

Article

The Multi-Dimensional Marginality of Inter-Provincial Border Regions: Spatio-Temporal Patterns and Driving Mechanisms in China

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Abstract

This study reconceptualises marginality in China's inter-provincial border regions as a dynamic, scale-sensitive spatial relationship rather than a static condition of underdevelopment. Using the Hubei–Henan–Anhui border area as a case study, we quantitatively assess marginality across three dimensions—production, livelihood, and ecology—based on panel data from 61 counties for 2000, 2010, and 2021. The entropy-weighted TOPSIS method is used to calculate comprehensive development indices, and geographic detector models identify key driving factors. The results show that production marginality is persistently shaped by economic level and industrial structure. Livelihood marginality exhibits a clear temporal shift: dominant drivers move from healthcare security to cultural amenities and finally to transport accessibility. Ecological marginality remains primarily determined by natural endowments such as habitat quality and ecosystem services. Theoretically, the study advances marginality analysis by integrating spatial, temporal and dimensional perspectives. Practically, it offers a diagnostic framework to support differentiated, cross-administrative governance strategies that can transform peripheral border regions into cooperative hubs.

Keywords: regional disparity; marginalization process; multi-criteria decision analysis; county-level analysis; China



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1. Introduction

Inter-provincial border regions (IPBRs) have attracted sustained academic attention as important spatial units in regional development research [1]. In China, IPBRs are defined as geographically continuous zones extending along administrative boundaries with a certain spatial width [2]. However, existing boundary theories—largely derived from European and North American contexts—primarily focus on national borders or supranational integration and provide limited explanatory power for transitional zones between high-level administrative units within sovereign states, such as provinces in China [3,4]. They account for approximately 47.9% of the national land area and represent a significant component of the country's spatial structure [5]. Despite their scale, these regions often experience persistent development constraints, including relatively low economic

performance, industrial convergence, inadequate infrastructure, and weak investment attractiveness [6,7]. These challenges indicate a structural condition of regional marginality.

Globally, the persistence of geographical inequalities has recently crystallized in the discourse of ‘left behind places’—areas that have failed to share in the prosperity and opportunities characterizing more successful regions [8]. As Pike notes, the notion of ‘left behind places’ is inherently multi-scalar and comparative, referring to areas at various geographical scales that have not “kept pace with” economic and social progress elsewhere [9]. Inter-provincial border regions in China represent a quintessential example of such ‘left behind places’ within the context of a rapidly developing economy, yet their systematic analysis remains underexplored in international literature. Existing studies have highlighted the dual characteristics of proximity and marginality in IPBRs. Proximity refers to geographical nearness, which generates potential for economic spillovers, cross-border cooperation, and regional integration. It represents the positive potential of regions. Marginality refers to the structural condition of being peripheral relative to cores—characterized by distance from decision-making centers, limited resource allocation, and weak institutional integration. It represents the constraints that hinder development. Most research, however, has focused on boundary effects associated with spatial proximity and their economic implications [6], while marginality as a structural constraint has not been systematically examined. In addition, many studies implicitly adopt an absolute spatial perspective, treating border regions as functionally integrated units and assuming that the development of central cities will naturally generate cross-regional spillovers. This assumption overlooks the role of administrative segmentation and institutional constraints, which significantly shape development outcomes in border areas. Given that most IPBRs have not yet been elevated to the national strategic level, a series of fundamental questions requires urgent re-examination. For instance, under the combined influence of strong administrative barriers and distance decay effects [10], what is the actual radiation effect of so-called central cities? Can their legitimacy be recognized across administrative boundaries? Do all types of border regions possess the foundational conditions necessary for collaborative development? If not, how should differentiated pathways for cooperation be designed? Addressing these questions requires placing the structural measurement and impact assessment of marginality at the center of the analytical framework.

As a distinct geographical-administrative spatial unit, IPBRs exhibit two defining characteristics. On the one hand, they are distant from the political and economic cores of their respective provinces; on the other, they lie adjacent to the administrative boundaries of neighboring provinces. This dual peripherality reflects not only physical distance but also the cumulative effects of institutional arrangements, resource allocation, and diminishing policy attention. Together, these factors create deep-rooted barriers that hinder endogenous development and regional integration. Within the broader national strategy that prioritizes urban agglomerations as the primary engines of regional development, inter-provincial border areas—marginalized both relative to provincial cores and major national urban clusters—often become policy blind spots and economically underdeveloped zones.

Marginality constitutes a central constraint on development, whereas proximity offers latent geographical potential for collaboration. However, within China’s local official evaluation and promotion system, characterized by a strong emphasis on economic growth and inter-regional competition, government behavior tends to be growth-oriented and competitive. Because the positive spillover effects of cross-administrative cooperation are difficult to internalize as local political achievements, officials are incentivized to concentrate scarce resources in core areas where performance is more visible. In some cases, institutional barriers are deliberately reinforced in border areas with overlapping jurisdictions, restricting factor mobility and preventing resource outflows, thereby intensifying

regional fragmentation [11]. From the perspective of collaborative governance theory, coordinated regional development depends on the efficient and orderly integration of structural and functional elements across regions. Yet, the diversity of regional units and the fragmented, multi-level administrative systems characteristic of inter-provincial border areas often result in superficial forms of cooperation. In such contexts, the shielding effect of administrative boundaries frequently outweighs their potential mediating effect, reflecting a lack of strategic coordination and mechanisms for deep integration. Against the backdrop of China's ongoing efforts to build a unified national market, overcoming institutional constraints in border regions, innovating collaborative models, and transforming boundaries from barriers into bridges have become pressing contemporary challenges.

Recent European scholarship has systematically reviewed the terminology, causes, models, and drivers of territorial marginality, highlighting the shift from spatial to aspatial factors and the emergence of "inner peripheries" [12]. Building on these insights, our study adapts a multidimensional measurement framework to the Chinese context. Therefore, analyzing IPBRs solely through the lens of geographical proximity fails to capture their complex developmental dynamics and inherent constraints. Any discussion of coordinated development that overlooks their intrinsic, multidimensional marginality risks resting on flawed assumptions. To address this issue, the present study pursues four specific objectives: (1) to construct a multi-dimensional, multi-scale, and multi-center analytical framework for measuring regional marginality in IPBRs; (2) to quantify the spatio-temporal evolution of marginality across production, livelihood, and ecological dimensions from 2000 to 2021; (3) to identify the key driving factors shaping marginality in each dimension and reveal their temporal dynamics; and (4) to propose differentiated governance strategies for transforming IPBRs from shielded peripheries into cooperative hubs. By systematically deconstructing and precisely measuring marginality, this study provides a robust scientific foundation for understanding and addressing development disparities in China's inter-provincial border regions.

2. Marginality and Its Measure

2.1. What Is Marginality?

The concept of marginality originated in sociology. In 1928, Park first systematically articulated the notion of marginality through the lens of cultural conflict and identity [13]. It was not until the 1990s, however, that the International Geographical Union formally incorporated the concept into geographical research, establishing it as a key framework for spatial analysis [14]. This marked an important shift in marginality studies, from a socio-cultural perspective toward a spatial-structural interpretation.

Within geography, definitions of marginal regions generally follow two complementary approaches. The first is an inductive approach grounded in the intrinsic characteristics of such regions. Early scholars, including Leimgruber, conceptualized marginality from a multidimensional perspective, identifying four core dimensions: geometric, ecological, economic, and social [15]. With the advancement of systems thinking, this framework evolved to distinguish between systemic marginality and process marginality, the latter emphasizing the dynamic mechanisms through which marginal conditions emerge [16]. A widely accepted definition, proposed by the International Union of Geographical Sciences, describes marginality as a condition in which a region remains relatively isolated within a given system, whether political, economic, social, or cultural [17]. This condition is typically manifested in persistent underperformance in key socioeconomic indicators and weak integration with core systems [18]. The second approach adopts a deductive perspective based on core-periphery theory. From this viewpoint, marginality refers to a state in which individuals or regions occupy relatively disadvantaged positions due

to their distance, geographical, economic, or institutional—from the core [19,20]. This interpretation highlights structural inequality, emphasizing that marginalization is often associated with developmental lag and limited access to opportunities.

