Spatial pattern of urban-rural integration in China and the impact of geography

Wei Pan, Jing Wang, Yurui Li, Shuting Chen, Zhi Lu

2023

This article was originally published at:
https://doi.org/10.1016/j.geosus.2023.08.001

Citation for this paper:

Wei, P., Wang, J., Li, Y., Chen, S., & Lü, Z. (2023). Spatial pattern of urban-rural integration in China and the impact of geography. *Geography and Sustainability*, *4*(4), 404–413. https://doi.org/10.1016/j.geosus.2023.08.001

Geography and Sustainability 4 (2023) 404–413

Contents lists available at ScienceDirect

Geography and Sustainability

journal homepage: www.elsevier.com/locate/geosus

Research Article

Spatial pattern of urban-rural integration in China and the impact of geography

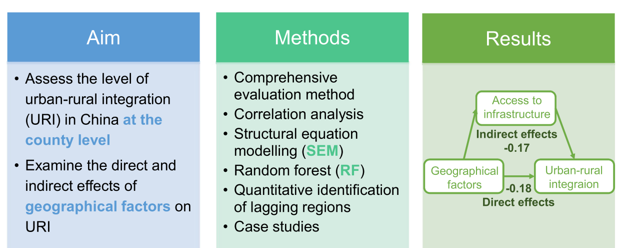
Wei Pan[a,b,c], Jing Wang[d], Yurui Li[a,b,c,*], Shuting Chen[e], Zhi Lu[f]

[a] Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China
[b] School of Resources and Environment, University of Chinese Academy of Sciences, Beijing 101314, China
[c] Key Laboratory of Regional Sustainable Development Modeling, CAS, Beijing 100101, China
[d] Beijing Academy of Social Sciences, Beijing 100101, China
[e] College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China
[f] Peter B. Gustavson School of Business, University of Victoria, BC, Canada

HIGHLIGHTS

- Urban-rural integration (URI) is a global issue highly related to SDGs.
- A new framework for analyzing the URI in China was established.
- The spatial pattern of URI in 2020 of China at county level was analyzed.
- The indirect negative effects of geographical factors on URI was detected.
- Eight types of 742 counties were identified as lagging regions of URI in China.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 January 2023
Received in revised form 19 August 2023
Accepted 29 August 2023
Available online 9 September 2023

Keywords:
Urban-rural integration
Relief degree of land surface
Infrastructure
Structural equation modelling
Sustainable urban and rural development patterns
Sustainable Development Goals

ABSTRACT

Urban-rural integration (URI) is a global challenge that is highly related to inequalities, poverty, economic growth, and other Sustainable Development Goals (SDGs). Existing research has evaluated the extent of URI and explored its influencing factors, but urban-rural linkages are seldom incorporated in evaluation systems, and geographical factors are rarely recognized as the influencing factors. We construct a URI framework including regional economy, rural development, urban-rural linkage, and urban-rural gap. Based on a dataset consisting of 1,669 counties in China in 2020, we reveal the spatial pattern of URI and find a high correlation between the spatial pattern of URI and the relief degree of land surface (RDLS). Using structural equation modeling, we discover that topography has direct (−0.18, $p < 0.001$) and indirect (−0.17, $p < 0.001$) effects on URI. The indirect negative effects are mediated through the infrastructure, and the combination of localized advantages and modern technical conditions could mitigate the negative impact of topography. Finally, we identify 742 counties as lagging regions in URI, which can be clustered into eight types. Our findings could facilitate policy designing for those countries striving for integrated and sustainable development of urban and rural areas.

1. Introduction

An enormous gap exists between rural and urban areas, involving access to safe water, clean energy, health care, good education, decent work and other Sustainable Development Goals (SDGs), which is a prominent feature of virtually all countries throughout the world, especially in developing countries (Sovacool et al., 2022). According to the United Nations, secondary school attendance in rural areas of developing countries has increased from 26% in the 1990s to 43% in the 2010s, and from 45% to 60% in urban areas during the same period (UN DESA, 2020). It suggests that despite the great progress rural areas have made, they still lag far behind urban areas, and the same holds true for other issues such as stunting, access to electricity and sanitation. Worldwide, the urban-rural gap accounts for 40% of mean country inequality and much of the cross-country variation (Young, 2013). A large rural-urban gap may lead to social division, rural dissatisfaction, and even unrest in some countries (Lichter and Ziliak, 2017). In sum, narrowing the urban-rural gap and promoting urban-rural integration

* Corresponding author.
E-mail address: liyr@igsnrr.ac.cn (Y. Li).

https://doi.org/10.1016/j.geosus.2023.08.001

(URI) is a global challenge that nearly all governments need to tackle, and it is closely tied to SDGs.

URI aims to change the urban bias in regional development strategies and move towards equalized development across urban and rural areas (Yang et al., 2021). It is directly related to SDG 10 (reduced inequalities) and SDG 11 (sustainable cities and communities). In addition, URI can drive regional growth through infrastructure investment, agricultural restructuring, rural development (Li et al., 2015; Pan et al., 2021) and employment generation (Liu et al., 2016), which could also affect the achievement of SDG 2 (no hunger), SDG 8 (decent work and economic growth), SDG9 (industry, innovation, and infrastructure) and SDG12 (responsible consumption and production). In this vein, assessing the level of urban-rural integration and identifying the influencing factors are of vital importance to the global process toward sustainable development.

