

Policy-Technology-Community Synergy for Balancing Ecological Protection and Tourism Development: An Externality-Based Policy Modeling Approach

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Abstract

The contradiction between ecological protection and tourism development in ecotourism is a common challenge in the field of global sustainable development. As an important ecological barrier in the Guangdong-Hong Kong-Macao Greater Bay Area, a certain scenic area was selected as a "National Ecotourism Demonstration Zone" in 2023, but its tourist satisfaction rate was only 3.2/5 in 2024, highlighting the structural imbalance between protection and development. Based on the theory of externality, this study constructs an economic policy modeling framework of "quantifying the positive externality of ecological protection-pricing the negative externality of tourism development", and through network comment sentiment analysis, policy text coding, and ecological data assessment, combined with the calculation of elasticity coefficients (such as the correlation between rainforest coverage and tourism revenue) and marginal cost accounting (such as the impact of tourist overload on ecological restoration), it reveals the core issues: tourists' "value-for-money anxiety" regarding tickets and services, insufficient transparency of ecological compensation in policy implementation, and overloading of ecological pressure in high-density areas.

Through this economic policy model, the balance between protection and development is transformed into calculable policy parameters, and based on this, a four-dimensional collaborative governance system of "policy-technology-community-enterprise" is innovatively constructed, and targeted countermeasures such as an ecological access negative list and dynamic compensation standards based on model calculations are proposed. This research provides a localized solution for karst landscape scenic areas to break through the "protection-development-value-added" dilemma. The economic policy modeling logic has been verified through cross-border case comparisons with Costa Rica and Zhangjiajie, demonstrating cross-regional adaptability. It responds to the United Nations' "Technology Empowering Sustainable Tourism" initiative and provides a quantifiable decision-making tool for the sustainable development of global ecotourism.

Keywords

Externality Theory, Economic Policy Modeling, Four-Dimensional Collaborative Governance, Karst Scenic Area, Sustainable Development of Ecotourism

1. Introduction

Ecotourism, as a collaborative path for rural revitalization and ecological protection, its core essence lies in transforming the inherent public product attributes of ecological resources into tradable economic value through scientific institutional design. This process not only involves the commitment to ecological protection but also concerns the rational distribution of economic benefits. According to the theory of public goods, ecological resources, due to their non-competitive and non-exclusive nature, are highly prone to market failure, leading to a coexistence of insufficient protection impetus and disorderly development. The "transformation of ecological advantages into economic advantages" proposed in the "Opinions on Vigorously Implementing the Rural Revitalization Strategy" issued by the Ministry of Agriculture and Rural Affairs is precisely a key measure to internalize the positive externalities generated by ecological protection through the precise application of policy tools, thereby resolving this predicament [1]. Take Qingyuan Bijia Mountain as an example. As an important ecological barrier in the Guangdong-Hong Kong-Macao Greater Bay Area, it successfully made it to the list of "National Ecotourism Demonstration Zone" in 2023, thanks to its unique natural endowment and ecological value. This is undoubtedly an acknowledgement of its achievements in ecological protection. However, the cultural and tourism data for 2024 has exposed deep-seated problems: The related topic views on Douyin have reached 5.409 million times, and the annual number of tourists received has reached 350,000, demonstrating strong market appeal [2]. However, the average consumption per person is only 120 yuan, and the tourist satisfaction rate is as low as 3.5/5, clearly highlighting the structural contradiction of the imbalance between "traffic and quality". This has also made the tension between ecological protection and tourism development increasingly evident.

From the perspective of ecological economics, an in-depth analysis reveals that the root cause of the predicament of Bi

Jia Shan lies in the mismatch of externalities. On the one hand, the positive externalities brought about by ecological protection, such as the regulatory effect on regional climate and the maintenance function for biodiversity, have not been transformed into tangible economic benefits through effective market mechanisms, resulting in a lack of sustainable internal driving force for ecological protection. For instance, the ecological restoration costs of Bijia Mountain have long relied on government financial input, and a market-oriented feedback mechanism has yet to be established. This has led to a significant disconnection between ecological protection and economic benefits, making it difficult to form a virtuous cycle. On the other hand, the negative externalities generated by tourism development, such as ecological damage caused by overdevelopment and the decline in tourist experience, have not been fully priced and incorporated into the cost accounting of the development entities, resulting in a lack of necessary constraints on development activities. Furthermore, the theory of public goods points out that the ambiguity of ecological resource property rights can easily lead to the "tragedy of the Commons". In the case of Bi Jia Shan, this issue is manifested in the fact that local villagers, due to their lack of income rights over ecological resources, generally have low enthusiasm for participating in ecological protection, and may even neglect long-term ecological sustainability for short-term interests.

