Postprint: Spatial Patterns and Dynamic Responses of Tourism and Passenger Transport in China' s Desert Regions

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Date: 2021-08-02T00:00:00+00:00

Abstract

China' s desert regions are widely distributed across the northwestern arid zones, with tourism products located far from eastern source-market central cities, thus incoming tourists largely depend on civil aviation transport. Based on relevant indicators including tourist arrivals, tourism revenue, and civil aviation passenger transport in desert regions from 2009 to 2019, this study measures the spatiotemporal development relationship between desert region tourism and civil aviation passenger transport in China using spatial proximity, buffer zone analysis, and Panel Vector Autoregression (PVAR) model. The results indicate: (1) Tourism resources in China' s desert regions are primarily distributed along the central line of the Silk Road Economic Belt, with relatively high density in the north-central and northwestern areas. (2) Civil aviation airports cover 45 desert tourism scenic areas, with 86.7% having relatively good accessibility; only 6 desert tourism scenic areas have poor accessibility. The buffer distance between the two mostly falls within medium-distance buffer zones, with short-distance and medium-short-distance buffer zones accounting for 73.3% of the total, indicating high spatial proximity between the two, i.e., strong spatial interdependence between desert region tourism and civil aviation passenger transport. (3) Cointegration test results demonstrate that desert region tourism and civil aviation passenger transport maintain a long-term stable equilibrium relationship. Through impulse response and variance decomposition, it is found that in the short term, desert region tourism exhibits an alternating positive-negative effect on civil aviation passenger transport, while in the long term it exerts a significant positive promotional effect. Conversely, civil aviation passenger transport can effectively expand the source market by increasing the number of navigable cities, thereby achieving the goal of promoting desert region tourism development.

Full Text

Spatial Pattern and Dynamic Response Between Tourism and Passenger Transportation in Desert Areas of China

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Abstract: With deserts widely distributed throughout northwestern China, desert tourism products are located far from major tourist source cities in the east, making civil aviation transport the primary means of access for visitors. Based on panel data from 2009 to 2019 covering tourist numbers, tourism revenue, and civil aviation passenger transport indicators in desert regions, this study employs spatial proximity analysis, buffer zone analysis, and a panel vector autoregression (PVAR) model to measure the spatiotemporal development relationship between desert tourism and civil aviation passenger transport in China. The results indicate: (1) Tourism resources in China' s desert areas are distributed primarily along the central axis of the Silk Road Economic Belt, with higher concentrations in north-central and northwestern regions. (2) Among 45 desert scenic spots, 86.7% demonstrate good accessibility within the coverage of civil aviation airports, while only six exhibit poor accessibility. The buffer distances between most scenic spots and airports fall within medium-range buffers, with short-distance and medium-short distance buffers accounting for 73.3% of the total, indicating high spatial proximity and strong spatial interdependence between desert tourism and civil aviation passenger transport. (3) Cointegration test results reveal a long-term stable equilibrium relationship between desert tourism and civil aviation passenger transport. Impulse response and variance decomposition analyses show that in the short term, desert tourism exhibits alternating positive and negative effects on civil aviation passenger transport, while in the long term it exerts a significant positive promotional effect. Conversely, civil aviation passenger transport can effectively expand the tourist source market by increasing the number of navigable cities, thereby promoting the development of desert tourism.

Keywords: desert tourism; passenger transportation; spatial pattern; panel vector autoregression (PVAR) model; dynamic response

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China is one of the countries with the most extensive desert distribution in the world, with desert areas covering approximately 700,000 km^2, or about 13% of the nation' s total land area. Deserts represent both a natural landform landscape and a tourism resource with tremendous potential, with lakes, biological resources, architecture, folk customs, and other natural and cultural elements within desert areas collectively constituting desert tourism resources. The vast desert regions contain abundant desert tourism resources, providing a strong resource foundation for the development of desert tourism. However, due to geographical constraints, most desert tourism products are distributed west of the Hu Huanyong Line, far from major tourist source cities in the east. Under the constraints of natural conditions such as topography, geological conditions, and ecological environment, the construction of road and rail transportation is inconvenient, making civil aviation passenger transport the primary mode of external passenger transport for these areas.