China has experienced the most rapid urbanization in the world, along with a fast increase in urban-rural inequalities. Since its reform and opening up policy, China's urban-rural income gap has shown an inverted U shape; namely, it first expanded and then narrowed. The average urban-rural income ratio was 2.57 in 1978, reached a peak of 3.11 in 2010, and narrowed to 2.56 in 2020. To coordinate development between rural and urban areas, China has issued a series of policies. For instance, China established 11 national pilot areas for integrated urban-rural development in 2019, which aims to break down the shortcomings of institutional mechanisms and promote the free flow and equal exchange of various factors of production between urban and rural areas. The current challenges China faces are shared among many developing countries. Thus, studies on the experiences of URI in China may provide reference to and consequently benefit other countries who also grapple with similar challenges in urban-rural integration.

A county is an important unit for URI in China, which plays an intermediate connecting role between large, medium, and small cities, and small towns and villages. In 2021, the No. 1 Central Document of China proposed faster integrated urban-rural development within counties. However, due to the limitations of the statistical data availability, the current evaluation of China's URI level is mainly at the provincial level (Chen et al., 2020; Liu et al., 2013; Yang et al., 2021) and lacks evaluations at the county level. Therefore, leveraging unique geographic spatial data and revealing the spatial pattern of urban-rural integration at the county level can provide a valuable reference for policy making.

Previous research has made progress in evaluating the URI level, mainly employing three types of indicators (Ma et al., 2020; Yuan et al., 2020; Zhou and Shi, 2022): (1) comprehensive indicators, which reflect the overall development level of urban and rural areas, such as GDP per capita reflecting the overall economic development of the region; (2) comparative indicators, which reflect the difference between urban and rural areas in a certain aspect, such as the income ratio of urban and rural residents reflecting the income gap between them (Yuan et al., 2020); (3) catch-up indicators, which refer to the extent for rural areas in a disadvantaged position to continuously catch up their urban counterparts (Combes et al., 2020). For example, the per capita disposable income of rural residents is commonly selected to reflect the economic level of rural areas, despite the fact that the evaluation of URI is more systematic and scientific and gradually approaches the theoretical connotation of URI. However, these indicators have a deficiency in accurately depicting the linkage and social-economic interdependence between urban and rural areas, and they don't reflect the flow of production factors and the economic and social interactions between the urban and rural areas.

In terms of influencing factors, prior research has examined the following influence on URI: industrial structure (Guo et al., 2022), urbanization level (M. Chen et al., 2022; Wan et al., 2022b), infrastructure and public service accessibility (Cattaneo et al., 2022), and geographical factors (Wan and Zhou, 2005). Notably, although existing research acknowledges the impact of geographical factors on urban-rural integration, the study of how topography influences urban-rural integration has received only sporadic attention to date. We contend that in addition to directly influencing the level of URI, geographical factors may also have indirect effects on URI by influencing industrial structure, urbanization level, and infrastructure and public services accessibility. In particular, the immovability and persistence of infrastructure may reinforce the influence of geographical factors, which could stagnate the outcome of regional inequalities (Pandey et al., 2022; Thacker et al., 2019). In line with this reasoning, examining and comparing the direct and indirect effects of geographical factors on URI could provide new insights into the paths to achieve URI.

This research aims to assess the level of URI in China at the county level and explore the role of geography in shaping it. Firstly, we construct a theoretical framework of URI, with the inclusion of indicators specifically reflecting urban-rural linkages and interactions. Secondly, we conduct an empirical analysis using more granular county-level data which captures the smaller within-county topographic variations compared to the provincial level data that have been primarily employed in previous studies. Therefore, we believe this county-level data is more conducive to capturing the impact of topography on urban-rural integration. Notably, this unique data on urban and rural income at the county level is mined from a vast amount of county-level statistical bulletins and government work reports to reflect the gap between urban and rural areas. Thirdly, the direct and indirect effects of geographical factors are explored with structural equation modeling to reveal the paths through which geographical factors influence urban-rural integration. And finally, the lagging regions of URI are identified based on a set of criteria to reveal the current development status and challenges faced by specific regions in URI. We hope that our intriguing findings will shed light on URI and provide help to other countries in achieving their URI and SDGs.

2. Materials and methods

2.1. An analytical framework for URI

URI is complex and involves a variety of aspects of socioeconomic development. Making urban and rural development more conducive to the SDGs entails an integrated framework which could also help us analyze the connotations of URI. To do that, we draw from prior literature to establish the main theoretical constructs and explore the connotations of URI from four dimensions: overall regional development, rural development, urban-rural mutual linkage, and urban-rural gap (Fig. 1).

URI means integrating both urban and rural interests to achieve overall regional development. Hence it is necessary to acknowledge the shared interests that unify urban and rural areas rather than divide them into isolated dichotomized categories (Lichter and Brown, 2011). We argue that focusing on the integrated regional development status is the first key point of urban-rural integration, a crucial feature that distinguishes it from early concepts such as urban-rural equalized development (Liu et al., 2015). The higher level of URI, the more prosperous regional development.

Rural areas are typically at a disadvantage in terms of regional development, so the trend of rural decline must be reversed to achieve URI.

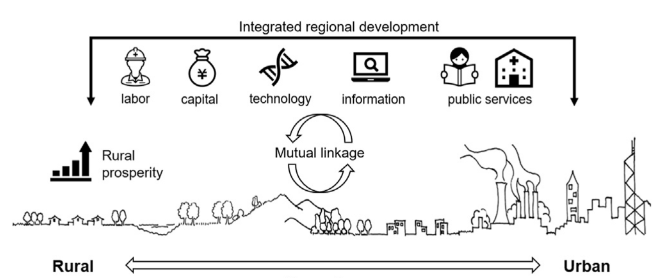


Fig. 1. Connotations of URI.

In the Lewis model, development entails widespread migration from rural to urban areas. In this process, rural areas play a passive rather than active role (UN DESA, 2021). However, this urbanization view usually leads to an urban-centric development strategy, leaving rural areas on the sidelines in policy discussions and far away behind the country's economic bounty. The decline of rural areas' development capacity and the intensification of "rural disease" issues (Liu and Li, 2017) must be changed in the process of URI, and rural areas should share prosperity as well.