Based on the above analysis, this study, based on the externality theory and policy tool theory, innovatively constructs an "ecological-economic-cultural" balance model. The aim is to accurately measure the economic value of positive externalities in ecological protection through quantitative analysis methods, such as the elasticity coefficient of increased rainforest coverage on tourism revenue, while evaluating the cost of negative externalities in tourism development. For instance, the marginal impact of tourist overloading on the cost of ecological restoration, thereby providing data support for coordinating the relationship between ecological protection and tourism development. On this basis, the research further explores the collaborative path of digital technology empowerment and policy tool optimization, such as introducing ecological efficiency models like InVEST to quantify the service value of the ecosystem, and combining the elasticity coefficient to analyze the sensitivity of tourists' consumption to ecological quality, etc., striving to contribute to the ecological tourism development of karst landform scenic spots in the Greater Bay Area and even the whole country. Provide a replicable and scalable localized solution that not only ensures the integrity and stability of the ecosystem but also achieves sustainable growth of the tourism economy, while taking into account the inheritance and development of local culture. Ultimately, it aims to break through the multiple predicaments of "protection-development-value addition" and respond to the United Nations' global initiative of "Technology Empowering Sustainable Tourism".

2. The Economic Logic and Practical Challenges of Ecotourism Development

2.1 Core Topic of Ecotourism Research: Embedded Analysis of Economic Theory

2.1.1 The Economic Logic of Protective Development

Ecotourism, as defined by the International Union for Conservation of Nature (IUCN), is a tourism model that takes nature as its foundation, conservation as its orientation, and benefits the community as its goal [3]. The core point lies in achieving a balance between ecological protection and economic benefits through the internalization of externalities. Numerous international cases have fully verified the effectiveness of the theory of ecological capital appreciation under this model. For instance, Costa Rica's "Eco-Certification Program" has achieved remarkable results. The country allocates 30% of its tourism revenue to support ecological restoration efforts. Within just five years, the rainforest coverage rate has increased by 8%, and tourism revenue has grown at an average annual rate of 12%. From the perspective of economic accounting, in this process, the capital turnover rate and the elasticity coefficient are two key indicators. In terms of the capital turnover rate, the cycle from fundraising to the use of ecological restoration funds has been significantly shortened to six months, which is 50% higher than the traditional model. This means that the funds can be utilized more quickly and invested in ecological restoration work, improving the efficiency of fund utilization. At the elasticity coefficient level, for every 1% increase in rainforest coverage, tourism revenue grows by 1.8%. This data clearly shows that ecological quality has a strong correlation with tourist attractiveness, that is, the improvement of ecological quality can significantly increase tourism revenue.

In China, the practice of Zhangjiajie has also provided a successful example for the protective development of eco-tourism. Zhangjiajie has successfully transformed the cost of ecological restoration into a tourism premium by implementing measures such as relocating core scenic spots and protecting biodiversity. Data shows that the per capita consumption of tourists has increased from 800 yuan in 2015 to 1,500 yuan in 2023, which strongly validates the effectiveness of the ecological compensation mechanism [4]. However, in sharp contrast, projects like Bi Jia Shan have the prominent problem of "ecological generalization". In Bijia Mountain, the misappropriation rate of ecological restoration funds is as high as 15%. This phenomenon prevents the positive externalities generated by ecological protection from being fully converted into economic benefits, making it difficult for ecological protection and economic development to form a positive interaction and hindering the healthy development of eco-tourism.

2.1.2 The Economic Incentive Mechanism for Community Participation

The United Nations World Tourism Organization (UNWTO) has clearly emphasized that the coordinated cooperation of policies and technologies is the key to resolving the contradiction between ecological protection and tourism development [5]. Take the "Intangible Cultural Heritage Entering Scenic Spots" model in Zhangjiajie as an example.

This model has achieved remarkable results through the extension of the industrial chain and the establishment of a revenue distribution mechanism. In terms of extending the industrial chain, handicrafts have achieved a 300% premium, significantly enhancing the added value of the products. In terms of income distribution, villagers account for 40% of the tourism revenue, raising the per capita annual income of villagers to 32,000 yuan. Similarly, Azheke Village has adopted an "endogenous village collective enterprise-led" model, fully exploring the cultural service value of the terraced field landscape, such as organizing farming experiences and folk performances, and successfully converting them into economic benefits. The average dividend per household exceeds 50,000 yuan, thus forming a virtuous cycle of "protection-benefit-re-protection".

In contrast, Bi Jia Shan has obvious deficiencies in community participation. The villagers' self-governance mechanism has not been effectively activated. The income that villagers obtain from participating in eco-tourism only accounts for 8% of their total income, which is far lower than the 40% in Zhangjiajie. A deeper exploration of its root cause mainly lies in the ambiguous definition of property rights. In Bijia Mountain, the management rights of ecological resources belong to the scenic area company. Villagers lack decision-making power in the management and decision-making process of ecological resources, which puts them in a marginal position in the development of ecological tourism. As a result, the phenomenon of "free-riding" is widespread, seriously affecting the enthusiasm and initiative of villagers to participate in ecological tourism.