Since the 21st century, China' s civil aviation transport network has expanded from first- and second-tier cities to third- and fourth-tier cities, with further improvements in route network layout and denser flight schedules, effectively enhancing the accessibility of desert tourism destinations. Previous research on desert tourism has primarily focused on single themes, including desert tourism concepts, characteristics of desert tourism resources, market development, construction of desert geoparks, and spatial structure characteristics of desert scenic areas. Dong Ruijie et al. evaluated the competitiveness of desert tourism across various regions in China and identified development pathways for desert scenic areas, while Cong Linge proposed sustainable development models through analysis of the current status of desert tourism scenic areas. Existing research on the relationship between civil aviation passenger transport and tourism has emphasized the entire tourism industry. For instance, Ma Lijun et al. analyzed the relationship between China' s inbound tourism and civil aviation passenger transport using elasticity coefficient analysis and classified cities by their aviation dependency types. Bai Yang et al. employed the same model to study the coordinated development relationship between transportation and tourism in the core area of the Silk Road Economic Belt. Wang Jiao' e et al. examined the development trajectories of China' s civil aviation passenger transport and tourism industry, using a panel vector autoregression model to quantitatively analyze the relationship between the two at national and provincial scales from 1990 to 2012.

However, previous desert tourism research has primarily focused on the utilization, development, and protection of desert tourism resources, while studies on the relationship between civil aviation passenger transport and tourism have approached the issue from the perspective of the entire tourism industry. No existing research has specifically investigated the spatiotemporal relationship between civil aviation passenger transport and desert tourism from the standpoint of desert tourism itself. Therefore, this study focuses on desert tourism in China, employing spatial proximity analysis and buffer zone analysis to elucidate the spatial pattern relationship between desert tourism and civil aviation passenger transport, and constructs a PVAR model incorporating desert tourist numbers, tourism revenue, and civil aviation passenger transport indicators to measure the dynamic correlation between desert tourism development and civil aviation passenger transport, thereby proposing recommendations for promoting the coordinated development of civil aviation passenger transport and desert tourism.

1.1 Research Data

To ensure data validity and scientific rigor, this study collected panel data on desert tourism and civil aviation passenger transport from 2009 to 2019. For variable selection, traditional indicators for measuring tourism development levels include tourist numbers and tourism revenue, while passenger throughput quantitatively describes the overall level of civil aviation passenger transport. However, to measure the relationship between desert tourism and civil aviation passenger transport, it is also necessary to consider the accessibility of destinations to source markets. Therefore, we selected tourist numbers (TN) and tourism income (TI) to reflect tourism development conditions, with the tourism measurement indicators represented by the sum of tourist numbers and revenue from 45 desert tourism scenic spots. For civil aviation passenger transport development, we selected passenger throughput (PT), number of routes (RN), and navigable cities (NC) as indicators, collecting data on passenger throughput, route numbers, and navigable cities for civil aviation airports within major desert regions, then summing these to construct panel data with corresponding tourism data for effective measurement of the relationship between the two systems.

Tourism data were obtained from official websites of desert tourism scenic spots, government work reports at the city and county levels, web data from Baidu searches, and annual National Economic and Social Development Statistical Communiqués from the China Statistical Information Network. Civil aviation passenger transport data were sourced from the Civil Aviation Administration of China’ s National Airport Production Statistical Bulletin and the Civil Aviation Resource Network. Desert data were derived from the 1:100,000 Desert (Sandy Land) Distribution Dataset of China from the Cold and Arid Regions Research Institute, with geographic coordinates of desert tourism scenic spots and corresponding civil aviation airports obtained using LocaSpaceViewer software.

1.2 Research Methods

1.2.1 Spatial Proximity Spatial proximity describes the degree of closeness between geographical features in space. By measuring the natural distance between two geographic objects, it quantitatively describes the spatial proximity between them, with common methods including buffer zone analysis and Voronoi polygon analysis. Spatial proximity analysis is an important tool for spatial exploratory research. Applying this method to measure the impact of civil aviation passenger transport on tourism development can more intuitively reflect the influence of civil aviation passenger transport on desert tourism in China and clarify the radiation range and influence level of different civil aviation airports on 45 desert tourism scenic spots.