To promote shared prosperity, URI requires strong mutual links between urban and rural areas through flows of labor migration, capital, goods, technology, information, and other production factors (Lichter and Brown, 2011; Liu, 2018). Traditionally, roads facilitate the flow of labor and goods. However, urban areas usually play a dominant role, leading to a one-way flow of resources from rural to urban areas (Wan et al., 2022a). The rise of new digital technologies offers platforms for the exchange of technology and information between urban and rural areas, which provides the basis for interaction to ensure a balanced development of both urban and rural areas rather than exclusively benefiting urban development.

The urban-centric development strategy and the one-way flow of resources from rural to urban areas usually lead to a sizable urban-rural gap. Given URI denotes equalizing development across urban and rural areas and diminishing the urban-rural gap (Lagakos, 2020), this necessities a more spatially inclusive approach and consequently indicates that the policies tackling development issues and benefiting the cities must be extended to the rural areas. The dual-track structure of urban-rural development needs to be eliminated to realize the prosperity and well-being of both urban and rural areas.

These four dimensions of overall regional development, rural development, urban-rural mutual linkage, and urban-rural gap are correlated with each other, with each of them reflecting the connotations of URI. Notably, URI highly depends on the local physical and institutional conditions, such as topography, natural resource endowments, and access to public services, among others. The effects of geographic factors on URI may be both direct, through influencing the four dimensions, and indirect, through influencing the distribution of public infrastructure.

2.2. Measuring the URI of China at the county level

Integrating the analytical framework and previous studies (Cattaneo et al., 2021; Yang et al., 2021) and considering data accessibility at the county level, this research establishes a URI evaluation index system that covers four dimensions as we discussed: regional economic development, rural development, urban-rural linkage, and income gap between urban and rural areas (Table 1). Specifically: (1) GDP per capita and total consumption per capita are selected to reflect the level of regional economic development from the perspective of production and consumption in a county. GDP per capita is an important indicator to portray regional economies, while total consumption per capita can reflect both people's living standards and the potential of consumption to drive macroeconomic growth. (2) The level of rural development is reflected by the per capita disposable income of rural residents. Due to the constraints of the current statistical system, the indicators used to reflect rural development at the county level are limited. The disposable income of rural residents is the commonly used indicator because it has a strong correlation with the living standard of rural residents. (3) The average distance to transportation infrastructure and the rural digital index are chosen to comprehensively reflect the level of urban-rural linkage. The average distance to transportation infrastructure is calculated by the cost distance method on ArcGIS software, which could model the proximity of population distribution to the transport facilities (S. Chen et al., 2022). It can reflect the accessibility of counties and the spatial basis and potential of urban-rural interaction at the county level. The rural digital index is a composite index involving the construction of rural digital infrastructure and the degree of digitization of economy, governance, and life. The improvement of rural digitalization level establishes the platform and technological groundwork for the linkage of urban and rural areas in the context of accelerated integration of new-generation information technology and the real economy. And (4) the income gap between urban and rural areas is measured by the income ratio of urban and rural residents, which is frequently used as an important economic indicator delineating the urban-rural divide in many studies (Yuan et al., 2020). To measure the multicollinearity among these indicators, we tested the variance inflation factor (VIF) of the indicators and found VIFs are less than 5, with a maximum value of 3.48 and a mean value of 2.00, indicating that there is no significant multicollinearity among the indicators and the indicator system is reasonable to set.

Based on the constructed framework of the URI evaluation index system, the data must first be preprocessed. We use the maximum difference normalization method for data standardization. Consistent with previous research (Xu et al., 2020), all criteria are weighted equally in the URI index, conveying that each dimension is equally important for achieving URI. This also suggests that these counties should prioritize all dimensions to enhance their levels of URI, with special emphasis on the dimensions that are farthest from achieving URI. By focusing on these areas, counties can expect to make rapid progress and see incremental improvements.

2.3. Exploring URI influencing factors with structural equation modeling

Structural equation modeling (SEM) is an extension of the general linear model (GLM) and can examine the complex relationships among variables (Grace et al., 2016). We applied SEM to explore the factors influencing URI for the following reasons: First, SEM can include latent variables to represent theoretical variables that cannot be measured directly. URI is a comprehensive and abstract concept that is difficult to be depicted by a single indicator, and the latent variables through SEM can provide a way to observe and process it. Second, SEM can explicitly examine both direct and indirect relationships between variables, thereby could help us better understand the role of geography in shaping the pattern of URI in China.

We chose one latent variable and five observed variables to detect the direct and indirect effects of geography on URI based on our proposed framework, previous studies (Cattaneo et al., 2022), and available data. The level of URI is the latent variable (Y) that is observed by the level of regional economic development, rural development, urban-rural linkage, and urban-rural income gap. The name and descriptions

Table 1
Evaluation index system for URI level.

Criterion	Index	Direction	Weight
Regional economic development	GDP per capita (RMB/person)	+	0.125
	Total consumption per capita (RMB/person)	+	0.125
Rural development	Rural disposable income per capita (RMB/person)	+	0.25
Urban-rural linkage	Distance to transportation infrastructure (km)	−	0.125
	Rural digital index	+	0.125
Urban-rural income gap	Income ratio of urban and rural residents	−	0.25

Table 2
Information of the observed variables.