In summary, marginality is a highly contextualized and interdisciplinary concept. Drawing on the tradition of spatial analysis in geography and incorporating insights from political economy, this study defines regional marginality as a multidimensional condition in which a city or region experiences systemic disadvantages in development capacity, access to opportunities, and levels of integration. Such disadvantages arise when the region is distant from core centers of decision-making and resource allocation in terms of political authority, economic resources, social capital, and infrastructural connectivity. These conditions are typically reflected in slow economic growth, inadequate public services, and restricted mobility of production factors.

It is worth mentioning that recent scholarship has advanced the conceptual understanding of marginality by distinguishing between marginality as a condition and marginalization as a process [21]. While marginality refers to a state of being peripheral within a system, marginalization emphasizes the dynamic social, economic, and political processes through which regions are actively produced as peripheral [22]. This distinction is crucial for understanding inter-provincial border regions, whose marginality is not a natural given but an outcome of ongoing institutional arrangements, policy decisions, and power relations. Furthermore, the relationship between marginality and the core–periphery model has been critically re-examined [23]. Rather than a static binary opposition of “good” (core) and “bad” (periphery), contemporary scholarship emphasizes the relational and dynamic nature of core–periphery structures: peripheries can become centers, and centers can become peripheries, through changing economic and political configurations [20]. This perspective resonates with the ‘relational turn’ in economic geography, which conceptualizes regions not as bounded containers but as nodes within networks of flows and relations. The emerging discourse on ‘left behind places’ has further enriched marginality studies by foregrounding the multidimensionality of geographical disadvantage [24]. ‘Left behind places’ are characterized not only by economic deprivation—such as low income, productivity, and employment—but also by social disadvantage, restricted access to public services, and poor environmental quality [8]. This multidimensional framing aligns closely with our study’s production–livelihood–ecology approach. Moreover, scholars have emphasized that ‘left behind’ conditions are self-perpetuating and path-dependent: once established, geographical inequalities tend to persist and even widen, as lock-in effects and cumulative causation reinforce initial disadvantages [25].

In a word, marginality theory provides a robust framework for understanding spatial disparities in regional development. Its core implications can be summarized in three aspects. First, it presupposes structural spatial imbalances: any economic system, regardless of scale, can be conceptualized as a continuum ranging from core to periphery, with a region’s position along this spectrum determining the degree of its marginality. Second, marginality is not driven by a single factor but results from the interaction of multiple organizational systems—such as economic structures, administrative arrangements, and socio-cultural dynamics. When these systems align and reinforce one another, regional integration is enhanced and marginality diminishes; when they conflict, fragmentation intensifies and marginalization deepens. Third, marginality is not merely a qualitative construct but a measurable and comparable condition [26], enabling rigorous empirical analysis.

2.2. How to Measure It

Research on the measurement of regional marginality has evolved along three main methodological trajectories, reflecting a shift from qualitative description to quantitative analysis and, more recently, to integrated approaches. First, qualitative approaches emphasize theoretical development and contextual understanding. Scholars clarify conceptual boundaries, distinguish types and characteristics of marginality [27–29] and employ methods such as expert interviews, mental mapping, and participatory observation to investigate specific regions. These approaches help identify key constraints, extract core drivers of marginalization, and inform context-sensitive policy responses [30–34].

Second, quantitative approaches—now dominant in the field—seek to standardize the measurement and spatial comparison of marginality through the construction of indicator systems. These systems typically encompass three dimensions: social (e.g., institutional quality, demographic structure, education levels) [35–37], economic (e.g., economic output, industrial structure, income inequality), and environmental (e.g., ecological vulnerability, resource accessibility) [38].

Third, to overcome the limitations of single-method approaches, recent studies have increasingly adopted integrated methodologies. Qualitative analysis is often used to identify context-specific dimensions, which are then operationalized into structured indicator systems [31]. Advanced research further combines composite marginality indices with spatial analytical tools, such as accessibility measures and locational metrics, to produce marginality hotspot maps. This enables both visualization and deeper analysis of spatial patterns and the underlying mechanisms driving marginalization [31,38].

Despite substantial progress in marginality research, its systematic application to the analysis of China's inter-provincial border regions remains limited. Existing measurement frameworks, while methodologically robust, tend to emphasize general applicability at the expense of contextual specificity. As a result, they often fail to capture the unique forms of marginality arising from the interaction between administrative boundaries and geographical location in IPBRs. Accordingly, this study seeks to build upon and extend existing theoretical and methodological foundations by developing a multidimensional measurement framework tailored to the context of China's inter-provincial border regions. This framework aims to provide a solid analytical basis for examining how marginality constrains and shapes pathways of collaborative development.

3. Research Approach and Indicator System

3.1. Basic Thoughts and Methods

3.1.1. The Basic Thoughts of Measurement

With the relational turn in economic geography, the concept of scale has been redefined as a socio-political construct, making it an increasingly important theoretical lens for understanding regional spatial reconfiguration [39]. From this perspective, geographical scales are not fixed containers but dynamic outcomes shaped and contested through power relations, institutional arrangements, and capital flows. For IPBRs, their marginality arises from the superimposition and interaction of political and economic systems operating at multiple scales (provincial, municipal, and county levels). The segmentation of administrative boundaries not only results in policy fragmentation but, reinforced by local protectionism, also limits the ability of border regions to absorb spillover effects from central cities [40]. Instead, it may intensify factor outflows and lock these regions into a scale trap.

Within this theoretical framework, this study proposes an integrative analytical model that conceptualizes the marginality of IPBRs as a composite spatial condition shaped by multiple dimensions, scales, and centers. Building on the approach outlined by Petrov [26],

we adopt the premise that regional spatial structures are inherently nested and dynamic core–periphery continua. These structures coexist and interact across multiple analytical dimensions, spatial scales, and functional domains, collectively producing the complex and multidimensional marginality of border regions.

1. Multidimensional Analysis: Identifying Marginal Multidimensional Compositions

A multidimensional perspective emphasizes that marginal spatial structures evolve across different analytical domains, each of which may exhibit distinct core–periphery patterns. A region may be economically peripheral while occupying a relatively central position in ecological or social terms, thereby revealing potential pathways for coordinated development. To capture this complexity, this study constructs a measurement framework based on three core dimensions: production, livelihood, and ecology. This approach moves beyond reliance on single economic indicators and instead highlights the relative and uneven nature of marginality across different functional domains, enabling a more comprehensive characterization of the multidimensional vulnerabilities of IPBRs.

2. Multi-scale Perspective: Analyzing the Hierarchical Embedding of Marginality

A multi-scalar perspective underscores that marginality is produced and reinforced across different spatial levels. For IPBRs, marginality is shaped at least at two key scales. First, at the macro level, border regions occupy peripheral positions within broader regional cooperation frameworks, such as adjacent metropolitan areas or urban agglomerations. Second, at the meso level, marginality is reflected in the internal spatial structure of border regions, particularly in the developmental gradients and connectivity patterns among county-level units. This study adopts a cross-scale analytical approach to examine how the structural characteristics of higher-level regional systems are transmitted downward, thereby influencing the overall marginality of border regions.

3. Multi-center cognition: Deconstructing the internal heterogeneity of marginality

The multi-center perspective highlights that even within a single dimension or scale, multiple centers may coexist. Regions often contain several heterogeneous functional centers or growth poles, each associated with its own peripheral areas, forming complex and layered spatial structures. In this study, multi-center characteristics are indirectly identified through multidimensional and multi-scalar measurement results. By examining the spatial misalignment and overlap of core–periphery structures across different dimensions and scales, the analysis reveals patterns such as the decentralized distribution of resources, fragmented growth drivers, and the coexistence of cooperative and competitive dynamics among multiple centers.

3.1.2. The Main Methods

Our study is grounded in the core premise that marginality fundamentally represents a relative gap to the core within a given reference system. The measurement procedure is as follows.

Firstly, the entropy-weighted TOPSIS method is employed to calculate the comprehensive development index (C_i value) for each county within its respective metropolitan region across three dimensions: production, livelihood, and ecology. This index reflects the relative position of each county compared to other units within the same metropolitan system for each dimension.

