement, with an efficiency value of 1.43 in 2023. There are significant differences in efficiency between regions, and regions A3 and A6 with stronger technology absorption capacity lead the efficiency growth.

(3) The coefficients of the core explanatory variable D*T are 0.082 and 0.081 in models (1) and (2), respectively, and both of them pass the test at 1% and 5% significance levels. The forest ticket system has a significant positive effect on the efficiency of ecological product value transformation, and the efficiency increases by 8.1%-8.2% on average after the implementation in key ecological functional areas, and the placebo test further verifies the robustness of the results.

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