Revealing the Economic Value of Grassland Eco-tourism Services: Using Mobile Phone Data

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Introduction

- Importance of assessing the economic value of ecosystem services, particularly tourism services provided by grasslands.
- Lack of research on the recreational value of grassland ecosystems, despite their extensive global coverage.
- Limitations of previous studies: reliance on survey data, focus on specific sites, simplistic demand function estimation.
- Potential of mobile phone data and advanced estimation methods to enhance the accuracy of recreational value assessments.

Objectives

- Estimate the recreational value of grasslands in Inner Mongolia, China, using mobile phone data and the travel cost method.
- Introduce non-parametric estimation techniques to enhance the accuracy of demand curve estimation.
- Quantify the impact of COVID-19 on grassland tourism value through simulation analysis.
- Identify key factors influencing tourist numbers and recreational value to inform policy development.

Background: The tourism of Inner Mongolia in China

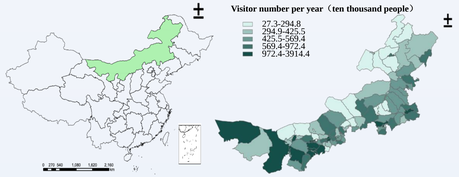

Figure 1.The location of Inner Mongolia in China and the visitor number of counties in Inner Mongolia in 2020

- Inner Mongolia is endowed with vast natural grasslands, ranking as the second-largest grassland province in China, with its grassland area constituting 20.06% of the national total.
- The types of grasslands in Inner Mongolia are highly diverse, including 8 grassland classes and 476 types.
- The ecological values of Inner Mongolian grasslands are significant.
  - As the top choice for grassland tourism in China, it's urgent to foster the development of industries focused on sand prevention, control, and ecological restoration.
  - Given its unique geographical position in the northeast of China, the grasslands serve as an ecological barrier and are crucial for preventing downstream dust storms.

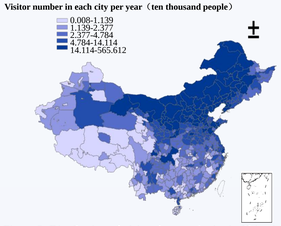

Figure 2. Distribution of visitor from each city in China in 2020

Data and analytical issues

- Mobile Phone Signal Data from China Unicom:
  - Weekly mobile phone signal data capturing tourist movements from 333 cities to 103 counties in Inner Mongolia (May-October 2020).
  - Including a user's residence, destination, and transportation mode based on the geographical information of the connected base stations.
- To define the number of tourists, we define tourists as individuals who travel more than 10 kilometers away from their primary residence for at least 6 hours by excluding users with non-tourism purposes such as business.
- Supplementary Data Sources

Table 1 Variables and data sources

Variables	Data sources
Car fee and duration	The data, from the Gaode map, includes the distance, tolls, and duration from the government of origin to the government of destination.
- Fuel consumption	The fuel consumption of passenger cars is 0.0628 L per km obtained from the Ministry of Industry and Information Technology.
- Price of gasoline	The average monthly gasoline price of each province in 2020 is 5.79 yuan per L.
Plane fee and duration	The airfare and flight time are from the VariFlight app. The duration and distance from origin and destination to the nearest airport are from the Gaode map.
Train fee and duration	The train data comes from 12306 website. The train fee uses a weighted average of fares and times for all trains from origin to destination by number of different type (D/G/T/Z).
Bus fee and duration	The data comes from bus ticket website. When there is no direct bus from the origin to the destination, the total fare and time can be obtained according to the optimization with the shortest time.
Proportion of transport	The proportion of transportation from origin to destination is derived from mobile phone signal data.
Hour salary	From China Statistical Yearbook and National Bureau of Statistics.

Grassland recreation value evaluation method

- Travel Cost Estimation: Zonal travel cost method accounting for transportation costs (flights, trains, buses, private vehicles) and time costs.

$$TC_{ij} = \sum_{N=1}^{n} w_{ijn}\, cost_{ijn} + \sum_{N=1}^{n} w_{ijn}\, Time_{ijn} \times \frac{1}{3} wage_i \quad (1)$$

where TC_{ij} represents the travel cost from residence *i* to destination *j*, $cost_{ijn}$ is the cost of transportation mode *n* that a tourist chooses for travel from residence *i* to destination *j* (i.e., ticket price). w_{ijn} is the proportion of tourists choosing transportation mode *n* for travel from residence *i* to destination *j*. $Time_{ijn}$ is the travel time (in hours) from residence *i* to destination *j* using transportation mode *n*, and $wage_i$ is the average hourly wage at residence *i*. As the value of leisure time is often lower than the value of working time, one-third of the average wage is used as the value of leisure time following the approach of previous literature (Armbrecht, 2014; Jaung and Carrasco, 2020).

- Demand Curve Estimation:

$$VR_j = f(TC_j), \quad \text{For each } i \quad (2)$$

where VR_j is the visitor rate from origin *j* to destination *i*, and TC_j is the travel cost from origin *j* to destination *i*. We use both parametric and nonparametric methods to estimate the model.

- Parametric: Log-linear, linear-log, log-log functional forms tested.

$$x_i = b + \alpha\, ln(TC_i) \quad (3)$$

where x_i represents the tourist rate from all prefecture-level administrative regions in the country to all counties in Inner Mongolia, and TC_i represents travel costs. The equation adopts the widely applied logarithmic linear model.