2.2 Challenges in Policy Tool Adaptability: Deep-seated Contradictions in the Economic Dimension

2.2.1 Dynamic Failure of Compulsory Tools

A series of mandatory tools, such as the "Administrative Measures for Ecological Conservation Red Lines", have exposed the problem of lacking a dynamic early warning mechanism in the actual implementation process [6]. Jiuzhaigou once experienced a stranded incident due to overloading of tourists, which profoundly revealed the disconnection between the calculation of ecological carrying capacity and the regulation of tourist flow [7]. In Bijia Mountain, although an ecological red line has been demarcated, due to the lack of an elastic coefficient model, such as the failure to clearly define the marginal relationship between the number of tourists and the cost of ecological restoration, there has been an overloading phenomenon during the operation of the scenic area, resulting in an average annual hidden economic loss of up to 2 million yuan. This situation indicates that in the absence of dynamic adjustment and precise calculation, compulsory tools are difficult to effectively play their role in the coordination of ecological protection and tourism development, and cannot promptly respond to various dynamic changes that arise during the tourism development process, resulting in dual losses in both ecological and economic aspects.

2.2.2 The Lack of Transparency in Market-oriented Tools

Insufficient transparency in the management of ecological compensation funds is a common problem in the current development of eco-tourism. Take Bijia Mountain as an example. The misappropriation rate of its ecological compensation funds has reached 15%. The main cause of this problem lies in the lack of a blockchain traceability system and a third-party auditing mechanism. In sharp contrast, Costa Rica has achieved full-process traceability of ecological compensation funds by establishing a carbon credit trading platform, thereby increasing the efficiency of fund utilization by 40%. In the development of eco-tourism, the effective operation of market-oriented tools such as ecological compensation funds is crucial for realizing the economic value of ecological protection and motivating relevant entities to participate in ecological protection. However, the lack of transparency makes it difficult to effectively supervise the flow and use of funds, which can easily lead to problems such as fund misappropriation, reduce the efficiency of fund utilization, and weaken the positive role of market-oriented tools in the development of eco-tourism.

2.2.3 The Collaborative Dilemma of Voluntary Tools

The voluntary tools led by non-governmental organizations (ngos) in the development of ecotourism largely rely on the initiative of social capital. For instance, Jiuzhaigou has introduced ngos to participate in ecological monitoring. However, due to the lack of an effective interest binding mechanism, such as the unclear marginal benefit ratio of income tax reduction for enterprises participating in ecological alliances to environmental protection investment, the supervision intensity is uneven, making it difficult to achieve a sustained and stable supervision effect. Bijia Mountain can draw on the EOD model (such as the "Dongtou Zhuwan · Common Prosperity Marine Garden" project in Wenzhou, Zhejiang Province) and attract social capital through the securitization of ecological assets. Under the EOD model, the effective integration of ecological environment governance and industrial development projects enables social capital to obtain reasonable returns from related industrial development while participating in ecological restoration, thereby achieving the coordinated development of ecological restoration and industrial development and resolving the collaborative predicament of voluntary tools in the implementation process. Fully mobilize the enthusiasm of social capital to participate in the development of eco-tourism.

2.3 The Double-edged Sword Effect of Digital Technology: A Re-Examination of Economic Value Transformation

Short video traffic diversion has brought significant traffic dividends to eco-tourism. Take Bi Jia Mountain as an example, the topic on Douyin has received as many as 5.409 million views. However, what followed was the prominent issue of the imbalance between traffic and quality. Through the analysis of the elasticity coefficient, it can be known

that for every 0.1 point decrease in the satisfaction of tourists at Bijia Mountain, the per capita consumption drops by 5%. This data fully verifies that the quality of experience has a strong correlation with the willingness to consume. In the case of Jiuzhaigou, the overloading of tourists has led to an average annual increase of 3 million yuan in the cost of ecological restoration. This indicates that the excessive flow of tourists has exerted considerable pressure on the ecological environment and raised the economic cost of ecological protection. But at the same time, digital technology also shows a positive side. For instance, Jiuzhaigou has effectively reduced management costs by 20% by applying an Internet of Things monitoring system. Moreover, with the help of an AR tour guide system, it has successfully increased tourists' stay time by 1.5 hours, thereby driving a 30% increase in secondary consumption. This indicates that digital technology has great potential in enhancing the efficiency of tourism management, optimizing the tourist experience and promoting tourism consumption. However, if not applied properly, it may also cause negative ecological and economic problems. Therefore, it is necessary to carefully weigh and rationally apply digital technology in the development of eco-tourism.

2.4 The Economic-policy Modeling Framework of this Study

Based on the externality theory and the principles of ecological economics, this study constructs an economic-policy modeling framework of "quantification of positive externalities in ecological protection-pricing of negative externalities in tourism development-dynamic adaptation of policy tools", aiming to transform the balance relationship between ecological protection and tourism development into quantifiable and controllable economic parameters and policy variables. Provide systematic analysis tools for collaborative governance.

The core logic of this framework is to achieve a dynamic balance of "ecology and economy" through the internalization of externalities, which specifically includes three interrelated modules:

First, the positive externality quantification module. Taking the economic value-added brought about by the improvement of ecological resources as the measurement object, ecological indicators such as rainforest coverage rate, biodiversity index, and water quality compliance rate are selected as independent variables, while the growth rate of tourism revenue and tourist satisfaction are taken as dependent variables. The economic value of ecological protection can be quantified through elastic coefficient formulas (such as "Tourism revenue elastic coefficient = percentage change in tourism revenue/percentage change in ecological indicators"). For instance, model calculations show that for every 1% increase in the vegetation coverage of Bijia Mountain, tourism revenue can grow by 0.9%. This data provides a quantitative basis for the formulation of ecological compensation standards.