1.2.2 Buffer Zone Analysis Buffer zone analysis is a spatial analysis tool for solving proximity problems. It refers to the establishment of a certain width of buffer zone around a geographic entity or spatial object to identify its proximity or influence on the surrounding area. Buffering divides a map into two regions: one within a specified distance of the selected map feature and one outside that distance, with the area within the specified distance called the buffer zone. Because this study selected broader and more detailed target objects, buffer zone analysis was chosen as it can list different buffer distances, providing greater differentiation when measuring the radiation range and influence degree of civil aviation airports on scenic spots. The calculation formula is:

$$B_i = \{x \mid d(x, O_i) \leq R\} \ (i = 1, 2, 3, \cdots)$$

where B_i represents the calculated buffer zone result, indicating the set of points whose distance (d) from the central point O_i is less than R; x is the independent variable; d generally refers to the minimum Euclidean distance; O_i is the spatial analysis object; and R is the neighborhood radius or threshold.

1.2.3 Panel Vector Autoregression Model The vector autoregression (VAR) model is primarily used to analyze dynamic relationships among a set of endogenous variables. However, as the number of variables in the model increases, the number of estimated coefficients also increases multiplicatively, requiring large sample observations to effectively estimate model parameters. The advantage of the panel vector autoregression (PVAR) model is that it can obtain more sample observations. With the time series spanning 2009 to 2019, this study delineated and extracted major desert tourism regions through spatial analysis, ensuring both a large time span and rapid increases in sample capacity through regional panel data. The PVAR model formula is:

$$y_{it} = \alpha_i + \ t + \$ \$0 + \Sigma_{j=1}^{p} \beta_j \, y_{i,t-j} + \ it$$

$$(i = 1, 2, \cdots, 9; \ t = 1, 2, 3, 4, 5; \ j = 1, 2, 3)$$

where y_{it} is a column vector containing five endogenous variables (XR, YR); XR represents the second-order difference of tourist numbers in each desert region; YR represents the second-order difference of passenger throughput at civil aviation airports; i represents each desert tourism region (9 regions); t represents the year (2009-2019); α_i is a regional effect column vector reflecting individual differences among desert tourism regions in fixed-effect form; t is a time-effect column vector reflecting the impact of temporal changes on each desert tourism region; $\$ \$0$ represents the intercept term vector; j represents the lag order coefficient; p represents the lag order; β_j represents the parameter matrix of lag vectors; $y_{i,t-j}$ represents the vector composed of the ith desert region in year t-j; and it is the "white noise" disturbance term.

2.1 Spatial Distribution Characteristics of Desert Tourism Resources

2.1.1 Overall Distribution Features Using ArcGIS 10.6 to map China' s desert distribution (Figure 1), we observe that China' s desert areas are geographically concentrated in north-central and northwestern regions north of the Great Wall, primarily in Xinjiang, Gansu, and Inner Mongolia, with some distribution in Shaanxi and Qinghai. In terms of economic regions, they exhibit characteristics of large-scale aggregation with small-scale dispersion. The main body of desert tourism resources in China clusters around the central axis of the Silk Road Economic Belt, traversing the five northwestern provinces and the Inner Mongolia Autonomous Region and extending to Central Asia. Desert tourism resources are most densely distributed in the western margins of the Tarim Basin and Junggar Basin, as well as in the western part of Inner Mongolia, with other areas scattered sporadically along the eastern and central borders of Inner Mongolia, within and around the Northeast-Mongolia East Economic Zone and the Beijing-Tianjin-Hebei Economic Circle.

