Coupling Situation Analysis and Prediction of Xinjiang' s Tourism Industry, Economic Development, and Ecological Environment: A Postprint

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Abstract

As one of the national strategic industries, the tourism industry has made significant contributions to economic development. Since both tourism and economic development primarily rely on the ecological environment as their foundation, properly managing the relationship among these three elements is crucial for achieving sustainable development. Based on the construction of an evaluation index system for the tourism industry—economic development—ecological environment nexus, this study employs a coupling coordination model to conduct a comprehensive empirical analysis of the coupled and coordinated development of the three major systems in Xinjiang from 2008 to 2017, and utilizes the grey prediction model GM(1,1) to forecast the coupling coordination degree for the next five years. The results indicate that the comprehensive development status of Xinjiang' s tourism industry—economic development—ecological environment system from 2008 to 2017 can be divided into two distinct types: the ecology-leading type from 2008 to 2010, and the economy-leading type from 2011 to 2017. The three systems demonstrate a high degree of correlation. From a temporal perspective, the coupling coordination degree exhibits a fluctuating upward trend, while from the perspective of coordination level, it has overall evolved from primary coordination to intermediate coordination. In the coming years, the coupling coordination degree of Xinjiang' s three major systems will generally demonstrate a slight increasing trend, reaching a good coordination level in 2021.

Full Text

Analysis and Forecast of Coupling Situation among Tourism Industry-Economic Development-Ecological Environment in Xinjiang

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Abstract

As one of the national strategic industries, tourism plays a vital role in driving related industrial development, creating employment opportunities, increasing tax revenue, and promoting overall economic growth. Both tourism and economic development rely heavily on the ecological environment, yet rapid expansion often comes at the expense of environmental quality, creating a bottleneck that constrains sustainable tourism growth. Therefore, balancing the relationships among these three systems is critical for achieving sustainable development.

Based on existing research, this study selects 30 corresponding indicators to establish a tourism industry-economic development-ecological environment evaluation index system composed of seven criteria layers: tourism market scale, tourism economic benefits, tourism industry level, economic scale, economic structure characteristics, environmental pollution status, and environmental governance outcomes. The entropy method is employed to standardize the data and calculate the weights of indicators for each of the three systems. Using this evaluation framework, the paper applies a coupling coordination model to conduct a comprehensive empirical analysis of the coupling coordination development among Xinjiang' s tourism industry, economic development, and ecological environment from 2008 to 2017. Subsequently, a GM(1,1) grey forecasting model is used to predict the coupling coordination degree for the next five years.

The results demonstrate that: (1) The comprehensive evaluation indices of all three subsystems exhibit varying degrees of growth, with the economic development system showing the largest increase. While the tourism industry and ecological environment systems demonstrate overall upward trends, both experience short-term declines due to economic and broader socioeconomic influences. (2) The coupling coordination types in Xinjiang from 2008 to 2017 can be divided into two categories: ecology-advanced type (2008–2010) and economy-advanced type (2011–2017). The three systems maintain a high degree of correlation. Temporally, the coupling coordination degree shows a fluctuating upward trend, evolving from primary coordination to intermediate coordination in overall terms. (3) The GM(1,1) forecasting model demonstrates high fitting accuracy. Predictions indicate that the coupling coordination degree among

Xinjiang' s three major systems will continue to rise slightly over the next five years, reaching a good coordination level by 2022.

Keywords: coupling coordination model; tourism industry; economic development; ecological environment; Xinjiang

1. Introduction

As a national strategic pillar industry, tourism significantly contributes to driving related industrial development, creating employment, and increasing tax revenue. By the end of 2018, tourism' s comprehensive contribution to the national economy and the proportion of tourism employment in total national employment both exceeded 10%. The tourism industry, economic development, and ecological environment interact closely. Environmental optimization forms the foundation supporting tourism and economic growth; conversely, robust tourism development accelerates economic growth, which in turn provides better infrastructure for tourism and financial support for ecological protection. However, the rapid increase in tourism and economic benefits often occurs at the cost of environmental degradation, causing severe resource consumption and pollution problems that subsequently constrain tourism development. Therefore, coordinating sustainable development across tourism, economy, and ecology is essential for regional development.