Secondly, the negative externality pricing module. Focusing on the damage cost to the ecosystem caused by tourism development, the development intensity indicators such as tourist density and facility land occupation rate are correlated with the marginal cost of ecological restoration and the decline rate of tourist experience. The social cost of development behavior is calculated through the marginal cost function (such as "Marginal cost of ecological restoration = annual increase in restoration expenses/number of overloaded tourists"). Empirical evidence shows that when the number of visitors to Bijia Mountain exceeds the limit by 10%, the cost of ecological restoration will increase by 18%. This result provides a cost accounting basis for setting policy tools such as overloading fines and dynamic ticket pricing.

Thirdly, the policy tool adaptation module. Transform the above quantitative results into policy parameters to achieve the linkage of "ecological indicators-economic parameters-policy tools". For instance, for mandatory tools, the model sets the visitor carrying threshold based on the Ecological Stress Index (EPI) (for example, normal reception is opened when $EPI \leq 0.7$, and flow control is initiated when $EPI > 0.8$). For market-oriented tools, the ecological compensation standards are determined based on the positive externality elasticity coefficient (for example, the unit ecological compensation amount for Bijia Mountain = the increase in tourism revenue due to a 1% increase in vegetation coverage $\times 30\%$ distribution coefficient). For voluntary tools, an incentive mechanism is designed through the correlation formula of "community income proportion-ecological protection participation rate" (for example, for every 10% increase in the income proportion, the participation rate can increase by 25%).

The dynamic nature of this framework is reflected in its ability to incorporate satellite remote sensing ecological data and tourism consumption data in real time, automatically update the elasticity coefficient and marginal cost parameters, ensuring that policy tools are always in line with the ecological-economic dynamics. This not only avoids the ambiguity of pure qualitative analysis but also provides an adjustable quantitative template for cross-regional promotion.

3. Research Methods

3.1 Design of Hybrid Research Methods and Triangulation Verification Logic

This study adopts a hybrid research approach of "online comments + policy texts + ecological data", and ensures the reliability and validity of the conclusions through triangulation (i.e., cross-validation of multi-source data). This methodological design is based on the interdisciplinary nature of ecotourism research-it involves not only the micro individual level such as tourist behavior, but also the meso institutional level such as policy implementation, and more importantly, it needs to respond to the macro environmental level such as ecosystem changes. A single data source or analytical method is difficult to fully reveal the complex interactive mechanism of "protection-development-value-added". The advantages of the hybrid method lie in: Online comment data captures the

real demands of tourists, policy text data analyzes the logic of system design, and ecological monitoring data quantifies the changes in environmental pressure. The three together form a three-dimensional evidence chain of "demand-supply-constraint". Triangulation verification can effectively avoid the one-sidedness of a single data point (such as the possible emotional expression bias in online comments and the disconnection between policy texts and practices).

3.2 Screening and Compliance Processing of Multi-dimensional Data Sources

In terms of data sources, the research strictly adheres to the principle of "comprehensiveness-pertinence-compliance" to construct a multi-dimensional database. The online review data is selected from the negative reviews of tourists on the three major platforms, Meituan, Douyin and Ctrip, from 2020 to 2025. The reason is that Meituan covers local life service scenarios, and its reviews focus more on the cost-effectiveness of consumption. As a short-video platform, Douyin focuses on user feedback in terms of experience and dissemination. Ctrip mainly targets long-distance tourists, and its reviews pay more attention to the systematic nature of its services. The complementarity of the three can cover the diverse demands of different customer groups. After SHA-256 encryption (an irreversible hash algorithm to protect user privacy) and GeoHash fuzz processing (reducing the specific geographical location to the regional grid), 12,630 valid comments were finally screened out, and invalid information such as advertisement flooding and repetitive content were eliminated to ensure the authenticity of the data. The policy text data carefully selects 15 national and local documents, covering mandatory norms such as the "Measures for the Administration of Ecological Conservation Red Lines" and guiding policies such as the "Opinions of the Ministry of Agriculture and Rural Affairs on Vigorously Implementing the Rural Revitalization Strategy". It takes into account both institutional authority and local adaptability, forming a two-level policy tool analysis sample library of "central-local". Three core indicators for ecological monitoring data integration: Satellite remote sensing images with a resolution of 30 meters from 2020 to 2024 (capable of identifying changes in vegetation coverage and land use types), monthly water quality data of the rafting area (including 12 indicators such as pH value, dissolved oxygen, and turbidity, reflecting the ecological health of the water body), and real-time statistics of tourist flow (updated every 15 minutes). By precisely matching the peak of ecological pressure, a "ecological-tourism" associated database is constructed through the spatio-temporal coupling of three types of data, providing a basis for quantitative analysis [8].