Name	Description
RDLS	Relief degree of land surface, a synthetic representation of the altitude and incision depth of a region. Higher values indicate more pronounced topographic relief
Location	Travel time to the provincial capital, higher values indicate worse location and transportation
Financial	Financial Inclusion Index involves coverage breadth, usage depth, and digitization level
Medical	Kernel density values for points of interest (POI) on hospitals, higher values indicate better medical services
School	Kernel density values for POI on schools, higher values indicate better educational services

of the five observed variables can be found in Table 2. We chose relief degree of land surface (RDLS) as the proxy variable for geography because it synthetically represents the altitude and incision depth of a region (Feng et al., 2008) and has a more direct and stronger association with socioeconomic activities and infrastructure construction than other geographic elements such as temperature and precipitation. For accessibility to infrastructure and public services, we select indicators from four typical areas: transportation, finance, healthcare, and education.

2.4. Ranking variable importance based on random forest

To confirm the role of geography in shaping URI, we rank the influencing factors according to the variable importance calculated by random forest (RF). RF is an increasingly used statistical method and is very powerful in revealing underlying phenomena that may be neglected by traditional regression (Breiman, 2001). The principle of RF algorithm is to merge numerous binary decision trees created using several bootstrap samples from the learning sample and randomly select a subset of explanatory variables at each node (Genuer et al., 2010). Given that traditionally geography has been generally ignored by macroeconomics due to both theoretical and empirical constraints (Nordhaus, 2006). Therefore, we deem that the application of RF may lead to new insights. The RF model in this study is operated in the R Statistical Software (R version 4.0.2) with the package “randomForest”.

2.5. Quantitative identification of lagging regions

Identifying lagging regions can help to design and improve regional policies. To quantitatively identify lagging regions of URI, we drew on the established methods that have been used in previous research (Li et al., 2014) and proposed five evaluation criteria as follows: (1) URI index lower than 50% of the national average; (2) regional economic index lower than 50% of the national average; (3) rural development index lower than 50% of the national average; (4) urban-rural linkage index lower than 50% of the national average; (5) income gap index lower than 50% of the national average. A county may be categorized as a lagging region if it fits one or more certain criteria. Based on the aforementioned five criteria, we did an overlay analysis using ArcGIS’s Spatial Query Tool. We then categorized the lagging regions into different types in conjunction with the systematic clustering analysis of the URI index and individual dimension indexes.

2.6. Data sources

County-level socioeconomic data were mainly obtained from the *Chinese Counties (Cities) Socioeconomic Statistical Yearbook (2021)*. Data on the disposable income of urban and rural residents were mined from the statistical bulletins and governmental reports of each county. When preparing the dataset, the statistical yearbooks of each province and prefecture were used for revising and validating data accuracy. DEM data for calculating the relief degree of land surface (RDLS) were derived from the National Resources and Environmental Database presented by Resources and Environmental Scientific Data Center, Chinese Academy of Sciences. The transportation data on the average distance to transport infrastructure and travel time to the provincial capital is from the literature (S. Chen et al., 2022). The data of the financial inclusion index is sourced from the Digital Financial Inclusion Index of China by Peking University (Guo et al., 2020). The Digital Rural Index is derived from the County Digital Rural Index Database by Institute for New Rural Development, Peking University and Ali Research Institute. POI data on hospitals and schools is sourced from Gauteng Maps. The population and urbanization rate data were obtained from the national 2020 census. Together we obtained data of 1,669 counties, consisting of 89.4% of China’s cities at the county level, counties and autonomous counties, and thus have strong representativeness.

3. Results

3.1. Spatial pattern of URI at the county level

China’s URI level exhibits a steady, falling geographical trend from east to west, constrained by physical restrictions and overall socioeconomic growth (Fig. 2(a)). The average URI index is 49.596 (SD (standard deviation)=20.778; CV (variation coefficient)=0.419), with a low

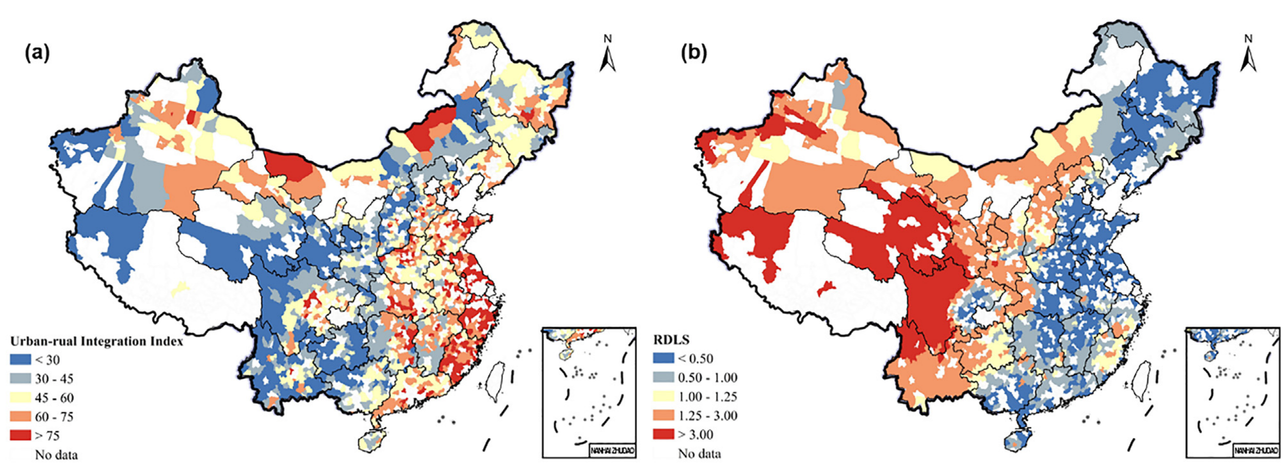


Fig. 2. Spatial pattern of (a) URI and (b) RDLS.

overall level and large regional disparities. The counties with higher URI index are mainly concentrated in eastern coastal China, due to its advantages such as favorable physical conditions and strong economic foundation. The counties with lower URI index are mainly located in mountainous areas in west China, spatially overlapping with areas of high relief degree of land surface (Fig. 2(b)). It suggests that the level of URI is lower where the topography is more undulating.