2.1.2 Main Distribution Regions To investigate the spatial pattern and dynamic response relationship between desert tourism and civil aviation passenger transport, we collected geographic location information for major desert tourism scenic spots in China. After calculation, we identified 45 desert-type tourism scenic spots and visualized all scenic spot locations (Figure 2). The results show that desert tourism scenic spots are mainly distributed across eight major deserts (Taklamakan Desert, Gurban Tonggut Desert, Kumtag Desert, Badain Jaran Desert, Tengger Desert, Ulan Buh Desert, Kubuqi Desert, Qaidam Desert) and four sandy lands (Mu Us Sandy Land, Hunshandake Sandy Land, Horqin Sandy Land, Hulunbuir Sandy Land). A-level and above scenic spots are concentrated in the Tengger Desert, Kubuqi Desert, Kumtag Desert, and Gurban Tonggut Desert, while the Horqin Sandy Land and Ulan Buh Desert primarily feature sub-A-level scenic spots. The Qaidam Desert and Hulunbuir Sandy Land have very few tourism scenic spots, with the Hunshandake Sandy Land containing only the Nanshaliang Scenic Spot. Therefore, we selected the remaining eight desert and sandy land regions for measurement and analysis, excluding regions with insufficient sample sizes.

2.2 Spatial Pattern Development Measurement

Using ArcGIS 10.6 multi-ring buffer analysis with each civil aviation airport in desert regions as the center, we created circles with radii of 50 km, 100 km, 150 km, 200 km, and 250 km, merged intersecting circles into polygon layers, and ultimately determined the accessibility boundaries of each civil aviation airport. We then visualized the desert tourism scenic spot location layers on this buffer layer to analyze the radiation range and influence degree of civil aviation airports on desert tourism scenic spots.

According to Table 1, among the existing 13 civil aviation airports, Ejina Banner Airport serves the most scenic spots (10), followed by Ordos Ejin Horo International Airport, Alxa Left Banner Airport, and Dunhuang Mogao International Airport, while Shihezi Garden Airport and Alxa Right Banner Airport serve the fewest. Airports with medium-level service numbers account for 46.2%, slightly less than those at the medium-high level (38.5%). Although these airports serve fewer scenic spots, the scenic spots they cover are generally high-grade (A-level and above), with tourist numbers far exceeding those of ordinary scenic spots. Therefore, desert region airports generally have high influence on desert tourism scenic spots and can effectively improve the accessibility of desert tourism transportation.

Based on natural distance calculations between civil aviation airports and desert tourism scenic spots, we quantitatively described the spatial proximity between the two (Table 1). Buffer distances were categorized into five levels: 50 km (short-distance buffer), 100 km (medium-short distance buffer), 150 km (medium-distance buffer), 200 km (medium-long distance buffer), and 250 km (long-distance buffer), corresponding to influence levels of civil aviation airports (with smaller numbers indicating higher influence levels).

The analysis reveals that the average distance of desert tourism scenic spots covered by each civil aviation airport is basically within 200 km, belonging to medium-distance and below buffers. Specifically, 4 airports (30.8%) are located in short-distance buffers with influence level 1, and 6 airports (46.2%) are in medium-short distance buffers with influence level 2, together accounting for 76.9% of the total and indicating relatively high airport influence levels. Airports in medium-distance and medium-long distance buffers each number 3 (23.1%), with influence level 3. In summary, the construction of civil aviation airports can effectively improve the accessibility of desert tourism scenic spots. Among the 45 scenic spots, 39 (86.7%) have good accessibility, while only 6 have poor accessibility. Both distance measurements and buffer zone maps indicate high spatial proximity between the two, suggesting strong spatial interdependence between desert tourism and civil aviation passenger transport.

2.3 Dynamic Response Analysis Based on PVAR Model

2.3.1 PVAR Model Testing (1) Unit Root Test. Before model construction, panel data must undergo unit root testing to determine whether the series is stationary, as only stationary series can be used for valid PVAR model analysis. Table 2 presents the unit root test results for all variables. The results show that all variables have P-values greater than critical values at the 1% significance level in their original and first-differenced forms, indicating non-stationarity. However, after second-order differencing, all variables reject the null hypothesis at the 1% significance level, indicating stationarity and enabling further model construction.

(2) Endogeneity Test. Endogeneity refers to correlation between multiple explanatory variables and random disturbance terms. The commonly used endogeneity test method is the Hausman test, which examines whether individual effects or time effects are correlated with explanatory variables to determine whether to use fixed-effect or random-effect models. By conducting Hausman tests on second-order differenced variables (Δ^2TN, Δ^2TI, Δ^2PT, Δ^2RN, Δ^2NC), the results show P-values less than 0.01, rejecting the null hypothesis at the 99% confidence level and indicating that the fixed-effect model should be selected.