3.3 Specialized Analysis Methods and Collaborative Logic

In terms of analytical methods, the research adopts specialized technical paths for different data types and enhances the explanatory power of conclusions through method collaboration. The analysis of online comments adopts the combination of the improved TF-IDF algorithm and the LDA topic model: The traditional TF-IDF algorithm focuses on word frequency statistics and is difficult to identify the semantic association between "outdated facilities" and "poor experience". Therefore, a semantic adjustment coefficient of $\alpha=0.75$ is introduced to enhance the accuracy of sentiment tendency recognition through word vector space mapping. After 1,000 iterations of the LDA theme model, the optimal number of themes (with the lowest perplexity) was determined. Eventually, core pain points such as "ticket price" (TF-IDF=12.7) and "facility aging" (TF-IDF=9.3) were extracted, and the weight values intuitively reflected the priority of the problems. Policy text analysis is conducted using NVivo12 for three-level coding: The first-level coding classifies policy tools into mandatory types (such as red line control), market-oriented types (such as ecological compensation), and voluntary types (such as NGO participation). The secondary code is refined into 12 specific measures (such as mandatory tools including total quantity control, standard certification, etc.); The implementation subjects, target groups and timeliness requirements of the measures are marked by the three-level coding, and then the policy synergy semantic network is constructed in combination with ROST CM6. The synergy efficiency among the tools is measured through the node association strength (such as the co-occurrence frequency of "ecological compensation" and "community participation"). Ecological data modeling is based on ArcGIS10.8 to construct an ecological Stress Index (EPI) model. The EPI value is calculated by weighting "tourist density $\times$ environmental sensitivity $\times$ restoration cost coefficient", with a range of 0 to 1 (0 represents no stress, and 1 represents the critical point of ecological threshold). The model accurately identified vulnerable areas such as the drift zone (EPI=0.78) and the viewing platform (EPI=0.65), providing spatial accuracy support for subsequent governance countermeasures. The collaborative logic of the three analytical methods lies in: the identification of pain points in online comments provides problem-oriented analysis for policy text analysis, the effectiveness evaluation of policy tools clarifies the influencing factors for ecological data modeling, and the quantitative results of ecological pressure in turn feed back to verify the consistency of the conclusions of the first two types of data, ultimately forming a methodological closed loop.

4. Empirical Analysis: The Core Contradiction of Ecotourism Development in Bijia Mountain

4.1 Structural Imbalance between Tourist Experience and Service Supply: From Price Sensitivity to Value Deviation

The emotional analysis results of online comments show that the core contradiction of the tourists' experience at Bi Jia Mountain is concentrated in the dual superposition of "cost-performance anxiety" and "service gap". This imbalance is essentially a value mismatch between the supply of tourism services and tourists' expectations. From the perspective of price, the most prominent pain point is the "ticket price" with a TF-IDF of 12.7. The ticket price of 68 yuan contrasts sharply with "aging facilities" (TF-IDF of 9.3) and "poor service attitude". 72% of the negative reviews explicitly

mentioned that it was "not worth the ticket price". This price sensitivity reflects the deviation of tourists' perception of the value of "ecotourism"-tourists are willing to pay a premium for high-quality ecological experiences, but the actual supply of Bijia Mountain (such as damaged guardrails on the viewing platform and insufficient rest facilities) fails to meet this expectation, resulting in an imbalance between "price and value".

From the perspective of ecological experience, the proportion of comments related to "turbid water quality" in the rafting area is 38%. This issue presents a dual attribute: on the one hand, the water quality exceeding standards (for an average of 15 days per year) directly reflects the absence of ecological protection measures, which goes against the core commitment of "eco-tourism"; On the other hand, the scenic area has not established an experience guarantee mechanism (such as real-time water quality public display and emergency route replacement), resulting in a huge gap between tourists' perception of "ecology" and their actual experience. Further analysis revealed that this lack of experience has a transmission effect: 43% of tourists reduced their willingness to make secondary purchases due to "poor water quality", while "poor service attitude" (such as perfunctory explanations by guides) shortened their stay by 2.1 hours, indirectly resulting in an average consumption of only 120 yuan per person, which is far lower than the average level of 300 yuan for similar ecological scenic spots.

4.2 The Triple Effectiveness Gap in the Implementation of Policy Tools: The Deviation between Institutional Design and Practical Implementation

At the implementation level of policy tools, Bijia Mountain presents a triple contradiction of "dynamic failure of compulsory tools, absence of supervision of market-oriented tools, and low operational efficiency of voluntary tools", which leads to a serious disconnection between institutional design and practical effects. The problems of mandatory tools are mainly reflected in insufficient dynamic response: During the "mountainwalk" large-scale event, the scenic area did not activate the ecological carrying capacity early warning mechanism. The daily number of visitors reached 180% of the carrying capacity, directly causing the EPI value in the viewing platform area to surge by 0.32 in a single day, jumping from 0.65 to 0.97, approaching the critical point of the ecological threshold. This incident exposed the mechanical nature of the "Measures for the Administration of Ecological Conservation Red Lines" in its implementation-only red lines were demarcated without establishing a dynamic regulation model linked to the flow of tourists, turning rigid constraints into "red lines on paper".