The specific computational steps are as follows. First, the original indicator data were dimensionless normalized to construct a normalized decision matrix. Second, the entropy weight method was applied to determine objective weights for each indicator, and a weighted normalized decision matrix was constructed. Third, the positive ideal solution (S_j^+) and negative ideal solution (S_j^-) were identified. Fourth, the Euclidean distances

between each county's indicator vector and both the positive and negative ideal solutions were calculated. Finally, the comprehensive development index (C_i) for each county was computed, where a larger C_i value indicates better development performance.

Secondly, for each dimension, the highest C_i value observed among all units within the metropolitan region is taken as the benchmark representing the ideal core state. The marginality of a given county in a specific dimension is then defined as the difference between its C_i value and this benchmark.

$$M_b = \sum \left(W_{max} \times V_{max} \times \frac{D_{min}}{D_{maxb}} - W_b \times V_b \times \frac{D_{min}}{D_{maxb}} \right) \quad (1)$$

where:

M_b : marginality value of each county within the provincial metropolitan system;

W_{max} : weight of the county with the maximum indicator value (i.e., the benchmark core county), derived from the entropy-weighted TOPSIS procedure.

W_b : weight of the county b ;

V_{max} : comprehensive development index (C_i value) of the benchmark core county.

V_b : comprehensive development index of county b ;

D_{min} : shortest distance from the benchmark core county to any surrounding county within the same metropolitan region (used to normalize distance effects);

D_{maxb} : distance from the benchmark core county to county b .

This formulation is grounded in four theoretical premises. First, following core–periphery theory, marginality is conceptualised as a relational gap between a given county and the dominant core within the same metropolitan system. The term V_{max} therefore serves as the reference point, while V_b captures the absolute developmental distance from that core. Second, spatial friction is explicitly incorporated through the distance ratio D_{min}/D_{maxb} . This ratio reflects the idea that the influence of a core decays with geographical distance, and that counties closer to the core should, *ceteris paribus*, exhibit lower marginality. By normalising with D_{min} , the measure accounts for the spatial configuration of the entire metropolitan region rather than applying a generic distance decay parameter. Third, the entropy-weighted TOPSIS weights W_{max} and W_b ensure that each county's performance is evaluated across multiple indicators (production, livelihood, ecology) in a data-driven manner, avoiding arbitrary weighting. The product $W \times V$ thus represents a multi-dimensional, objective composite of development status. Fourth, the summation operator aggregates differences across all dimensions, reflecting the multidimensional nature of marginality: a county may be close to the core in one dimension but far in another, and the total marginality captures the cumulative disadvantage. Together, these features make Equation (1) a theoretically coherent and empirically operational measure of relative, distance-sensitive, multidimensional marginality. The methodological meaning of each component of the equation will be clarified as follows:

1. Benchmark using the maximum C_i value (V_{max}): Following core–periphery theory, marginality must be defined relative to an explicit reference point. The highest C_i value within a metropolitan region is selected as the benchmark because it represents the attainable “best practice” or frontier in that dimension. Using the maximum rather than the mean or median ensures that marginality reflects a strict deficit relative to the leading performer, which is conceptually appropriate for identifying “left-behind” areas. This choice also makes the measure sensitive to improvements in the core. In the event that the frontier progresses, the marginality of all other counties undergoes an automatic adjustment, thereby capturing the dynamic characteristics of peripheralization.

2. Weights W_{max} and W_b : These are objective weights derived from the entropy-weighted TOPSIS procedure. They reflect the contribution of each underlying indicator to the overall development index. Multiplying V by W yields a weighted performance score that accounts not only for the absolute level of development but also for its structural composition. Two counties with identical V could have different W because their strengths lie in different indicators (e.g., one in industry, the other in agriculture). Thus, the difference $W_{max}V_{max} - W_bV_b$ captures structural disadvantage beyond simple output gaps.
3. Distance-based normalisation D_{min}/D_{maxb} : This component operationalises distance decay. D_{maxb} is the spatial distance from the benchmark core to county, which is the shortest distance from that core to any of its neighbouring counties. The ratio D_{min}/D_{maxb} normalises absolute distances to make them comparable across metropolitan regions of different sizes. It equals 1 for the core's nearest neighbours and decreases towards 0 as distance grows. Multiplying the performance gap by this ratio introduces a spatial friction penalty: counties farther from the core are considered more marginal even if their development indices are not much lower, because they suffer from weaker accessibility, lower spillovers, and higher transaction costs. This captures the siphoning effect of metropolitan cores on peripheral border regions.
4. Summation over dimensions: Marginality is inherently multidimensional. A county may be close to the core in ecology but far in production or livelihood. Summing the dimension-specific differences yields a composite index that reflects cumulative disadvantage across all three functional domains, preventing the measure from being dominated by a single dimension and aligning with the holistic view of regional development.

3.2. The Index System of Marginality Measurement from the Three-Dimensional Perspectives of Production, Livelihood, and Ecology

The production dimension evaluates a region's capacity for economic development, encompassing both current performance and future potential. Current vitality is shaped by factors such as total economic output, household consumption, agricultural productivity, and industrial structure. In the Central Plains context, grain production is a key indicator of agricultural capacity. Future potential is closely linked to government investment, which reflects both the effectiveness of past investments and the scale of current funding. Labor is a fundamental driver of economic value creation: a large population not only ensures an ample labor supply but also generates diversified consumption demand, thereby supporting broader economic development (Table 1).

The livelihood dimension assesses the extent to which a region satisfies diverse human needs within its living environment, encompassing both material and non-material aspects. This includes three components: basic security, convenience, and comfort. Basic security forms the foundation of well-being and includes income, healthcare, education, and employment. Convenience relates to infrastructure and service accessibility, such as transportation, energy supply, and communication systems. Comfort reflects higher-level living conditions, including cultural amenities and environmental quality (Table 2).

The ecological dimension evaluates both the stock of ecological resources and the value of ecosystem services. Ecological resources reflect the overall condition of the natural environment and include water resources, forest land, grassland, and habitat quality. Ecosystem service value represents the functional benefits provided by ecosystems. As cultural services are incorporated within the livelihood dimension, this analysis focuses on three categories: provisioning, regulating, and supporting services (Table 3).

Table 1. Production Dimension Index System.

Sub-Dimensions	Index Layer	Criteria Layer (Units)	Data Sources
Production basis	Economic development level (X_1)	GDP (10^8 CNY)	<i>Statistical Yearbooks of Henan, Hubei, and Anhui Provinces (2001, 2011, 2022); China County Statistical Yearbook (2001, 2011, 2022); Yearbook of County Construction in China (2001, 2011, 2022).</i>
	Standards of consumption (X_2)	Total retail sales of consumer goods (10^4 CNY)	
	Crops Production Level (X_3)	The ratio of cultivated land area in a region to the total area of the region (%)	
	Industry Structure (X_4)	Output value of the primary industry (10^4 CNY)	
		Added value of the secondary industry (10^4 CNY)	
		Added value of the tertiary industry (10^4 CNY)	
Development potential	Economic potential (X_5)	Regional local fiscal revenue (10^4 CNY)	
		Year-on-year growth rate of fixed assets investment (%)	
	Population Potential (X_6)	Permanent resident population (10^4 CNY)	

Table 2. Livelihood Dimension Index System.

Sub-Dimensions	Index Layer	Criteria Layer (Units)	Data Sources
Livelihood security	Consumption Protection (X_7)	Urban dweller disposable income (1 CNY)	<i>Statistical Yearbooks of Henan, Hubei, and Anhui Provinces (2001, 2011, 2022); China County Statistical Yearbook (2001, 2011, 2022); Yearbook of County Construction in China (2001, 2011, 2022).</i>
		Country dweller disposable income (1 CNY)	
	Health Insurance (X_8)	Number of medical beds (beds per 10,000 persons)	
	Education Guarantee (X_9)	Basic education Number of schools (count)	
	Employment Security (X_{10})	Township registration jobless rate (%)	
Convenience degree	Convenient travel (X_{11})	Highway density (km/km^2)	The road network data for 2021 was downloaded from OpenStreetMap, while the data for 2010 and 2000 were sourced from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences: https://www.resdc.cn/Datalist1.aspx?FieldTypeID=7,1 (accessed on 6 January 2025)
		Railway density (km/km^2)	

Table 2. Cont.