3.2. Four dimensions of URI

Patterns of the regional economic index, rural development index, urban-rural linkage index, and income gap index are shown in Fig. 3.

The average regional economic index is 8.905 (SD = 6.153; CV = 0.691). Counties with higher regional economic index are mainly located in the eastern coastal regions or surrounding the provincial capitals. Counties with lower regional economic index are mainly located on the Tibetan Plateau, Loess Plateau, Yunnan-Guizhou Plateau, and Northeast China.

The average rural development index is 10.708 (SD = 6.997; CV = 0.653). Its spatial pattern is similar to that of the regional economic index. Counties with higher rural development index are mainly located in the eastern coastal regions, and counties with lower regional economic index are mainly located on the Loess Plateau and Yunnan-Guizhou Plateau.

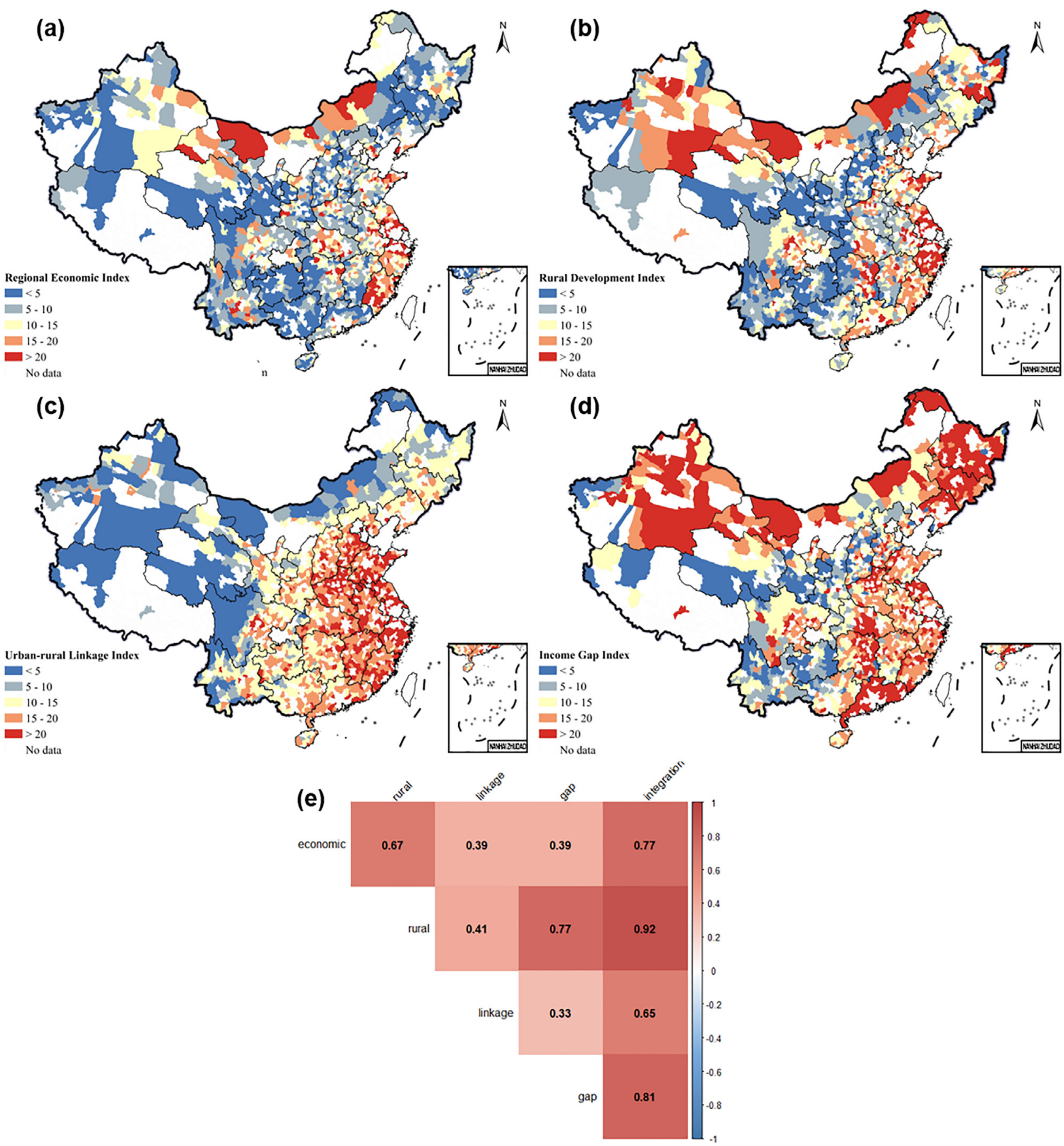


Fig. 3. Spatial pattern of four dimensions of URI.

The average urban-rural linkage index is 15.317 (SD = 6; CV = 0.392). Counties with higher urban-rural linkage index are mainly located in the plains, and counties with lower urban-rural linkage index are mainly located in the Tibetan Plateau, Inner Mongolia Plateau, and northwest China.

The average income gap index is 14.665 (SD = 7.063; CV = 0.482). Counties with higher income gap index, i.e., smaller urban-rural income gap, are mainly located in east, northeast, and northwest China. Counties with lower income gap index are mainly located in the Tibetan Plateau and Loess Plateau.

The four dimensions, as well as the URI index, are significantly correlated with each other. The highest correlation coefficient is found between the rural development index and the rural-urban integration index, at 0.92 (p < 0.001, Fig. 3e), indicating a strong correlation between rural development and URI. The main obstacles to achieving URI are rural backwardness; hence there is much room for enhancing rural prosperity and well-being.