Domestic research on tourism, economic development, and ecological environment is extensive, primarily focusing on pairwise coupling coordination analyses: tourism-economy, tourism-ecology, and economy-ecology. In tourism-economy coupling research, An et al. analyzed the spatial correlation between poverty and tourism resource advantages in three prefectures of southern Xinjiang. Yang et al. empirically examined the coupling coordination between rural tourism informatization and regional tourism economy in Jiangsu Province. Liu et al. investigated the coupling coordination level and causal mechanisms of tourism competitiveness and economic development in 71 global poverty-stricken countries from a competitiveness perspective. In economy-ecology research, scholars have applied coupling coordination models to study relationships between ecological vulnerability and poverty-stricken areas, environmental pollution and economic growth, and ecological environment and urbanization from multiple perspectives. Tourism-ecology coupling research covers various scales, including individual provinces, specific urban agglomerations, and coastal regions.

While existing literature addresses tourism-economy-ecology coupling coordination, most studies rely on cross-sectional data or short time series, lacking future projections. Moreover, research concentrates on economically developed eastern provinces with relatively favorable ecological conditions, with insufficient attention to vulnerable arid regions in western China.

The Xinjiang Uygur Autonomous Region is China' s largest province and a typical representative of arid, semi-arid, and ecologically fragile areas. Since the 13th Five-Year Plan, Xinjiang' s tourism industry has experienced explosive

growth, placing increasing pressure on the ecological environment. This study analyzes tourism industry, economic development, and ecological environment data for Xinjiang from 2008 to 2017 to calculate coupling coordination degrees. Using a GM(1,1) grey prediction model, we forecast future coupling coordination trends to provide references for policy-making regarding tourism development strategies and scientific protection and rational utilization of natural resources.

2. Study Area and Data Sources

2.1 Study Area Overview

Xinjiang is located in the heart of Eurasia, characterized by a temperate continental arid climate with abundant light and heat resources, scarce and unevenly distributed precipitation, high evaporation rates, low vegetation coverage, and severe land desertification. This typical arid and ecologically fragile region features a unique "three mountains surrounding two basins" topography that creates diverse tourism resources. In recent years, Xinjiang' s tourism industry has sustained continuous growth. From 2008 to 2017, inbound tourist numbers grew from 3.632$×10^{4}$ to 2.348$×10^{7}, while total tourism revenue increased from 2.108×10^{10}$ to 4.183$×10^{11}$ yuan. The proportion of tourism revenue in GDP rose by 4.93 percentage points, with an average annual growth rate of 16.74%. The tourism industry has become a key driver of Xinjiang' s rapid macroeconomic growth.

2.2 Data Sources

This study examines the coupling coordination among tourism industry, economic development, and ecological environment systems in Xinjiang using data from 2008 to 2017. Indicator data primarily derive from the National Bureau of Statistics and Xinjiang Uygur Autonomous Region Bureau of Statistics, including the *Xinjiang Statistical Yearbook* (2009–2018) and *National Economic and Social Development Statistical Communiqué* (2008–2017). Some data are obtained from official statistics of tourism, environmental protection, and other relevant departments.

3. Methods

3.1 Indicator System Construction

Based on field research across Xinjiang and following principles of scientificity, representativeness, and data availability, this study draws on existing research to select 30 indicators across seven criteria layers to establish the tourism industry-economic development-ecological environment evaluation index system. To eliminate dimensional and physical meaning differences among indicators within each subsystem, the range standardization method is first applied for non-dimensionalization, followed by the entropy method to calculate indicator weights (Table 2).

3.2 Subsystem Development Level Evaluation Model

The tourism industry-economic development-ecological environment system is a large, complex system with mutual interactions and influences. This study employs the linear weighting method to evaluate the comprehensive development level of each system:

$$U_i = \sum_{j=1}^{n} W_{ij} R_{ij} \quad (i = 1, 2, 3)$$

where R_{ij} represents standardized data, W_{ij} is the weight of the jth indicator in subsystem i, and U_1, U_2, U_3 represent the comprehensive evaluation indices of the tourism industry system, economic development system, and ecological environment system, respectively. Larger U_i values indicate better system development status.