Sub-Dimensions	Index Layer	Criteria Layer (Units)	Data Sources
Convenience degree	Energy Convenience (X_{12})	Water access rate (%)	Statistical Yearbooks of Henan, Hubei, and Anhui Provinces (2001, 2011, 2022); China County Statistical Yearbook (2001, 2011, 2022); Yearbook of County Construction in China (2001, 2011, 2022).
		Gas penetration rate (%)	
	Convenient communication (X_{13})	Postage business volume (10^4 CNY)	
Comfort level	Cultural environment Comfort (X_{14})	Rate of harmless disposal of domestic waste (%)	The 30 m annual land cover datasets and its dynamics in China from 1985 to 2023 (https://zenodo.org/records/12779975) (accessed on 6 January 2025) [41] and adopt the calculation method developed by Xie Gaodi et al. [42].
		Sewage disposal concentration ratio (%)	
		Number of books in the collection per 10,000 people (volumes)	
	Natural environment Comfort (X_{15})	Per capita park area green area (m^2)	
		Green coverage rate of built-up area (%)	
		The cultural service value of regional ecosystem (ecosystem service value equivalent)	
		PM2.5 ($\mu g/m^3$)	The atmospheric composition analysis team at Dalhousie University observed and calculated the China PM2.5 emissions.

Table 3. Ecological Dimension Index System.

Sub-Dimensions	Index Layer	Criteria Layer (Ecosystem Service Value Equivalent)	Data Sources
Ecosystem service value	Supply Service (X_{16})	Food production Raw material production Water supply	The 30 m annual land cover datasets and its dynamics in China from 1985 to 2023 (https://zenodo.org/records/12779975) [41] and adopt the calculation method developed by Xie Gaodi et al. [42].
	Regulation services (X_{17})	Gas regulation Climatic regulation Environmental purification Hydrological regulation	
	Support Services (X_{18})	Nutrient cycling Maintain the soil Biodiversity	
Biological resources Ownership	Water abundance (X_{19}) Forest coverage (X_{20}) Grassland coverage (X_{21}) Habitat quality (X_{22})	Water coverage Forest coverage Grassland coverage Habitat quality index	

3.3. Overview of the Study Area

This study focuses on the Hubei–Henan–Anhui inter-provincial border region (H-H-A IPBRs), with its spatial scope defined according to the *Dabie Mountain Revolutionary Base Revitalization and Development Plan (2015–2020)*. The study area includes 10 cities and

61 districts/counties across Henan Province, Anhui Province, and Hubei Province (Figure 1). These areas are situated within three major metropolitan systems: the Zhengzhou Metropolitan Region, Wuhan Metropolitan Region, and Hefei Metropolitan Region. As peripheral zones of these metropolitan regions, the H-H-A IPBRs have long experienced economic underdevelopment, largely due to the siphoning effects of central cities. Although the region's GDP grew steadily between 2000 and 2021, it continued to lag significantly behind the three metropolitan regions, with the development gap widening over time (Figure 2).

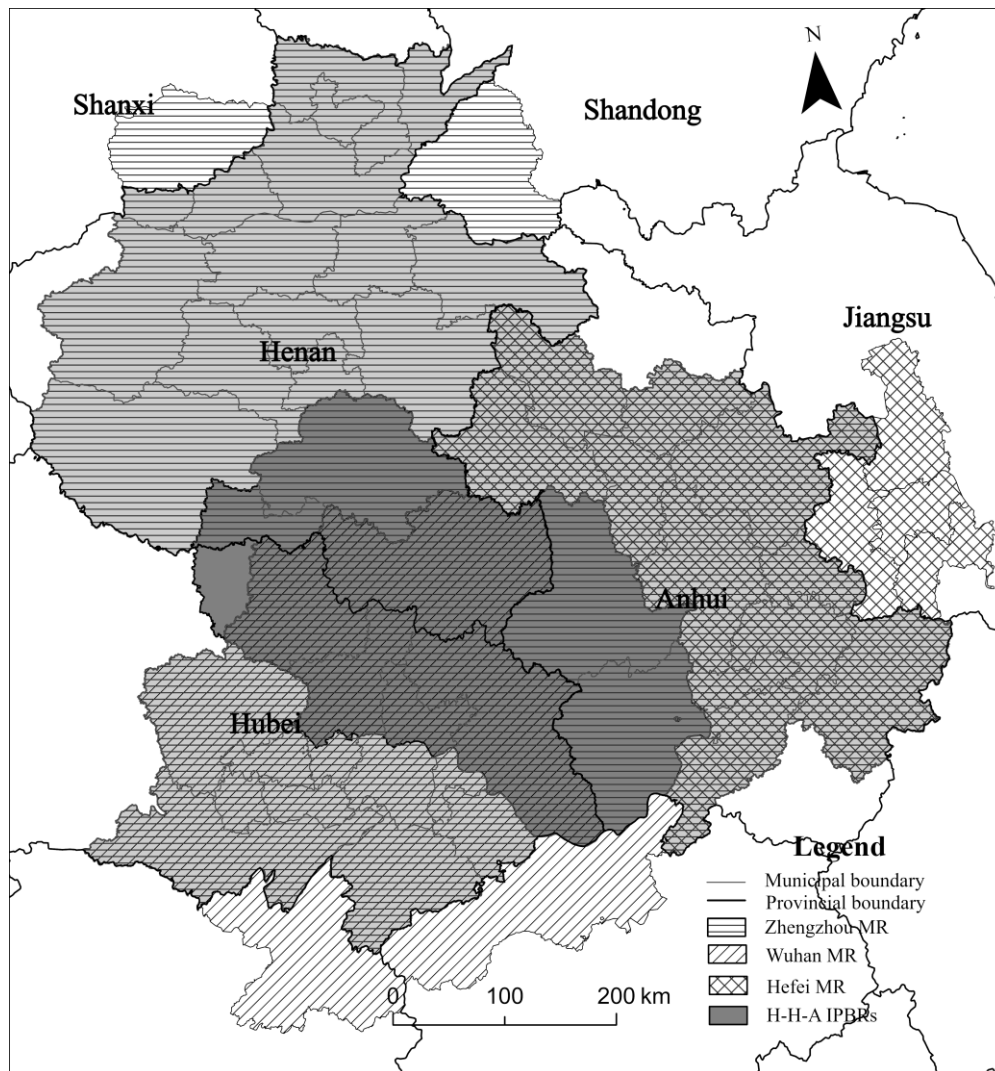


Figure 1. Location map of IPBRs across Hubei, Henan and Anhui provinces (Source: Authors' own creation).

The years 2000, 2010, and 2021 were selected as temporal cut-off points to capture distinct phases of regional development under the influence of metropolitan (urban agglomeration) strategies in China, while ensuring data consistency and analytical comparability. 2000 serves as the baseline year, marking the start of the 21st century and predating the large-scale implementation of metropolitan strategies in Henan, Hubei, and Anhui provinces. By 2010, key metropolitan strategies had been formally launched: the Wuhan Metropolitan Region was approved as a national comprehensive reform pilot zone in December 2007, and the Anhui Provincial Government issued the Development Plan for the Hefei Metropolitan Economic Circle (2007–2015) in 2008; the Zhengzhou Metropolitan Region also gained significant momentum during this period. Thus, 2010 allows us to

observe the initial effects of these strategies on the spatial reconfiguration of the border region. 2021 is the most recent year for which complete and consistent data are available across all three provinces, capturing the medium to long-term outcomes of metropolitan development and aligning with the end of China's 13th Five-Year Plan. All indicators are derived from consistent data sources using identical definitions and measurement protocols; the entropy-weighted TOPSIS method standardises socio-economic indicators before aggregation, and spatial analysis employs the same parameters across periods, ensuring that observed changes reflect real spatial dynamics rather than methodological artefacts. The three-time-point design enables the study to trace the evolution of marginality before and after the implementation of metropolitan strategies, identify dimension-specific temporal trajectories, assess the intensification of core-periphery polarisation over two decades, and detect path-dependent “lock-in” effects in the border region.

