# Post-print: Evolution of Road Accessibility and County-level Economic Linkage Patterns in Qinghai Province

**Authors:** Yang Xiaomin, Li Lingqin

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## Abstract

Employing GIS analytical methods including weighted average travel time, gravity model, Kriging interpolation, XY to line, natural breaks classification, and graduated symbols, and selecting 1986, 1995, 2004, and 2016 as temporal cross-sections, this study analyzes the evolutionary patterns of accessibility and county-level economic connection configurations for 43 major node towns within Qinghai Province' s highway network. The findings indicate that: from 1986 to 2016, the accessibility isolines of Qinghai Province' s highway network displayed an irregular semi-ring distribution pattern, with primary influencing factors comprising location, transportation, economy, and temporal distance; the accessibility interpolation exhibited orientation toward major transportation arteries. The overall accessibility level of Qinghai Province' s highway network improved, with accessibility value changes characterized by concurrent similarities and disparities. From 1986 to 2016, both economic connection intensity and total external economic connection volume in Qinghai Province demonstrated growth trends, particularly with accelerating growth in total economic connection volume. Counties ranking in the top five for economic connection intensity and top three for total economic connection volume were predominantly concentrated in the Xining and Haidong regions, manifesting Qinghai Province' s typical single-core urban spatial structure and the pronounced radiating and driving role of the provincial capital. Economic connection intensity, total economic connection volume, and accessibility all exhibited positive correlations.

## Full Text


## Abstract

Due to its natural geographical location, economic conditions, and other factors, transportation development in Qinghai Province, China has remained relatively backward, with highways occupying a crucial position in the province' s transportation network for an extended period. This study selects 1986, 1995, 2004, and 2016 as temporal cross-sections, constructs a highway traffic network database for Qinghai Province using ArcGIS spatial analysis modules, and analyzes the accessibility and its evolution across 43 major nodes in the province' s cities using the weighted average travel time method and Kriging interpolation for spatial pattern analysis. Overall, the spatial distribution of accessibility exhibits a decreasing trend from Xining City and Haidong City to other parts of the province, with contour accessibility lines displaying a semi-annular, irregular distribution pattern. Xining City and Haidong City maintained the best accessibility levels throughout the study period, with Xining City showing the highest accessibility. Key factors influencing accessibility include geographical location, traffic conditions, and urban economic development. The accessibility interpolation results demonstrate the directional influence of trunk roads. Dynamic evolution of accessibility reveals that accessibility levels for all 43 nodes in Qinghai Province have improved, with variation patterns showing both convergent and divergent characteristics. The spatial distribution of contour accessibility variation ratios reflects the directionality of trunk roads, such as national highways and expressways. The similarity index shows a declining trend from the northeastern to the western and southern regions of the province, though differences exist in accessibility levels across the three research stages. During 1986–2016, both the intensity and volume of economic linkages among counties in Qinghai Province displayed a growing trend, with total economic linkage volume increasing at an accelerating rate. The top five counties in economic linkage intensity and the top three in economic linkage volume are primarily concentrated in Xining and Haidong Cities, reflecting Qinghai Province' s typical "single-core" urban spatial structure and the prominent radiating and leading effects of the provincial administrative center. A positive correlation exists between regional accessibility and economic linkage intensity or volume.


**Keywords:** accessibility; economic linkage; spatial pattern; Qinghai Province

## 1 Introduction

Transportation infrastructure serves as the material basis for socio-economic development and a prerequisite for inter-regional economic exchange. Road accessibility and economic linkages are critical research topics in transportation geography and economic geography. Hansen [**?**] first introduced the concept of accessibility, defining it as the degree of difficulty in overcoming spatial separation to participate in various activities. Subsequent scholars [**?**] expanded accessibility research into multiple domains. Gutiérrez [**?**] analyzed the impact

of the European transnational road network on regional accessibility. Domestic research has examined accessibility in developed areas [?], the influence of arterial highway systems on municipal accessibility [?], and urban accessibility in national trunk highway systems [?]. Studies have also analyzed spatial patterns of accessibility in the Yangtze River Delta [?] and Anhui Province [?], revealing that accessibility improvements enhance regional economic connections.

Economic linkage research primarily employs the gravity model. Russon and Vakil [?] applied population and convenience measurements to analyze airport economic linkages. Chinese scholars have used gravity models to study economic linkages between Shenzhen and the Pearl River Delta [?], along railway lines [?], and under high-speed rail conditions [?]. Research on Jiangsu Province [?] and Zhejiang Province [?] demonstrated that transportation infrastructure significantly influences regional economic linkages. Studies on Shaanxi Province [?] and the Yangtze River Belt in Anhui [?] further confirmed the relationship between accessibility and economic linkages.

Qinghai Province, located on the Qinghai-Tibet Plateau, faces constraints from topography, climate, and economic conditions that have resulted in relatively backward transportation development. The "National Highway 214 Construction and Socio-economic Development in Qinghai" [?] and "Seasonal Snow Cover and Its Effect on Highway Transportation in the Urumqi River Basin" [?] highlight transportation challenges in plateau regions. Research on permafrost along the Qinghai-Tibet Highway [?] and the impact of landforms on highway construction [?] further illustrate these difficulties. Over the past 30 years, Qinghai's highway network has developed significantly, with total road mileage increasing from 4,508 km (1985–1995) to 26,620 km (1995–2004). By 2015, the province's GDP reached ¥241.705 billion, with primary, secondary, and tertiary industries accounting for 8.64%, 49.95%, and 41.41% respectively. The urbanization rate reached 43.56%, with Xining and Haidong cities serving as core economic centers. This study analyzes the spatiotemporal evolution of accessibility and economic linkages across 43 counties in Qinghai Province from 1986 to 2016.