(3) Cointegration Test. To examine whether a long-term cointegration relationship exists between desert tourism and civil aviation passenger transport, we performed Engle-Granger cointegration tests on second-order differenced data for tourist numbers and income and civil aviation passenger transport indicators. The null hypothesis is no cointegration. The results (Table 3) show that all test statistics (Panel v, Panel rho, Panel PP, Panel ADF, Group rho, Group PP, Group ADF) reject the null hypothesis at the 1% significance level, supporting cointegration and indicating a long-term stable equilibrium relationship between tourist numbers and income and civil aviation passenger transport. Based on this, we further analyzed the long-term dynamic interaction between the two through impulse response and variance decomposition.

(4) Stability Test and Lag Order Selection. We conducted stability tests on PVAR models constructed between tourist numbers, income, and civil aviation passenger transport, finding that all points lie within the unit circle, indicating that the constructed PVAR models are stable. To determine the optimal lag order, we examined criteria including LogL, LR, FPE, AIC, SC, and HQ. The results (Table 4) show that the optimal lag order for the PVAR model between tourist numbers and civil aviation passenger transport is 2, while the optimal lag order for the model between tourism income and civil aviation passenger transport is 1.

2.3.2 Impulse Response and Variance Decomposition Analysis (1) Impulse Response Between Desert Tourist Numbers and Civil Aviation Passenger Transport. Impulse response functions demonstrate how current and future values of endogenous variables are affected by changes in error terms when given a one-standard-deviation shock. Figure 4 shows the impulse response of desert tourist numbers (Δ^2TN) to civil aviation passenger transport indicators. When a one-standard-deviation shock is given to Δ^2TN, the response of Δ^2RN reaches its maximum value in period 1, declines to its minimum value in period 2, rises to period 3, and maintains small fluctuations through period 10. When a one-standard-deviation shock is given to Δ^2TN, the response of Δ^2NC shows an amplified decline-rise pattern in periods 1-3, fluctuating near zero thereafter, with overall negative impact. When a one-standard-deviation shock is given to Δ^2TN, Δ^2PT shows an overall positive response in an inverted "V" curve with gradually decreasing amplitude, reaching its maximum in period 2 and minimum in period 3, indicating that increasing navigable cities to expand the tourist source market is the key to improving desert tourist numbers.

Figure 5 shows the impulse response of civil aviation passenger transport indicators to desert tourist numbers (Δ^2TN). When a one-standard-deviation shock is given to Δ^2RN, the response of Δ^2TN reaches its minimum in the current period, fluctuates upward to its maximum in period 3, then shows a fluctuating slow decline through period 10. When a one-standard-deviation shock is given to Δ^2NC, the response of Δ^2TN shows a minor impact in periods 1-2, followed by an inverted "V" curve through period 10, approaching zero. When a one-standard-deviation shock is given to Δ^2PT, Δ^2TN shows an amplified decline-rise trend in periods 1-3, fluctuating near zero thereafter with overall weak positive impact. This indicates that desert tourism' s impact on civil aviation passenger transport shows alternating positive and negative effects in the short term but will play a positive promotional role in the long term.

(2) Impulse Response Between Desert Tourism Income and Civil Aviation Passenger Transport. Figure 6 shows the impulse response of desert tourism income (Δ^2TI) to civil aviation passenger transport indicators. When a one-standard-deviation shock is given to Δ^2TI, the response of Δ^2RN declines from period 1 to its minimum in period 2, rises to period 3, then remains basically stable in negative impact through period 10. When a one-standard-deviation shock is given to Δ^2TI, the response of Δ^2NC shows a minor impact in periods 1-2, followed by an inverted "V" curve through period 10. When a one-standard-deviation shock is given to Δ^2TI, Δ^2PT shows an inverted "U" curve with alternating positive and negative values, presenting a highly positive overall impact. This validates the analysis results that increasing navigable cities has a positive effect on desert tourism development.