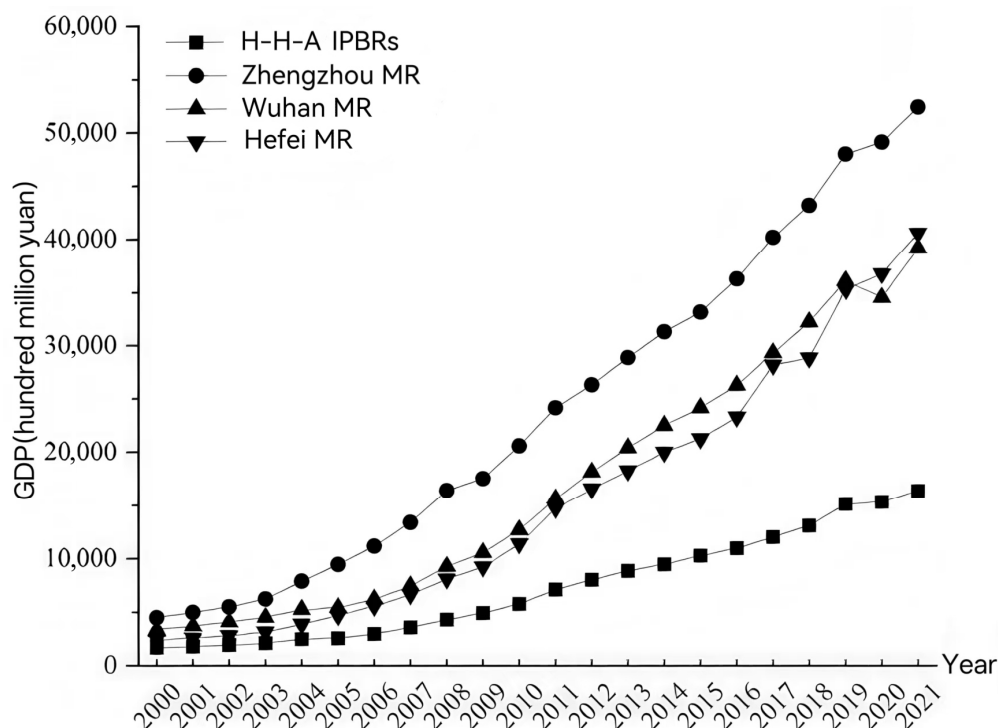


Figure 2. GDP Comparison Chart among H-H-A IPBRs, Zhengzhou MR, Wuhan MR, and Hefei MR (Source: Authors' own creation).

4. Empirical Results

4.1. Analysis of Temporal–Spatial Variations in IPBRs

Based on Equation (1), marginality indices were calculated for the years 2000, 2010, and 2021. Spatial analysis was performed using ArcGIS Pro 3.0. First, Global Moran's I with an inverse distance-based spatial weights matrix (threshold distance: 49,890 m) was applied to examine spatial clustering patterns of county-level marginality values across three time periods (2000, 2010, 2021). All Moran's I values were positive and significant at the 1% level, confirming strong spatial dependence. Subsequently, Ordinary Kriging with a stable semivariogram model was employed to interpolate these values into continuous raster surfaces. The interpolation was validated through leave-one-out cross-validation. To reveal detailed core-periphery spatial structures, a 32-level continuous classification was applied to the interpolated surfaces for production, livelihood, and ecological dimensions. The leave-one-out cross-validation of the Ordinary Kriging interpolation yielded a root-mean-square error (RMSE) of less than 0.05 for all three dimensions and years, indicating

satisfactory predictive performance. As a further robustness check, we also performed interpolation using Empirical Bayesian Kriging and Inverse Distance Weighting; the spatial patterns of core-periphery structures were visually consistent across methods, with the Pearson correlation coefficient between the original Ordinary Kriging surfaces and the alternative interpolations exceeding 0.89 in all cases.

4.1.1. Production Dimension: Consolidation of Marginal Patterns and Contraction of Scope

From the perspective of metropolitan regions, low-marginality areas (i.e., core production zones) exhibited persistent spatial clustering, gradually forming a pronounced core-periphery structure centered on provincial capitals between 2000 and 2021. In 2000, these core zones appeared as relatively contiguous patches within the Zhengzhou Metropolitan Region—primarily between Luoyang and Zhengzhou—and within the Wuhan Metropolitan Region, particularly around Xiantao, Tianmen, Qianjiang, and Zaoyang. By 2010, these areas had significantly contracted toward the provincial capitals—Zhengzhou, Wuhan, and Hefei—forming concentric spatial patterns. By 2021, this polarization intensified: the core areas of Zhengzhou and Hefei became highly concentrated and point-like, while Wuhan’s core extended in an elliptical form along Tianmen and Xiantao. Other low-marginality zones became increasingly fragmented, indicating the full establishment of a hierarchical spatial structure centered on provincial capitals, with border regions occupying peripheral positions.

Within the H-H-A IPBRs, production marginality remained relatively stable over the past two decades, demonstrating strong geographical inertia. However, its internal spatial structure underwent substantial reconfiguration. In 2000, low-marginality zones formed a linear belt from Tanghe County to Xinzhou District. Over time, these areas increasingly concentrated in Xinzhou and Huangpi districts under Wuhan’s jurisdiction. By 2021, these two districts had emerged as the sole production cores within the border region. This trajectory reflects the strong siphoning effect of the Wuhan core, whereby production resources are continuously absorbed and reorganized, leading to the formation of a dependent secondary core near administrative boundaries while reinforcing marginality in other border counties (Figure 3).

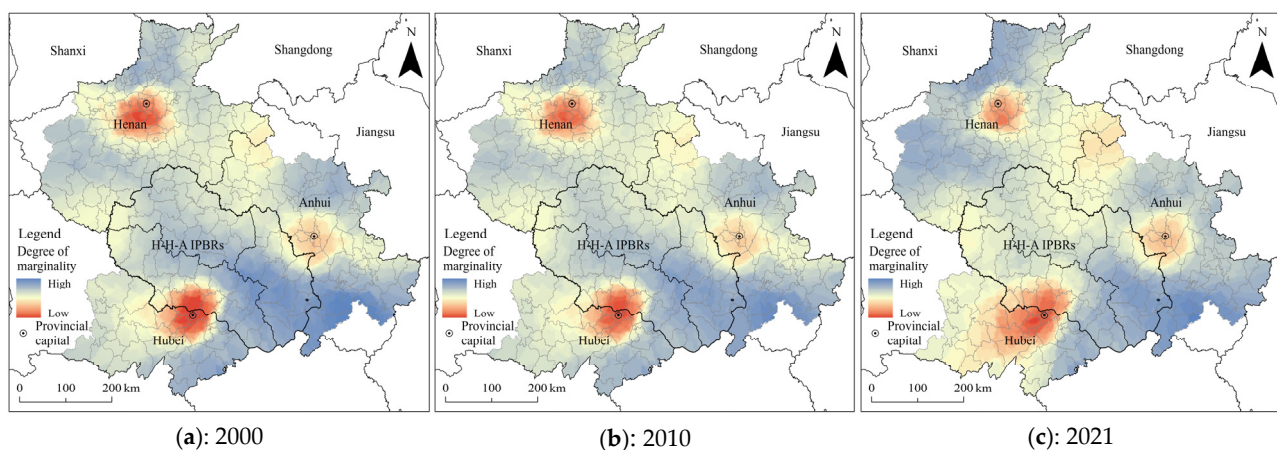


Figure 3. Core-periphery spatial structure of production dimension in 2000, 2010 and 2021 (Source: Authors’ own creation).

4.1.2. Livelihood Dimensions: Increased Marginalization and Core Area Sharpness

In the livelihood dimension, low-marginality areas within metropolitan regions evolved from clustered distributions to dispersed clusters and ultimately to highly concentrated single-core structures, accompanied by a marked reduction in spatial extent. In

2000, such areas were concentrated in Wuhan, Xiantao, and Suizhou. By 2010, they had consolidated into a single core centered on Wuhan. By 2021, the pattern further evolved into a dual-core structure anchored by Wuhan and Zhengzhou. This trend indicates an accelerating concentration of high-quality public services and living resources in leading metropolitan centers.