3.3. Correlation with typical covariates

The bivariate plots are employed to reveal the correlations between the URI index and other covariates that are highly related to URI based on previous studies (Cattaneo et al., 2022; Wan et al., 2022a). Fig. 4 provides clear evidence that the URI index is significantly higher in counties (i) with smaller RDLS, i.e., flatter topography (coefficient = −0.53, p < 0.001); (ii) with less travel time to the province capital (coefficient = −0.4, p < 0.001); (iii) with higher financial inclusion (coefficient = 0.72, p < 0.001); (iv) with more medical services (coefficient = 0.56, p < 0.001); (v) with more educational services (coefficient = 0.58, p < 0.001). Among these covariates, the strongest correlation coefficient is found between the URI index and financial inclusion, indicating that more inclusive financial services may benefit both urban and rural areas to improve the level of URI.

Meanwhile, in counties with larger RDLS, it often takes longer time to get to the provincial capital (coefficient = 0.49, p < 0.001), and public services such as finance, health care, and education lag further behind (coefficient = −0.38, −0.41, −0.5, respectively, p < 0.001). These findings indicate that counties with greater topographic relief tend to have lower accessibility to infrastructure and public services.

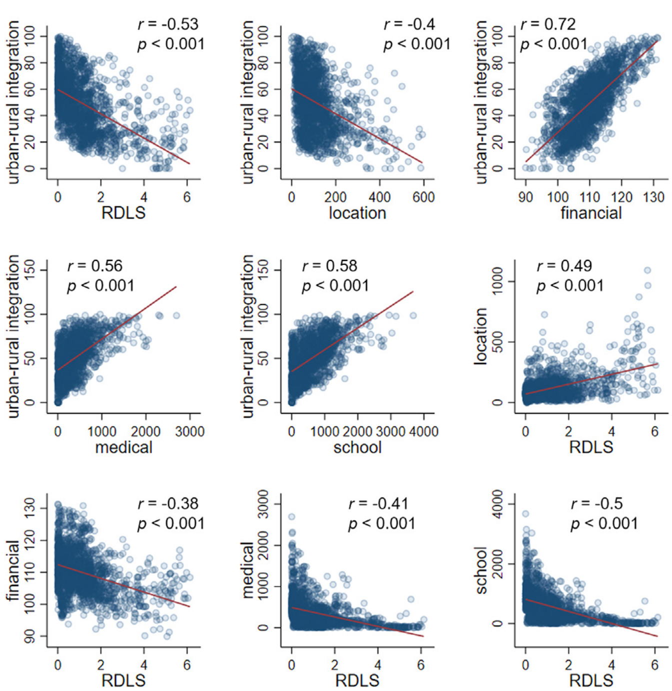


Fig. 4. Bivariate plots of typical covariates.

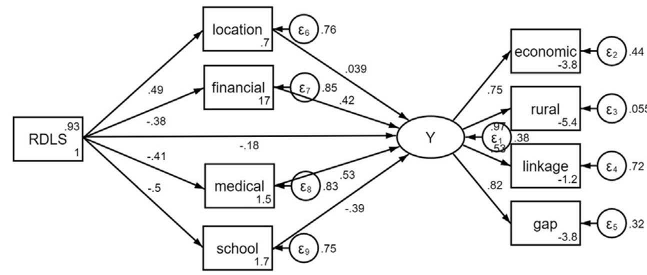


Fig. 5. Outcome of SEM.

3.4. Impact of RDLS on URI

To calculate the direct and indirect effects of RDLS on URI, a structural equation model is established. In the model for URI (Fig. 5), RDLS has a significant direct effect of −0.18 on URI (p < 0.001). Meanwhile, it does exhibit a significant negative indirect effect on URI (coefficient = −0.17, p < 0.001). This relationship is mediated by the positive effects of RDLS on travel time to the province capital (coefficient = 0.49, p < 0.001) and by the negative effects of RDLS on financial inclusion, medical services, and educational services (coefficient = −0.38, −0.41, −0.5, respectively, p < 0.001). In sum, the total impact of the RDLS on URI is −0.35 (p < 0.001) which implies that when RDLS increases by 1, the URI level decreases by 0.35. Where the topography is more undulating, the process of URI may face greater obstacles. Topography affects URI not only directly but also indirectly by influencing the distribution of infrastructure. The indirect effects of RDLS on URI are comparable with its direct effects, implying that overlooking indirect effects would lead to an underestimate of nearly 50% of its effect.

To verify the robustness of the SEM results, the importance of each covariate is further measured using RF (Breiman, 2001). Fig. 6 shows that RDLS has high importance in both mean decrease accuracy (%IncMSE) and mean decrease Gini (IncNodePurity), second only to the role of financial inclusion. This result further validates the findings obtained from SEM that RDLS is highly important to URI.

RDLS has a negative effect on URI, but it is difficult to be altered in a county. To explore how to mitigate the constraints of topography on URI, we chose Jiulong County in Sichuan Province and Sunan County in Gansu Province for brief case studies. These two counties have a high RDLS of 6.042 and 4.262, respectively, among the top 5% of counties in the country in terms of RDLS. And their urban-rural integration indices are 51.770 and 67.978, respectively, higher than the national average of 49.596.