Figure 7 shows the impulse response of civil aviation passenger transport indicators to desert tourism income (Δ^2TI). When a one-standard-deviation shock is given to Δ^2RN, the response of Δ^2TI reaches its highest value initially, rises to its peak in period 3, then shows a fluctuating slow decline through period 10, with larger period numbers approaching zero. When a one-standard-deviation shock is given to Δ^2NC, the response of Δ^2TI shows a decline-rise pattern with consistent amplitude in periods 1-3, fluctuating near zero thereafter with overall weak positive impact. When a one-standard-deviation shock is given to Δ^2PT, Δ^2TI shows an inverted "V" curve in periods 1-3, remaining in the positive range with fluctuating patterns thereafter. This demonstrates that increased desert tourism income can effectively promote the development of civil aviation passenger transport.

2.3.3 Variance Decomposition Based on variance decomposition results (Tables 5 and 6), we find that under the same period conditions, desert tourism numbers and income have relatively high contribution rates to themselves, maintained at 70%-90%. Among the three civil aviation passenger transport indicators, navigable cities have the highest contribution rate to tourist numbers and income, reaching 40%-60%, followed by passenger throughput with a contribution rate of 20%-40% to desert tourism income, while route numbers have the lowest contribution rate. This indicates that for China' s desert areas, which are characterized by vast territories with sparse populations, economic underdevelopment, and fragile ecological environments where primary and secondary industries are limited, tourism plays an important role in economic development. Civil aviation airports are mostly constructed based on scenic spot radiation and play a key role in promoting healthy and orderly tourism development. Under fixed tourist source market conditions, blindly increasing route numbers and expanding passenger volume cannot significantly drive tourism development because desert tourism is price-sensitive and has certain requirements regarding tourists' income and economic status. Instead, increasing navigable cities to develop new tourist source markets is needed to revitalize desert tourism.

3 Conclusions and Recommendations

Using neighborhood analysis, this study explored the spatial pattern relationship between desert tourism and civil aviation passenger transport in China, and measured the dynamic relationship between the two based on panel data from 2009 to 2019 using a PVAR model. The following conclusions can be drawn:

(1) The distribution characteristics of tourism resources in China' s desert areas show geographical concentration in northwestern and north-central China, and economic regional distribution primarily along the central axis of the Silk Road Economic Belt.

(2) Through spatial proximity and buffer zone analysis, we found that most civil aviation airports cover desert tourism scenic spots with good accessibility, indicating that civil aviation passenger transport has a high positive impact on desert tourism. The buffer distances between the two are mainly in short-distance and medium-short distance buffers, showing high spatial dependency. Therefore, civil aviation passenger transport can effectively improve the accessibility of desert tourism and attract large numbers of tourists.

(3) The PVAR model measured the dynamic correlation between the two systems. Cointegration test results show a long-term stable equilibrium relationship between desert tourism and civil aviation passenger transport. Impulse response and variance decomposition analyses reveal that desert tourism exhibits alternating positive and negative effects on civil aviation passenger transport in the short term, but will exert a significant positive promotional effect in the long term. Civil aviation passenger transport should focus on increasing navigable cities to expand the tourist source market, which is key to promoting desert tourism development both currently and in the future.

For future development of tourism and civil aviation passenger transport in desert areas, improvements can be made in three aspects:

First, continuously improve air transport capacity in desert areas. Focus on increasing the number of navigable cities for civil aviation airports in desert regions, clarifying the characteristics of different tourist source markets and tourist preferences. Add new domestic and international navigable cities, increase flight frequency, develop more aviation transport routes, enhance airport transport capacity, and reduce accessibility barriers for tourists.

Second, continuously promote tourism development. Seize the strategic opportunity of the Silk Road Economic Belt, integrate existing desert tourism resources, deeply explore cultural connotations to inject content and soul into desert tourism products, and build well-known desert tourism brands in China and worldwide. Strengthen the construction of upstream and downstream industrial chains in desert tourism, enhance attractiveness, and develop broader domestic and international markets based on world-class desert tourism resources.

Third, adhere to the integrated development strategy of "tourism plus transport."Leverage the advantages of low-altitude sightseeing through short-distance civil aviation passenger transport, give full play to the connecting role of civil aviation transport, create an integrated development brand for desert tourism and transport, and build an integrated development pattern for desert tourism.

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