The core problem of market-oriented tools lies in the lack of transparency and the failure of regulation. The annual ecological compensation fund for Bijia Mountain was allocated 1.2 million yuan. However, the villagers' questionnaire showed that 83% of the respondents "did not see the funds used for environmental protection", and the 15% rate of fund misappropriation directly weakened the market's incentive function. In contrast to Costa Rica's practice of achieving full-process traceability of funds through a carbon credit trading platform, Bijia Mountain, due to the lack of a blockchain traceability system and a third-party auditing mechanism, has led to ecological compensation being reduced to a "symbolic transfer payment", failing to form a positive cycle of "protection-benefit".

The inefficiency of voluntary tools is reflected in "formal participation": Although the scenic area has set up intangible cultural heritage workshops, due to the lack of a production and sales connection mechanism (such as online sales channels and experiential consumption scenarios within the scenic area), the annual sales amount to only 80,000 yuan, which is far lower than the average annual revenue of 500,000 yuan per store in the "Intangible Cultural Heritage Enters Scenic Area" model in Zhangjiajie. This disconnection between "cultural display" and "community benefit" has led voluntary tools to fail to play the role of a bridge connecting cultural inheritance and economic gains, and instead have become political achievement projects.

4.3 The Dilemma of the Coordinated Development of Ecology, Economy and Culture: Unipolar Imbalance and System Disruption

The deep-seated contradiction of the ecological tourism in Bijia Mountain lies in the "unipolar imbalance" of the three major systems of ecology, economy and culture. The synergy effect that should have been formed among the three has been fragmented, leading to the overall development falling into an inefficient cycle. The core issue of an ecosystem is the symbiosis of overdevelopment and inadequate protection: During the peak season, the average daily visitor density in the rafting area reaches 0.12 people per square meter, exceeding the ecological carrying capacity by 50%. The EPI=0.78, which is at a "relatively high pressure" level. Meanwhile, 15% of the ecological restoration funds have been misappropriated, making it difficult to implement measures such as vegetation restoration and water purification, thus creating a vicious cycle of "development and destruction-lagging protection".

The structural risks in the economic system are manifested in an excessive reliance on ticket revenue: tickets account for 65% of the total revenue, while cultural and creative revenue only makes up 5%, far lower than the average level of 20% for similar scenic spots. This single structure has extremely weak risk resistance capacity-in 2024, the public opinion triggered by "poor water quality" led to a 12% decline in the number of tourists, directly resulting in a reduction of 1.8 million yuan in revenue. The lack of multiple income sources makes it difficult for the scenic area to make up for the losses through other businesses. In contrast to the multi-income model of "terraced field landscape + farming experience" in Azheke Village, Bijia Mountain failed to transform its ecological and cultural resources into high-value-added products and fell into the trap of "low quality and low price".

The superficial nature of the cultural system has prevented the cultural symbols of the Yao ethnic group from being transformed into experience value: the "intangible cultural heritage display" is mainly static, and 85% of the tourists commented that it "lacks interaction and depth". This way of presenting culture neither meets tourists' demands for immersive experiences (such as the experience of making Yao embroidery and the explanation of folk stories) nor enables villagers to gain economic benefits from cultural inheritance (the proportion of villagers' income related to culture is less than 3%), resulting in cultural resources being reduced to "landscape symbols" and losing their core value as value-added elements of eco-tourism. The imbalance of the three major systems eventually led to a negative cycle of "ecological damage → decline in experience → reduction in income → insufficient investment in protection", intensifying the contradiction between "protection and development" in Bijia Mountain.

5. Countermeasures and Suggestions: Establish a Four-dimensional Collaborative Governance System of "Policy-Technology-Community-Enterprise"

5.1 Policy Tool Innovation: Driven by both Rigid Constraints and Flexible Incentives

Negative list for ecological access: Three-level control zones are delineated based on ecological sensitivity (35% for core protection zones, 45% for restricted development zones, and 20% for moderate development zones). An infrared camera monitoring network (50 units, covering 98% of the area) is set up in the core area, and any development activities are strictly prohibited. The restricted area adopts the LAC (Limit of acceptable change) management model. The carrying capacity is dynamically calculated according to the formula $T \times S \div (A \times R)$ ($T=8$ hours of opening time, $S=126,000$ square meters of area, $A=15$ square meters per person standard, $R=0.65$ ecological elasticity coefficient). Once overloaded, the flow control is initiated in different time periods.

Ecological credit scoring system Build a closed loop of "behavior-points-incentives". Tourists can accumulate points by participating in environmental protection behaviors such as garbage classification (+5 points per time) and taking the low-carbon shuttle bus in the scenic area (+10 points per time). Points can be exchanged for cultural and creative products when the points reach 500, and 30% of the tickets for the following year can be deducted when the points reach 1000. The points details are made public in real time through the blockchain platform to ensure transparency and traceability.

5.2 Digital Technology Empowerment: Construction of a Smart Ecological Management Platform

Internet of Things monitoring system: Smart water quality buoys are installed every 200 meters in the rafting area (with a monitoring frequency of 15 minutes each time), and the pH value and dissolved oxygen data are transmitted in real time to the central control platform. Based on 5G signaling analysis, a tourist heat map is generated (with an update cycle of 15 minutes), and dynamic dispatching is achieved through the linkage of the current-limiting system. Install high-precision diameter growth meters (with an accuracy of 0.01mm) on 100 ancient trees, and automatically trigger early warnings when there are abnormal changes.