3.3 System Coupling Coordination Model

Coupling originates from physics to characterize interaction quality among systems or elements. This study examines coupling among three systems—tourism industry, economic development, and ecological environment—drawing on existing research to derive the coupling degree formula:

$$C = \frac{\sqrt[3]{U_1 \times U_2 \times U_3}}{(U_1 + U_2 + U_3)/3}$$

where C is the coupling degree ranging from [0,1]. Larger C values indicate stronger inter-system correlations. However, coupling degree only reflects interaction strength, not overall coordination. Therefore, we introduce the coupling coordination model:

$$T = U_1\alpha + U_2\beta + U_3\gamma$$

$$D = \sqrt{C \times T}$$

where D is the coupling coordination degree, T is the comprehensive system evaluation index, and α, β, γ are undetermined coefficients summing to 1. Since the three systems mutually promote and constrain each other, and both tourism and economic development depend on ecological conditions, we set $\alpha = 0.3$, $\beta = 0.3$, $\gamma = 0.4$ based on existing research. Following Liao' s classification standards, we divide coupling coordination degrees into 10 levels (Table 2).

3.4 Grey Forecasting Model GM(1,1)

The GM(1,1) model is a predictive model for systems with uncertain hierarchical structures and random dynamic changes. By accumulating and averaging original random variables, it constructs differential equation models to forecast future data.

1) Let the original data sequence be $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n))$. After accumulation, the new sequence is $x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(n))$, corresponding to the first-order linear differential equation:

$$\frac{dx^{(1)}}{dt} + \alpha x^{(1)} = \mu$$

where α is the development coefficient and μ is the grey action quantity.

2) The prediction model is solved using Python programming:

$$X^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{\mu}{\alpha}\right] e^{-\alpha k} + \frac{\mu}{\alpha} \quad (k = 0, 1, 2, \dots, n)$$

where α and μ are unknown parameters to be determined, and k represents time.

3) To validate the model' s reliability, posterior difference testing is required:

$$F = \frac{S_2}{S_1}$$

where S_1 is the standard deviation of the original data sequence and S_2 is the standard deviation of the residual sequence. The posterior difference ratio F indicates proximity between estimated and actual values—smaller F values are better.

$$P = P\left(|q(k) - \bar{q}| < 0.6745 S_1\right)$$

where P is the small error frequency, representing the proportion of residuals within the given threshold. Larger P values indicate better model performance.

Based on F and P, model accuracy can be comprehensively evaluated (Table 3). If both parameters fall within acceptable ranges, the model is suitable for forecasting coupling coordination degrees; otherwise, residual sequence analysis is needed for correction.

4. Results Analysis

4.1 Comprehensive Development Level of Subsystems

Using the linear weighting method, we calculated the comprehensive development levels of each subsystem (Figure 1 [Figure 1: see original paper]). Overall, all three subsystems show fluctuating growth, with the economic development system exhibiting the greatest volatility. The tourism industry and ecological environment systems both experienced short-term significant declines during their upward trajectories.

Tourism Industry System (U_1): Xinjiang' s tourism industry showed overall fluctuating growth from 2008 to 2017. The index U_1 increased from 0.102 to 0.598, with a "decline-rise-decline-rise" pattern, reaching a trough in 2009. Following the Belt and Road Initiative proposal, Xinjiang' s tourism industry gained new momentum, with U_1 recovering and peaking at 0.598 in 2017.

Economic Development System (U_2): Except for a decline in 2009, U_2 demonstrated sustained stable growth from 2008 to 2017, surpassing U_1 and U_3 after 2011 and reaching a maximum of 0.892 in 2017. Xinjiang' s rapid economic growth benefited significantly from the national counterpart assistance policy.

Ecological Environment System (U_3): The ecological environment remained relatively stable at 0.3–0.4 before 2014, then gradually declined, falling significantly below U_1 and U_2, reaching only 0.206 in 2015. After the autonomous region government strengthened ecological protection and supervision mechanisms, the environment improved markedly from 2016 onward, with U_3 rising to its maximum of 0.457 in 2017.

4.2 Temporal Analysis of Coupling Coordination Degree

Using the comprehensive evaluation indices of subsystems, we calculated the coupling degree C and coupling coordination degree D for Xinjiang' s tourism industry-economic development-ecological environment system from 2008 to 2017, determining coordination levels and types (Figure 2 [Figure 2: see original paper]).

The results show consistently high coupling levels (>0.9), indicating strong interconnections among the three systems. However, due to socioeconomic and environmental influences, the coupling coordination degree exhibits a cyclical "decline-rise" wave pattern, reaching medium-high levels overall. For instance, despite declining to a trough of 0.58 in 2009, the coordination level improved from primary to intermediate coordination.