Jiulong County is located in the western part of Sichuan Province, in the transition zone between the Panxi Plain and the Tibet Plateau, with a complex topography and a wide range of heights. The harsh topograph-

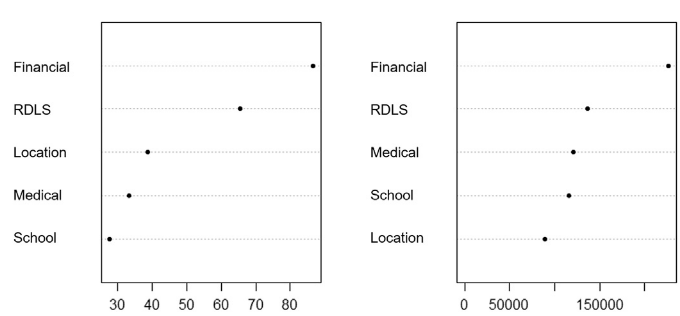


Fig. 6. Influencing factors ranked by variable importance.

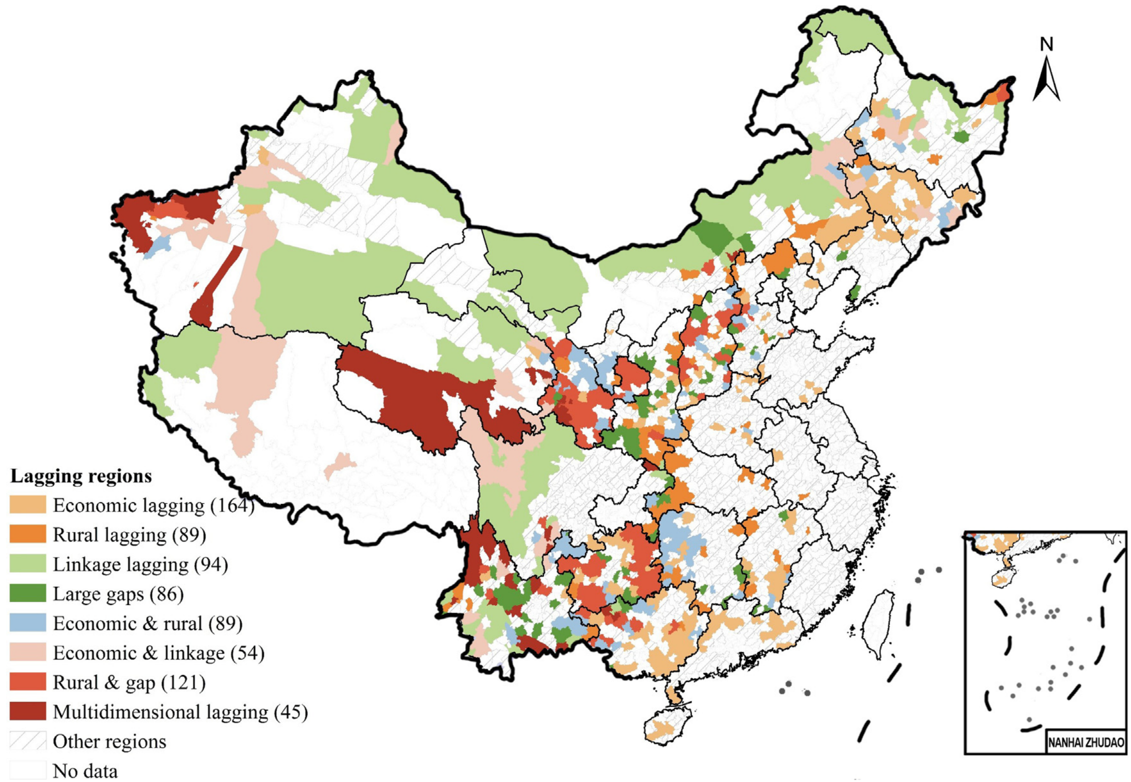


Fig. 7. Spatial pattern of lagging regions in URI.

ical conditions make its travel time to the provincial capital more than 2.5 times than the national average, and access to educational and medical services far below the national average. Fortunately, Jiulong County is 280 km from the airport, and it is the closest county to the airport in its prefecture, which provides good access to the development of e-commerce and logistic transportation. Jiulong County has a high level of digitalization in the rural economy, at 58.930, which is higher than the national average of 55.315. E-commerce and transportation platforms make it possible for local farmers to sell their products to broader markets than ever, which helps boost the rural economy and narrow the urban-rural gap. In 2018, Jiulong County was named as a "comprehensive demonstration county for e-commerce in rural areas". The per capita disposable income of farmers in Jiulong County in 2020 is 20% higher than the national average, and the urban-rural income gap is 30% lower than the national average. Rural digitalization combined with easy access to air transport has helped improve urban-rural integration in Jiulong County against the harsh topographical conditions.

Sunan County is located in southern Gansu, the central part of the Hexi Corridor and the northern foot of the Qilian Mountains. The unique natural conditions provide the basis for its speciality industries, and the breeding of Gansu alpine fine-hair sheep in Sunan County is a national geographical indication product. Additionally, inclusive rural financing provides better conditions for the development of speciality industries. The financial inclusion index of Sunan County is 114.427, which is higher than the national average of 110.037. Higher financial inclusion provides local farmers with more choices to adopt advanced technologies, better cash flow and risk management, thus improving productivity. The per capita GDP of Sunan County in 2020 is twice the national average, and the disposable income of rural residents is 1.24 times the national average. The development of speciality industries combined with the assistance of inclusive finance promotes the development of urban-rural integration in Sunan County.

To conclude, these two counties have improved URI upon their own unique geographic advantages and natural resources by fusing them with modern production and development, such as digitalization and financial inclusion. As a result, the limitations of geography have been somewhat mitigated, and a higher degree of urban-rural integration has been achieved.