Within the H-H-A IPBRs, the spatial evolution of livelihood marginality exhibits a clear trend of polarization and core concentration. In 2000, low-marginality zones (i.e., areas with better livelihood conditions) were scattered across the border region, forming several small patches without a dominant cluster. A relatively contiguous low-marginality belt could be observed extending from the northwestern part (e.g., Tanghe County) toward the southeastern area, but no single center had yet emerged. By 2010, these zones had noticeably shifted eastward and southward, beginning to concentrate in the northeastern part of the border region, particularly in the vicinity of Huangpi and Xinzhou districts under Wuhan's jurisdiction. By 2021, the concentration process had intensified markedly: low-marginality areas became highly clustered in three adjacent districts—Huangpi, Xinzhou, and Xiaonan District of Xiaogan—which together formed the primary livelihood core of the entire border region. Meanwhile, the vast majority of other counties experienced deepening marginalization, reflected in widening disparities in public service accessibility, infrastructure quality, and living standards. This spatial trajectory underscores the strong siphoning effect of the Wuhan metropolitan core, which continuously absorbs high-quality livelihood resources from peripheral counties, leading to the formation of a dependent sub-center near the administrative boundary while reinforcing the marginality of more distant areas (Figure 4).

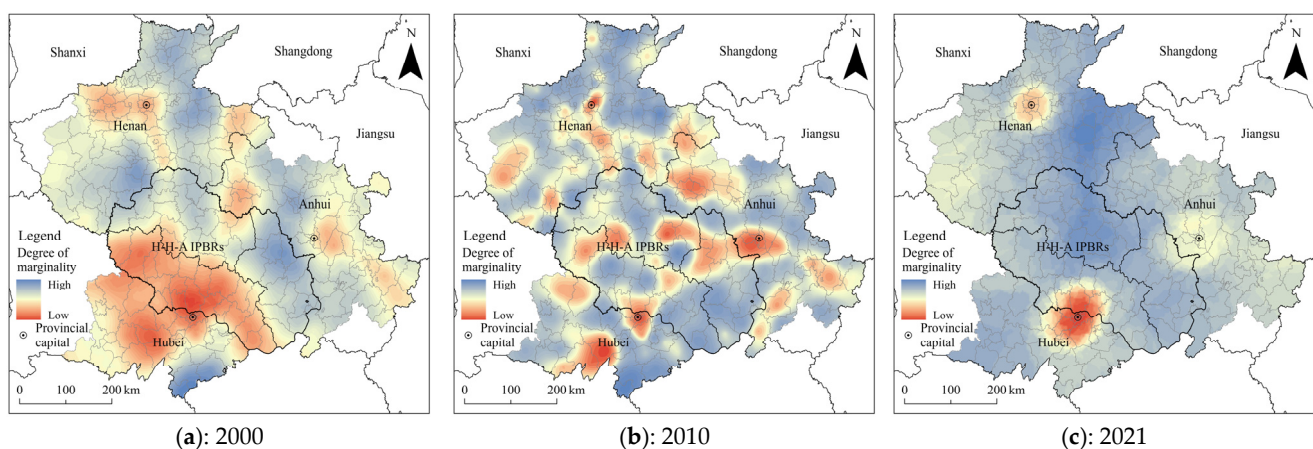


Figure 4. Core-periphery spatial structure of livelihood dimension in 2000, 2010 and 2021 (Source: Authors' own creation).

4.1.3. Ecological Dimension: Core Area Stability and Functional Marginality

In contrast to the production and livelihood dimensions, ecological marginality exhibited remarkable spatial stability throughout the study period. At both metropolitan and transitional scales, low-marginality ecological zones (i.e., ecological cores) consistently clustered in mountainous areas, including the Funiu, Tongbai, and Dabie mountain ranges, while high-marginality zones were concentrated in the Huang-Huai-Hai Plain. Within transitional zones, a stable dual-core ecological structure emerged, centered on the Tongbai Mountains (Suizhou-Nanyang border) and the Dabie Mountains (Lu'an-Anqing-Huanggang corridor).

Within the H-H-A IPBRs, ecological marginality exhibits a fundamentally different spatial logic from the production and livelihood dimensions. Low-marginality zones (i.e.,

ecological core areas) have remained remarkably stable throughout the study period from 2000 to 2021. These cores consistently cluster in two mountainous regions: the Tongbai Mountains, located along the border between Suizhou (Hubei) and Nanyang (Henan), and the Dabie Mountains, spanning the Lu'an-Anqing-Huanggang corridor across Anhui and Hubei. The spatial extent and shape of these ecological cores show almost no change over the two decades, reflecting the strong dependence of ecological functions on natural geographical conditions and the relative insensitivity of ecosystem service provision to short-term socioeconomic fluctuations. Importantly, there is a pronounced spatial mismatch between ecological centrality and socioeconomic development: most counties that serve as ecological cores (e.g., those in the Dabie Mountains) are simultaneously highly marginalized in production and livelihood dimensions. This structural tension reveals a critical challenge for inter-provincial border regions: ecologically valuable areas bear substantial conservation responsibilities—providing water retention, biodiversity maintenance, and climate regulation services—yet lack corresponding development opportunities, infrastructure investment, or ecological compensation mechanisms. This pattern highlights the multi-functional and often contradictory nature of marginality in border regions, where ecological centrality and socioeconomic peripherality coexist as two sides of the same coin (Figure 5).

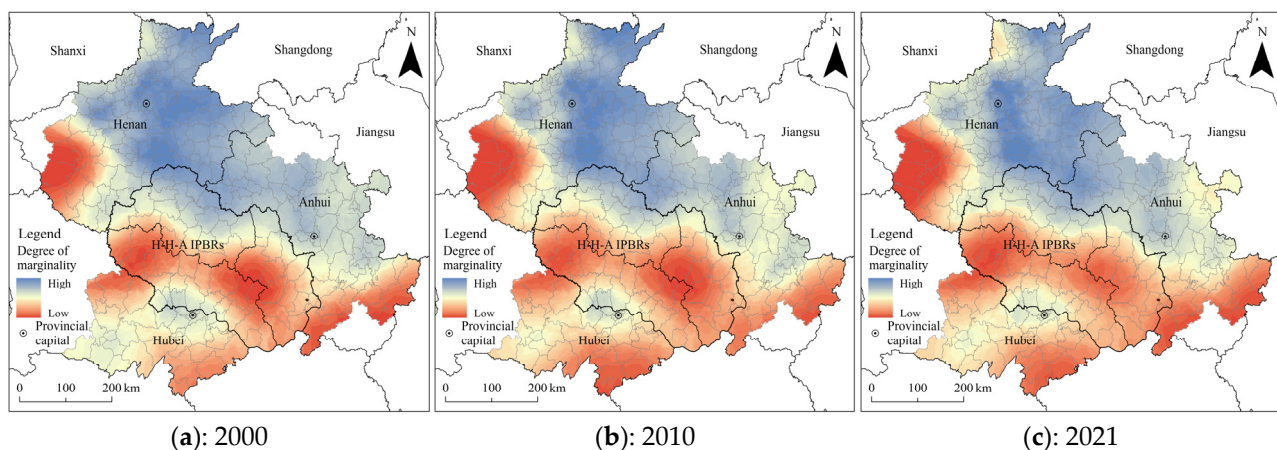


Figure 5. Core-periphery spatial structure of ecological dimension in 2000, 2010 and 2021 (Source: Authors' own creation).