## 2 Data and Methods

### 2.1 Data Sources

**2.1.1 Road Network Data** The study utilizes road network data from 1986, 1995, 2004, and 2016, including national highways, provincial roads, county roads, and rural roads. Data were obtained from the Qinghai Provincial Transportation Department and digitized using ArcGIS to establish a road network database. Technical road parameters include road grade, pavement type, and design speed. The formula for weighted average travel time is:

$$A_i = \frac{\sum_{j=1}^{n}(T_{ij} \times M_j)}{\sum_{j=1}^{n} M_j}$$

where $A_i$ represents the accessibility of node $i$, $T_{ij}$ is the travel time between nodes $i$ and $j$, $M_j$ is the socio-economic weight of node $j$ (GDP), and $n$ is the number of nodes.

**2.1.2 Socio-economic Data** Socio-economic data for each county were obtained from the Qinghai Statistical Yearbook and include GDP, population, and industrial structure.

### 2.2 Methods

The study employs a gravity model to calculate economic linkage intensity and volume. The economic linkage intensity formula is:

$$R_{ij} = \frac{\sqrt{P_i G_i} \times \sqrt{P_j G_j}}{D_{ij}^2}$$

where $R_{ij}$ represents economic linkage intensity between counties $i$ and $j$, $P_i$ and $P_j$ are populations, $G_i$ and $G_j$ are GDP values, and $D_{ij}$ is the distance between counties calculated using ArcGIS network analysis.

Economic linkage volume is calculated as:

$$V_i = \sum_{j=1}^{n} R_{ij}$$

where $V_i$ is the total economic linkage volume of county $i$.

The study uses Kriging interpolation to analyze spatial patterns and overlay analysis to examine relationships between accessibility, topography, and economic linkages.

## 3 Results

### 3.1 Accessibility Evolution

From 1986 to 2016, accessibility across Qinghai Province's 43 counties improved significantly. Weighted average travel time decreased from 13.31 hours to 2.45 hours, with a reduction rate of 0.44 hours per decade. The spatial distribution shows a clear core-periphery pattern centered on Xining and Haidong, with accessibility declining outward. Contour accessibility lines form semi-annular patterns that expanded over time, reflecting road network development.

The accessibility variation ratio demonstrates the directional influence of trunk roads. National highways and expressways created corridors of high accessibility, with similarity indices showing a declining trend from northeast to southwest. However, three distinct stages emerged: 1986–1995 (slow improvement), 1995–2004 (accelerated development), and 2004–2016 (network optimization).

### 3.2 Economic Linkage Evolution

Economic linkage intensity and volume among counties increased substantially from 1986 to 2016. Total economic linkage volume grew from 39,468,089.88 (units: $10^4$ people $\times$ $10^8$ yuan $\times$ $h^{-2}$) to 1,562,926,175.57, representing a 39.6-fold increase. The top five counties in linkage intensity accounted for 59.74% of the provincial total, with Xining and Haidong dominating.

The spatial pattern shows strong concentration: 24 counties (55.81%) had economic linkage volumes below 50% of the provincial average, while only 4 counties exceeded 150% of the average. The "single-core" structure is evident, with Xining' s linkage volume reaching 647,507,772.39, far exceeding other counties.

### 3.3 Relationship Between Accessibility and Economic Linkage

Overlay analysis reveals a significant positive correlation between accessibility and economic linkage. Counties with better accessibility, particularly along national highways G109, G214, G227, and G315, show higher economic linkage intensity and volume. The correlation coefficient between accessibility and economic linkage volume is 0.79 ($p < 0.01$).

Topographic factors create distinct patterns: areas above 4,000 m elevation show weak economic linkages due to poor accessibility, while valley regions along major roads exhibit strong linkages. The Qinghai-Tibet Highway (G109) and Qinghai-Tibet Plateau topography significantly influence the spatial distribution of economic linkages.

## 4 Discussion

The study reveals several key findings:

(1) Accessibility improvement directly enhances economic linkages. The development of national highways and expressways has created accessibility corridors that facilitate economic exchange. However, the benefits are unevenly distributed, with Xining and Haidong capturing the majority of linkage benefits.

(2) The gravity model effectively captures economic linkage patterns, but requires adjustment for plateau regions. The model shows that population and GDP are primary drivers, while distance remains a significant barrier in mountainous areas.

(3) The "single-core" spatial structure of Qinghai Province is reinforced by transportation networks. While this concentrates economic activity, it may exacerbate regional disparities. Future road development should focus on improving peripheral county accessibility to promote balanced development.

(4) Topographic constraints limit road construction and economic development. Areas above 4,000 m face natural barriers that require specialized

infrastructure solutions. The interaction between permafrost, snow cover, and road accessibility needs further investigation.

## 5 Conclusions

(1) Qinghai Province' s highway accessibility has improved significantly over the past 30 years, with weighted average travel time decreasing by 81.6%. The spatial pattern shows a core-periphery structure centered on Xining and Haidong, with semi-annular contour lines reflecting road network directionality.

(2) Economic linkage intensity and volume have grown substantially, with total linkage volume increasing 39.6-fold. The spatial distribution is highly concentrated, with Xining and Haidong accounting for over 60% of provincial linkages, demonstrating a pronounced "single-core" structure.

(3) A strong positive correlation exists between accessibility and economic linkages (r = 0.79). Trunk roads, particularly national highways, serve as primary corridors for economic exchange. Topographic factors significantly moderate this relationship, with high-altitude areas showing weaker linkages despite road improvements.

(4) Policy implications include prioritizing road development in peripheral counties to reduce regional disparities, considering topographic constraints in infrastructure planning, and leveraging the radiating effects of the Xining-Haidong core to stimulate broader regional development.

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