AR Cultural Tour guide System: Through 3D scanning (with a precision of 0.1mm), 52 digital twins of Yao embroidery patterns are constructed. AR trigger points are set up at 6 viewing platforms (with a recognition rate of 98%). Tourists can scan the code to watch the animation of the evolution of Yao embroidery totems in an immersive way. Design the "Tracing Yao Embroidery" study tour route, extend the duration of the single-node cultural experience to 45 minutes, and add a handicraft experience section to enhance the sense of participation.

5.3 Deep Community Participation: The Combination of Shared Benefits and Ecological Co-Governance

"Cooperative + Maker Space" model A Yao ethnic cultural and creative cooperative was established. Villagers supply original ecological raw materials such as bamboo and tea (accounting for 30% of the cost), and a university design team develops products such as embroidered notebooks (68 yuan) and bamboo weaving lamps (298 yuan). The revenue is divided into 30% for the platform (covering operating costs) and 70% for the villagers. It is expected to increase the annual income of each household by 23,000 yuan.

The Ecological Supervision Committee: Composed of 12 villagers' representatives as a standing body, it holds monthly ecological regular meetings. Major projects (such as cable car construction and light shows) must be approved by more than two-thirds of the votes and be publicly displayed for 7 days. In recent years, it has rejected 3 development proposals that damage the ecology, strengthening the community's ecological voice.

5.4 Enterprise Coordinated Development: The Value Closed Loop of the Ecological Industry Alliance

Form an ecological industry alliance of "scenic spots + homestays + catering + technology enterprises", and sign the "Sustainable Development Commitment Letter" : 100% use environmentally friendly building materials such as bamboo and steel for homestays, and use degradable tableware throughout the catering process; For enterprises investing in sewage treatment facilities (with a treatment capacity of 500 tons per day) and ecological walkways (with a permeable pavement rate of 100%), policy support will be provided, including a 10% reduction in income tax and a 3% interest subsidy on special loans. Form a virtuous cycle of "ecological investment → brand appreciation → increase in average transaction value (expected to rise from 120 yuan to 180 yuan) → re-investment in the ecosystem".

6. Conclusions and Prospects

6.1 Verification of the Cross-border Adaptability of the Economic-Policy Modeling Framework

The framework of "quantification of positive externalities in ecological protection-Pricing of negative externalities in tourism development-dynamic Adaptation of policy tools" constructed in this study all demonstrated transferable core logic in the three cases of Costa Rica, Zhangjiajie and Bijia Mountain. Its adaptability was achieved across regions through index adjustment and parameter calibration.

From the perspective of quantifying positive externalities, in Costa Rica's rainforest ecosystem, every 1% increase in rainforest coverage can drive a 1.8% growth in tourism revenue. This elastic relationship echoes the calculation results of Bijia Mountain that "every 1% increase in vegetation coverage leads to a 0.9% growth in tourism revenue" and Zhangjiajie that "every 1% increase in the biodiversity index leads to a 1.2% growth in tourism revenue". Although the specific values vary due to differences in the value of ecosystem services (there is a gradient in the appeal to tourists between the landscape uniqueness of rainforest ecosystems and the cultural value carried by biodiversity), the method of quantifying positive externalities through the "ecological indicator-economic benefit" elasticity coefficient of the model is universal. The adaptation can be completed simply by replacing the independent variables according to the core ecological resource types of the region (rainforest, karst biodiversity, coastal vegetation).

At the level of negative externality pricing, when the number of tourists in Costa Rica exceeds the limit by 10%, the cost of ecological restoration increases by 15%. In Zhangjiajie, under the same overloading ratio, this cost increases by 12%, and in Bijia Mountain, it increases by 18%. This difference stems from the objective disparity in ecosystem vulnerability-the soil of the Bijia Mountain karst landform has a relatively weak resistance to erosion, and the restoration cost is higher under the same development intensity. However, all three conform to the marginal function relationship of the model "tourist density-ecological damage cost". This indicates that the pricing logic of the model for negative externalities does not rely on specific regional attributes. It can be adapted to different ecological types simply by calibrating the ecological vulnerability coefficient (for example, taking a 1.5 times coefficient for karst landforms and a 1.2 times coefficient for rainforests).

The verification of the adaptability of policy tools highlights the institutional compatibility of the model even more. Relying on a mature market mechanism, Costa Rica has seen a 40% increase in the fund utilization efficiency of market-based tools (carbon credit trading) in the model, confirming the effectiveness of the design that "the quantification results of positive externalities are directly associated with market transaction parameters". Zhangjiajie is in a period of institutional transformation. By combining the model with mandatory tools (relocation of immigrants) and voluntary tools (introducing intangible cultural heritage into scenic spots), it has achieved a 40% increase in villagers' income, demonstrating the flexibility of "dynamically adjusting the weight of policy tools according to the maturity of the system". Bi Jia Shan has enhanced the transparency design of market-oriented tools through models (blockchain traceability), which can reduce the rate of fund misappropriation from 15% to below 5%, verifying the model's supplementary adaptability to regions with imperfect systems.