4.2. Mechanism Analysis of Marginalization in IPBRs

To examine the driving forces behind marginality patterns, GeoDetector (GeoDetector Software in Excel) was employed to analyze influencing factors across the three dimensions for 2000, 2010, and 2021. The analytical procedure was as follows. First, C_i values for each county were calculated using the entropy-weighted TOPSIS method. Second, all indicators (X_1 – X_{22}) were classified into five categories using the natural breaks method in ArcGIS Pro 3.0. This method was selected because it minimizes within-class variance while maximizing between-class differences, thereby respecting the inherent statistical distribution of the data and avoiding the arbitrary imposition of equal frequencies or equal intervals. The strong spatial autocorrelation detected in preliminary Moran's I analysis confirms that our data exhibit genuine spatial structure, which Natural Breaks is designed to preserve. While this approach may result in unequal class sizes, it ensures that class boundaries correspond to genuine discontinuities in the data, enhancing the interpretability of subsequent driver analysis. Third, categorical values were assigned accordingly (Level 1 = 1, Level 2 = 2, etc.). Finally, the C_i values and corresponding classified indicators were input into GeoDetector to identify the key driving factors for each dimension. The

factor detector quantifies explanatory power via the q -statistic, with significance tested using the non-central F -test ($p < 0.05$). The analysis includes 61 county samples, which exceeds the minimum recommended sample size of 15–25 for five-strata factors. The method assumes spatial heterogeneity, which is supported by significant Moran's I results (Section 4.1). Continuous indicators were discretized into five strata using Natural Breaks; sensitivity analyses confirmed robustness of factor rankings. Limitations include sensitivity to discretization (mitigated by sensitivity analysis) and scale dependence at the county level.

4.2.1. Production Dimension

The results (Table 4) indicate that economic level (X_1) and industrial structure (X_4) consistently served as the dominant drivers of spatial differentiation in production marginality from 2000 to 2021, with q -values exceeding those of other factors. In 2000, both factors exhibited comparable explanatory power, highlighting the importance of economic scale and industrial composition in the early stage. By 2010, the explanatory power of industrial structure had increased to match that of economic level, reflecting the growing role of industrial upgrading. Although their q -values declined slightly by 2021, their dominance persisted, with economic level maintaining a marginal lead.

The influence of economic potential (X_5) increased significantly after 2010, stabilizing as the third most important factor, suggesting that government-led investment has become increasingly influential in shaping regional production patterns. In contrast, consumption level (X_2) and population potential (X_6) showed relatively weak and fluctuating effects, while crop production level (X_3) consistently exhibited the lowest explanatory power. This underscores the declining role of agriculture in overall economic structure and its limited contribution to spatial differentiation. Overall, the evolution of production marginality reflects a transition from dominance by traditional economic scale toward a more complex mechanism driven jointly by industrial restructuring and state-led investment.

Table 4. Factor Detection Results of Production Dimension.

Year	Detectable Factor	X_1	X_2	X_3	X_4	X_5	X_6
2000	q statistic	0.83	0.45	0.14	0.82	0.42	0.44
	p value	0.00	0.00	0.00	0.00	0.00	0.00
2010	q statistic	0.84	0.53	0.04	0.84	0.56	0.31
	p value	0.00	0.00	0.03	0.00	0.00	0.00
2021	q statistic	0.72	0.48	0.11	0.66	0.49	0.57
	p value	0.00	0.00	0.00	0.00	0.00	0.00

4.2.2. Livelihood Dimension

The driving factors shaping marginalization in the livelihood dimension exhibit clear cyclical patterns (Table 5). In 2000, healthcare security (X_8) was the primary driver, followed by educational support (X_9) and communication convenience (X_{13}). This reflects the fact that disparities in basic public services, particularly healthcare, education, and communication infrastructure, were the principal determinants of quality-of-life differences at the turn of the century. By 2010, cultural environment quality (X_{14}) had replaced healthcare security as the dominant explanatory factor. This shift indicates that, as basic services and infrastructure improved, residents' needs evolved toward higher-order concerns, with cultural amenities and urban environmental quality—often described as soft livability factors—becoming key drivers of spatial differentiation. By 2021, travel convenience (X_{11}) had emerged as the most influential factor, with a q -value far exceeding those of other variables. At the same time, consumption security (X_7) rose from relative insignificance to

the second most important driver. These changes reflect the spatiotemporal compression effects associated with rapid transportation development, particularly high-speed rail and highway networks, as well as widening disparities in consumption capacity amid rising incomes. Together, these factors have become central in defining contemporary core–periphery patterns in living conditions.

This evolutionary trajectory clearly illustrates the upgrading of residents’ needs in China’s inter-provincial border regions, from basic survival and security, to quality of life, and ultimately to efficient mobility and consumption capacity, along with a corresponding transformation in the underlying drivers of spatial differentiation in living conditions.

Table 5. Factor Detection Results of Life Dimensions.

Year	Detectable Factor	X ₇	X ₈	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅
2000	<i>q</i> statistic	0.05	0.21	0.19	0.05	0.09	0.04	0.19	0.11	0.18
	<i>p</i> value	0.63	0.03	0.00	0.02	0.05	0.03	0.00	0.06	0.00
2010	<i>q</i> statistic	0.06	0.26	0.06	0.08	0.09	0.03	0.16	0.38	0.24
	<i>p</i> value	0.24	0.00	0.07	0.01	0.05	0.12	0.00	0.00	0.00
2021	<i>q</i> statistic	0.33	0.23	0.08	0.06	0.50	0.07	0.24	0.32	0.08
	<i>p</i> value	0.00	0.00	0.03	0.08	0.00	0.10	0.00	0.00	0.41

4.2.3. Ecological Dimension

The driving mechanisms of marginality in the ecological dimension remain comparatively stable (Table 6). Supporting services (X₁₈) and habitat quality (X₂₂) consistently exhibit the strongest explanatory power across the study period. In 2000, both factors were equally influential; by 2010, the importance of supporting services increased slightly; and by 2021, habitat quality (X₂₂) had risen significantly ($q = 0.81$), becoming the dominant factor. Regulating services (X₁₇) and woodland coverage (X₂₀) also maintained relatively strong explanatory power throughout.

These findings confirm that ecological marginality is fundamentally rooted in ecosystem integrity and the strength of ecosystem service functions. The increasing importance of habitat quality suggests a shift in ecological priorities, from a focus on surface-level indicators such as vegetation coverage to deeper dimensions, including biodiversity and ecosystem health. In contrast, water resource availability (X₁₉) remained insignificant across all periods, likely due to the absence of extreme water scarcity in the study area. Provisioning services (X₁₆) and grassland coverage (X₂₁) also had relatively limited influence, consistent with the region’s agricultural–forestry dominance and the relatively small extent of grassland.

Table 6. Factor Analysis of Ecological Dimensions.

Year	Detectable Factor	X ₁₆	X ₁₇	X ₁₈	X ₁₉	X ₂₀	X ₂₁	X ₂₂
2000	<i>q</i> statistic	0.36	0.61	0.73	0.04	0.70	0.11	0.73
	<i>p</i> value	0.00	0.00	0.00	0.21	0.00	0.05	0.00
2010	<i>q</i> statistic	0.44	0.75	0.76	0.03	0.67	0.20	0.73
	<i>p</i> value	0.00	0.00	0.00	0.32	0.00	0.00	0.00
2021	<i>q</i> statistic	0.50	0.72	0.70	0.04	0.65	0.30	0.81
	<i>p</i> value	0.00	0.00	0.00	0.14	0.00	0.00	0.00

4.2.4. Robustness and Sensitivity Checks

To assess whether the discretization of continuous indicators into five strata using the natural breaks method affects the GeoDetector results, we repeated the factor detection

using four strata and six strata respectively. The q -values for the dominant drivers remained highly stable: for economic level (X_1) in the production dimension, the q -value averaged 0.79 for four strata, 0.80 for five strata (original), and 0.81 for six strata, with a coefficient of variation below 2%. Similarly, for travel convenience (X_{11}) in the livelihood dimension (2021), the q -value varied from 0.48 to 0.51 across the three stratification levels. The ranking of dominant drivers did not change in any dimension. These results confirm that the discretization choice does not materially influence the conclusions.

Furthermore, we tested the sensitivity of the spatial autocorrelation analysis to the specification of the spatial weights matrix. Using a k -nearest neighbour matrix ($k = 8$) and a queen contiguity matrix instead of the original inverse distance-based matrix yielded Moran's I values that remained positive and significant at the 1% level for all dimensions and years, with magnitudes differing by less than 10% from the original estimates. Thus, the reported spatial clustering patterns are robust to the choice of weight matrix.