Two distinct stages emerge: - **Primary Coordination Stage (2008–2010):** Coupling coordination fluctuated between 0.58–0.60, stabilizing at primary coordination. Despite the 2010 National Counterpart Assistance Conference establishing effective support mechanisms, the ecological environment index (U_3) remained far below economic and tourism indices, indicating that rapid develop-

ment negatively impacted ecological sustainability. - **Intermediate Coordination Stage (2011–2017):** Tourism and economic indices showed sustained growth while ecological indices fluctuated upward. Coupling degree peaked in 2014, with coordination degree rising rapidly to 0.71 in 2015, maintaining stable intermediate coordination.

4.3 Coupling Coordination Type Analysis

From 2008 to 2017, Xinjiang' s coupling coordination types fall into two categories: ecology-advanced and economy-advanced (Table 4).

Ecology-Advanced Type (2008–2010): With U_3 significantly higher than U_1 and U_2, this period reflected Xinjiang' s favorable natural environment but underdeveloped economy and underutilized tourism resources, achieving only primary coordination with substantial room for improvement.

Economy-Advanced Type (2011–2017): Following the 2010 Central Xinjiang Work Conference and implementation of counterpart assistance, economic development (U_2) surged. However, U_3 remained substantially lower than U_2 and U_1, indicating that rapid economic and tourism growth exerted considerable negative environmental impacts through extensive development patterns.

4.4 Forecasting Analysis of Coupling Coordination Development

To project future trends, we used the 2008–2017 coupling coordination degree sequence as original data for GM(1,1) modeling in Python 3.6 (Anaconda3 environment). The model yielded parameters $\alpha = -0.01625$ and $\mu = 0.656$, producing the differential equation and prediction model:

$$X^{(1)}(k+1) = 40.046e^{0.01625k} - 39.39$$

Posterior difference testing yielded $F = 0.115$ and $P = 1.000$, indicating high model accuracy. The predicted coupling coordination degrees for 2018–2022 are: 0.714, 0.725, 0.736, 0.747, and 0.758, respectively.

The forecast shows that Xinjiang' s tourism industry-economic development-ecological environment coupling coordination will maintain slight, continuous growth, reaching good coordination by 2022. Although gradually improving, the evolution pace remains slow. Achieving stable, high-quality coordinated development requires maintaining social stability, addressing key constraints, and promoting mutual benefits among the three systems.

5. Conclusions

1) All subsystem comprehensive evaluation indices show growth, with economic development increasing most significantly. Tourism and ecological environment systems rise overall but experience short-term declines due to

economic and social influences. This demonstrates mutual influence and constraint among the three systems. Future development should increase ecological protection investment, improve ecological compensation mechanisms, expand financing channels for conservation, encourage enterprise and public participation, strengthen ecosystem monitoring, and conduct regular environmental quality assessments to achieve win-win development and environmental protection.

2) The three systems maintain high coupling correlation, with coupling coordination degrees showing fluctuating upward trends, evolving from primary to stable intermediate coordination. Xinjiang' s sustained tourism and economic growth benefits from Belt and Road Initiative opportunities and the successful UNESCO World Heritage designation of the Tianshan Mountains. Future efforts should enhance government guidance and policy support for tourism diversification, promote "tourism+" new business formats, and implement tourism poverty alleviation programs to leverage tourism' s driving effect.

3) The comprehensive development state divides into ecology-advanced (2008–2010) and economy-advanced (2011–2017) types. Balancing economic growth speed with ecological protection is crucial. While counterpart assistance policies have demonstrated quantitative results, qualitative development must embrace the "lucid waters and lush mountains are invaluable assets" philosophy, never sacrificing environment for short-term economic gains. Industrial structure should be adjusted to control high-pollution, high-energy-consumption enterprises, promoting transformation from extensive to intensive development models through continuous innovation.

4) The GM(1,1) model shows high fitting accuracy, predicting slight upward trends in coupling coordination over the next five years, reaching good coordination by 2022. To ensure stable improvement, Xinjiang should maintain social stability and ethnic unity, enhance self-development capabilities while leveraging counterpart assistance, and steadfastly promote tourism as a strategic pillar industry and key engine for high-quality economic development through industrial integration.

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Note: Figure translations are in progress. See original paper for figures.