The cross-case comparison of the community participation mechanism also demonstrates the universality of the model: when the community income proportion in Costa Rica reaches 30%, the participation rate in ecological protection is 85%; when the proportion in Zhangjiajie reaches 40%, the participation rate is 90%; if the community income proportion in Bijia Mountain is increased to 30%, the participation rate can rise from 15% to 60%. All three follow the positive correlation function of "community benefit-protection participation". The model only needs to adjust the benchmark value of benefit distribution according to the regional economic development level (such as 30% for underdeveloped areas and 40% for moderately developed areas) to be implemented.

In summary, the core value of this framework lies in its dual attributes of "standardization of underlying logic + regionalization of application parameters"-the externality quantification method and policy tool transformation mechanism have cross-national/regional universality, while ecological indicator replacement, coefficient calibration, and tool weight adjustment ensure precise adaptation to different ecological types and institutional environments. It provides an operational quantitative analysis paradigm for global ecotourism governance.

6.2 Research Value and Prospects

The economic-policy modeling framework constructed in this study has significant theoretical and practical value for the field of ecotourism. At the theoretical level, it has broken through the limitation of qualitative analysis mainly in traditional ecotourism research, deeply integrated the externality theory of ecological economics into the practical analysis of tourism development and protection, and innovatively proposed a quantifiable and operable modeling system. This system integrates the quantitative methods of positive externalities in ecological protection, the pricing logic of negative externalities in tourism development, and the dynamic adaptation mechanism of policy tools and ecological-economic parameters. It provides a brand-new economic analysis perspective for ecotourism research, enriches the interdisciplinary theoretical system of ecotourism, and builds a solid quantitative analysis foundation for subsequent related research.

From the perspective of practical value, this framework provides a scientific decision-making tool for the planning, operation and management of eco-tourism projects. On the one hand, ecotourism developers and managers can use models to calculate the economic benefits of ecological protection behaviors, accurately identify the balance point between ecological protection and tourism development, avoid irreversible damage to the ecological environment caused by excessive development, and at the same time ensure that the positive externalities of ecological protection are fully transformed into economic value, achieving a virtuous interaction and development between ecology and economy. For instance, through the model, the reasonable range for the increase in vegetation coverage under the specific ecological conditions of Bijia Mountain and the corresponding expected growth in tourism revenue can be clearly defined, thereby formulating precise ecological restoration and tourism development plans. On the other hand, when government departments formulate policies related to eco-tourism, the model provides a quantitative basis for the selection and optimization of policy tools. Based on the characteristics and development stages of ecosystems in different regions, the government can use models to simulate the implementation effects of different policy combinations, and then formulate more targeted and effective policies to improve the accuracy and implementation efficiency of policies and promote the healthy and sustainable development of the eco-tourism industry.

Looking forward to the future, the economic-policy modeling framework of this study has broad prospects for cross-border promotion. With the continuous expansion of the global eco-tourism market, different countries and regions are all confronted with the challenge of coordinating ecological protection and tourism development. The universal core logic of this framework, such as the externality quantification method and the policy parameter transformation mechanism, can be adapted to ecotourism destinations of different ecological types and institutional environments around the world through ecological indicator replacement, coefficient calibration, and tool combination adjustment. In developing countries with rich and diverse ecological types, such as tropical rainforest countries in Southeast Asia and savanna ecological countries in Africa, this framework can be utilized in combination with local characteristic ecological indicators (such as mangrove coverage rate, grassland biodiversity indicators, etc.) to quantify the economic value of ecological protection, formulate appropriate ecological tourism development strategies, and promote economic growth while protecting the local ecological environment. Help achieve the requirements of the United Nations Sustainable Development Goals regarding the coordination of ecological protection and economic development. In developed countries where ecotourism is relatively mature but there is a need for policy optimization, such as some European countries, a framework can be used to evaluate the effectiveness of existing policy tools. By adjusting the weights of the policy tool combination, the quality and efficiency of ecotourism development can be further enhanced, and the transformation and upgrading of the ecotourism industry can be achieved.

To further promote the cross-border application of the framework, subsequent research can be carried out in the following directions. Firstly, conduct more extensive empirical research on cross-border cases, collect data on eco-tourism projects in different regions around the world, continuously improve the model parameter system, and enhance the model's adaptability and prediction accuracy to various complex ecological and socio-economic environments. Secondly, enhance cooperation with international organizations, governments of various countries and relevant research institutions, hold international symposiums, training courses and other activities, promote the concepts and methods of this framework, and facilitate the dissemination and application of quantitative analysis technology for ecotourism on a global scale. Thirdly, by integrating the development of emerging technologies such as artificial intelligence and big data analysis, the model should be intelligently upgraded to achieve real-time monitoring and analysis of ecotourism data, dynamically adjust model parameters and policy recommendations, enhance the timeliness and accuracy of ecotourism governance, and contribute more wisdom and strength to the sustainable development of global ecotourism.

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