5. Discussion

5.1. From Static Marginality to Dynamic Marginalization: Reconceptualizing Spatial Inequality in Border Regions

Our findings contribute to ongoing theoretical debates about the nature of geographical marginality. First, the distinct evolutionary trajectories across production, livelihood, and ecological dimensions challenge static, uni-dimensional conceptualizations of “left behind places” prevalent in policy discourse. While the European literature on peripheralization [22] emphasises multi-causal drivers including de-industrialisation and welfare state retrenchment, our results show that in the Chinese context, state-led investment and industrial structure have become increasingly dominant over time. Rather than a monolithic condition, marginality in inter-provincial border regions emerges as a multifaceted and dynamically evolving phenomenon, consistent with recent calls to understand “left behindness” as a process of peripheralization rather than a fixed state [43].

The production dimension's relative stability and geographical “lock-in” resonate with theories of path dependence in regional development [25], a pattern also observed in declining industrial regions of Europe and North America [9]. However, unlike many Western “left behind places” where path dependence results from market-driven de-industrialisation, the lock-in we observe is reinforced by administrative segmentation and local protectionism mechanisms specific to China's multi-level governance system. Once locked into particular economic structures and roles within the broader division of labor, border regions face significant barriers to “new path creation” [25]. This finding empirically demonstrates how initial disadvantages become self-perpetuating through cumulative causation mechanisms, aligning with arguments that ‘left behind’ conditions are unlikely to be self-correcting.

The livelihood dimension's dramatic temporal shifts—from healthcare to cultural amenities to transportation accessibility—provide rare empirical evidence for the evolving hierarchy of needs in peripheral regions. This trajectory mirrors the relational understanding that peripheries are not intrinsically disadvantaged but become so through changing relations with cores [44]. Crucially, our finding that travel convenience became the dominant driver in 2021 resonates with Oppido et al. [12] observation that contemporary marginalization is driven by aspatial factors such as digital divide and institutional capacity—but with a distinct Chinese nuance: improved transportation infrastructure does not automatically reduce marginality; rather, it can intensify competition for resources between cores and peripheries. As basic needs are met, new dimensions of inequality emerge, suggesting that marginality is continuously re-produced through shifting societal priorities and infrastructure investments rather than being a stable attribute of place.

5.2. *The Relational Construction of Multi-Scale Marginality: Beyond Absolute Conceptions of Space*

Our study reveals the relational construction of marginality across scales. The macro-level polarization toward provincial capitals and the meso-level emergence of dependent sub-centers (Huangpi, Xinzhou) within the border region exemplify what Massey termed the ‘relational’ nature of spatial inequality [44]: places are not simply “left behind” in isolation but are actively produced as peripheral through their relations with cores. This relational dynamic is not unique to China; similar processes have been documented in European peripheries, where capital and talent concentrate in primate cities [20]. However, the siphoning effects documented in this study illustrate how the prosperity of metropolitan cores is relationally connected to the marginalization of border peripheries—a dynamic often obscured in policy discourse that treats ‘left behind places’ as passive residuals of growth elsewhere [9].

This multi-scale perspective addresses a critical gap in left behind places research, which has been criticized for neglecting the interrelations and interdependences between lagging and prosperous areas [7]. By demonstrating how macro-level processes (metropolitan polarization) and meso-level outcomes (border region restructuring) are mutually constituted, our analysis moves beyond the territorial trap that treats regions as bounded containers. The formation of sub-centers adhering to Wuhan’s administrative boundary illustrates what peripheralization theorists describe as the spatially unfixed and temporally unstable nature of peripheries. These sub-centers are not intrinsically core or peripheral; their status is continuously negotiated through changing relations with multiple metropolitan centers.

Furthermore, the ecological dimension’s spatial misalignment with economic and social dimensions underscores a key insight from the peripheralization literature: places peripheralized by capital may be abundant in other values [45]. Mountain counties that are economically marginal serve as ecological cores, embodying what Miller terms “social-ecological-economic communities of abundance” rather than landscapes defined solely by capital’s scarcity [46]. This finding directly engages with the emerging international discourse on “planetary rural geographies” [45], which argues that peripheries are not merely residual spaces but active sites of ecological and social reproduction. However, unlike some European contexts where such areas have leveraged payment-for-ecosystem-services schemes, the H-H-A border region lacks institutionalised compensation mechanisms, pointing to a specific form of “institutional marginality” that has received less attention in the Western literature. Also, our findings challenge the reductive framing of “left behind places” purely in terms of economic deficit and open space for recognizing their diverse extra-economic values—ecological richness, social use-values, and place attachments [47].

5.3. *Novelty, Research Limitations and Future Prospects*

While previous research on border regions has predominantly focused on international borders or the economic effects of proximity, our study advances the literature in several distinct ways. First, unlike conventional boundary studies that emphasize cross-border cooperation and spillover effects, we systematically theorize and measure marginality as a structural condition—a dimension that has remained largely implicit in border region research. This approach responds to calls from European scholars, such as Oppido and Leimgruber, to move beyond static core-periphery models. Second, moving beyond static core-periphery models that treat peripheries as homogeneous residuals of core dynamics, our framework reveals that border regions are internally heterogeneous, containing dependent sub-centers that emerge through relational interactions with multiple metropolitan cores. Our finding complements the European literature on “inner peripheries” by

showing that such peripheries can exist even within rapidly growing metropolitan systems. Third, while the emerging “left behind places” discourse has highlighted multidimensional disadvantage (economic, social, and environmental), existing studies often treat these dimensions separately or focus on economic metrics alone. Our study operationalises production, livelihood, and ecology as analytically distinct yet interacting dimensions, providing empirical evidence that each evolves according to different logics and temporal rhythms—a contribution that has not been systematically made even in the extensive European marginality literature.

This study has several limitations that point to directions for future research. First, while our quantitative measurement framework aims for comprehensiveness, it cannot fully capture informal social networks, local cultural identities, or residents’ subjective perceptions of marginality—dimensions that qualitative methods could better address. Second, the analysis focuses on a specific type of inter-provincial border region (Hubei-Henan-Anhui); applying this framework to other types—such as coastal-inland interfaces or regions spanning different economic zones—would help assess its broader applicability. Third, the Geodetector method identifies associations but does not establish causality; future research could employ more dynamic modeling approaches to simulate causal pathways and feedback mechanisms among different dimensions of marginality and policy interventions. Finally, the county-level analysis, while appropriate for policy relevance, may mask intra-county variations that finer-scale data could reveal.

6. Conclusions

This study seeks to advance the understanding of coordinated development in China’s inter-provincial border regions by constructing and applying an integrated framework for measuring marginality. Grounded in the relational turn in economic geography, the framework adopts a multi-dimensional, multi-scalar, and multi-center perspective, moving beyond the conventional view of marginality as a static condition of underdevelopment. Instead, it reconceptualizes marginality as a dynamic, multidimensional, and scale-sensitive spatial relationship.

Using the H-H-A IPBRs as an empirical case, the study demonstrates the analytical strength of this framework. It reveals distinct evolutionary trajectories of marginality across production, livelihood, and ecological dimensions—ranging from consolidation and polarization to relative ecological stability. It further uncovers the complex, scale-dependent processes through which macro-level polarization and meso-level internal restructuring jointly shape the spatial dynamics of border regions. By identifying the shifting dominant drivers of marginality across dimensions, the study also captures the evolving logic of regional disparities over two decades of rapid socioeconomic transformation.

The contributions of this study are threefold. Theoretically, it develops and operationalizes a nuanced understanding of border-region marginality, emphasizing its multi-dimensional, multi-scalar, and temporal characteristics. Methodologically, it offers a replicable framework for measuring and visualizing marginality across different functional domains. Practically, it provides a diagnostic toolkit and evidence-based insights for policymakers, highlighting the need for differentiated, integrated, and scale-sensitive governance strategies. Rather than pursuing uniform solutions, effective promotion of coordinated development in inter-provincial border regions requires a precise understanding of their specific marginality profiles, the strategic leveraging of functional complementarities, and sustained institutional innovation to overcome the persistent fragmenting effects of administrative boundaries.

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