- Non-parametric: K-nearest neighbor method.

$$\hat{m}_{KNN}(x_0) = \frac{1}{R}\sum_{d}^{n} 1\{x_i \epsilon N_k(x_0)\} \cdot y_i \quad (4)$$

where $N_k(x_0)$ represents the set of *k* observations x_i that are closest to x_0, and y_i is the corresponding dependent variable value for each x_i. After estimating the demand curve for each destination, calculate the tourism value. As non-parametric methods lack an analytical expression, this study differentiates the estimated values corresponding to each x_i. The total area under the demand curve for all departure locations is then summed, yielding the overall tourism value for each destination.

- Recreation Value Calculation:

$$CS_{ij}^{site} = N_j \times \int_{TC_{ij}^{0}}^{TC_{ij}^{*}} f(TC_{ij})\, dTC_{ij} \quad (5)$$

where TC_{ij}^{0} is the travel cost that visitors spend, TC_{ij}^{*} is the travel cost when the visitor rate is zero. CS_{ij}^{site} is the welfare loss of the site after its disappearance, which is also referred to as use value. N_j represents the population in origin *j*. For each *i*, tourism value can be obtained from the sum of the consumer surplus and travel expenses of all departure places, as shown in formula (6):

$$REV_i = \sum_{j=1}^{J} CS_{ij}^{site} + \sum_{j=1}^{J} TC_{ij} \times V_{ij} \quad (6)$$

where REV_i is the annual tourism value of destination *i*. TC_{ij} represents the average cost from original city *j* to destination *i*, V_{ij} is the visitor number traveling from original city *j* to destination *i*.

- Influencing Factors Analysis: Regression of county features (scenic spots, accommodations, economic development) on visitor numbers and recreational value.

$$Y_i = \alpha + \beta_N N_i + \beta_F F_i + \beta_C C_i + \varepsilon_i \quad (7)$$

where Y_i represents the tourist numbers in the 103 counties of Inner Mongolia in the year 2020. When investigating the impact of county features on tourism value, Y_i represents the tourism value in the 103 counties of Inner Mongolia in the year 2020. N_i denotes the natural factors for county *i*, including the total area, grassland area, NDVI, land use, etc. F_i represents infrastructure, including the number of star-rated hotels, and C_i represents historical and cultural factors, including the population of the county and the number of differently graded scenic areas.

Results

- The nonparametric method has the potential to enhance the adjusted R^2 of demand curve estimation.

Table 2 Comparison of adj R^2 values between nonparametric and parametric methods

	Nonparametric	Parametric
adj R²	0.686	0.388

- Recreation Value in 2020:
  - Parametric (Linear-Log):
    - Total: 523.21 billion CNY (30.26% of Inner Mongolia's GDP)
    - Range across counties: 16.79 (Wuhai) - 105.12 (Hohhot) billion CNY
    - Top 3 counties: Hohhot (105.12), Ordos (77.41), Baotou (64.04)
  - Non-parametric (K-nearest neighbor):
    - Total: 617.47 billion CNY (35.57% of GDP)18% higher than parametric estimates
    - Range: 16.79 (Wuhai) - 105.12 (Hohhot) billion CNY
    - Top 3: Hohhot (105.12), Ordos (77.41), Chifeng (62.52)

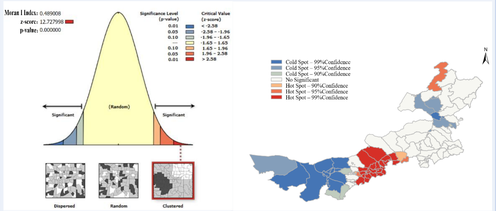

Figure 3. Spatial correlation and hotspot distribution of tourism value in Inner Mongolia Autonomous Region in 2020

- COVID-19 Impact Simulation:
  - Projected visitors without pandemic: 201.26 million (1.61x actual)
  - Simulated recreation value without COVID-19: 1161 billion CNY (1.88x actual)
  - 31% GDP loss in Inner Mongolia due to COVID-19 impact

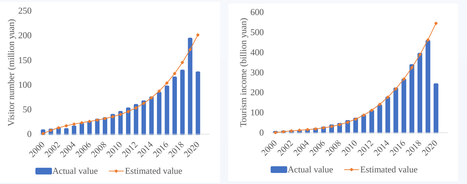

Figure 4. Visitor number and recreational income in 2000-2020

- Influencing Factors Analysis:
  - One additional 4A/5A scenic spot → 12.54% increase in visitors, 12.39% increase in value
  - One additional ≤3-star hotel → 5.17% increase in value
  - 1% increase in GDP → 0.48% increase in visitors, 0.39% increase in value

Conclusions

- Grasslands in Inner Mongolia yield substantial recreational value, accounting for 30-36% of regional GDP in 2020.
- Mobile phone data and non-parametric estimation enhance accuracy - 18% higher estimates compared to parametric methods.
- COVID-19 pandemic severely impacted tourism, causing 31% GDP loss in 2020. Simulation reveals potential value 1.88 times higher without the pandemic.
- Key factors driving tourist inflow and recreational value realization:
  - High-quality scenic spots (4A/5A ratings)
  - Availability of budget accommodations (≤3 stars)
  - Level of regional economic development
- Findings underscore economic importance of grassland tourism and vulnerability to external shocks.
- Policy implications: Preserve grassland health, enhance destinations, expand affordable accommodations, support regional economic development.

Contact

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