3.5. Identification of lagging regions

We identified 742 lagging counties upon the five criteria we established earlier in this paper (Fig. 7). With the systematic clustering of the URI index and each dimension index for 742 counties, these counties are categorized into eight types, and the basic characteristics of the eight types of lagging regions are shown in Table 3. A brief introduction of these lagging regions is as follows:

(1) Economic lagging type has a rather low level of regional economic index. This type includes 164 counties that are mainly distributed in northeast China, Guangdong, and Guangxi Province. The population living in this type of county is 82.3 million, which is the most among all the types of lagging regions. These regions feature relatively flat terrain, with an average RDLS of 0.706. While they enjoy good infrastructure and public service conditions, their low proportion of the secondary industry, at just 24.6%, may hinder their ability to stimulate regional economic development.
(2) Rural lagging type has a low level of rural development index. This type includes 89 counties that are mainly distributed in the geological transition zone of Chinese second and third ladders, i.e., north Hebei, southeast Shaanxi, and west Hubei. Counties of this type generally have long travel times to the provincial capitals and limited public service to benefit rural development.
(3) Linkage lagging type has a low level of urban-rural linkage index. This type includes 94 counties that are mainly distributed near the northern national borderline and in the geological transition zone of Chinese first and second ladders. The major constraints

Table 3
Basic characteristics of lagging regions.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population (million people)	82.30	25.97	11.52	24.04	31.53	9.40	32.73	6.68
Proportion of secondary industry (%)	24.6	31.2	27.2	36.3	26.3	18.4	26.2	26.9
Urbanization rate (%)	41.2	44.1	47.6	48.6	40.5	33.7	39.3	34.6
RDLS	0.706	1.161	2.631	1.367	1.268	2.866	1.711	3.695
Location (minutes)	102.1	126.9	265.2	87.4	127.3	290.2	109.0	303.5
Financial	107.4	109.2	106.7	109.4	105.2	100.4	104.7	101.1
Medical	314.1	251.0	43.4	298.1	233.3	55.3	219.4	79.8
School	570.1	424.7	58.6	503.7	372.4	75.2	337.9	107.0
Fiscal independence (%)	15.4	14.6	15.5	21.0	11.9	9.4	11.8	7.5

Note: The first rows (1)-(8) represent Economic lagging type, Rural lagging type, Linkage lagging type, Large gaps type, Economic & rural lagging type, Economic & linkage lagging type, Rural lagging & large gap type, and Multidimensional lagging type, respectively.

on development in these regions are the undulating topography and remote location.

(4) Large gaps type has a low level of income gap index. This type includes 86 counties that are mainly distributed in Yunnan, Guizhou, Shannxi, and Shanxi Province. In these regions, the urbanization rate and the proportion of secondary industry are high, but the urban-centric development strategy has not been changed, resulting in a large urban-rural gap.

(5) Economic & rural lagging type has both low levels of regional economic index and rural development index. This type includes 89 counties that are mainly distributed in west Hunan, north Jiangxi Province and near the border between Ningxia and Gansu Province. In these regions, urbanization is lagging and fiscal revenue is far below fiscal expenditure, and the public expenditure may not meet local needs well.

(6) Economic & linkage lagging type has both low levels of regional economic index and urban-rural linkage index. This type includes 54 counties that are mainly distributed at the border of Sichuan and Gansu provinces and in the southern Xinjiang region. The average RDLS of these regions is 2.866, indicating significant topographical variations. Furthermore, they experience low accessibility to infrastructure and public services, which hinders urban-rural connectivity. Additionally, the average proportion of secondary industry is only 18.4%, highlighting an imbalanced industrial structure.

(7) Rural lagging & large gap type has both low levels of rural development index and income gap index. This type includes 121 counties that are mainly distributed in Guizhou, south Gansu Province. These regions have a relatively low proportion of secondary industry at 26.2% and a relatively lagging urbanization rate at 39.3%. Moreover, they also demonstrate a significant dependence on financial support from the higher-level government.

(8) Multidimensional lagging type refers to regions where, out of the four dimensions of URI, three or more dimensions have lower development levels, and the URI index is also low. This type includes 45 counties that are mainly distributed on the Tibetan Plateau, South Xinjiang regions and Yunnan-Guizhou Plateau. These regions exhibit an average RDLS of 3.695, characterized by challenging transportation conditions and limited access to public services such as healthcare, education, and financial services. The urbanization rate is relatively low at 34.6%, and the fiscal self-sufficiency is also low. Consequently, these regions rely heavily on higher-level government finances to meet their needs.

4. Discussion

4.1. Understanding the role of geography in shaping URI

Our results show that URI is lagging in the mountainous area in West China. The overall spatial pattern at the county level found in our study is basically consistent with the previous empirical studies at the province level (Yang et al., 2021), corroborating the reliability of our results. Nevertheless, physical geography conditions vary considerably within provinces, making it difficult to reflect the impact of topography on URI. Based upon empirical analysis at the county level, this research finds that the relief degree of land surface not only has a direct negative effect on the level of URI but also has an indirect negative effect by influencing the distribution of infrastructure. Our results highlight that geography plays an important role in URI, which is consistent with earlier findings that regional inequalities caused by physical geographical factors are growing (Xu et al., 2020). Meanwhile, our findings extend the existing literature on the perception of geography and sustainable development (Fu, 2020).

Geography is essential in determining URI as it is closely related to non-removable resources as well as to market access, infrastructure, and public services. The quantitative findings of this study indicate that the direct impact of topography on URI and the indirect impact mediated through infrastructure and public service provision are roughly equal. This finding suggests that infrastructure development and public service provision exacerbate the negative impact of topography on URI, doubling its effect. This interesting insight provides robust empirical evidence for previous research, affirming the viewpoint that the immobility and persistence of infrastructure lock and even exacerbate inherent regional inequalities. It is worth noting that geography is not the only thing that matters for URI (Nunn, 2020) given ample evidence has shown that social-economic factors are also important (Cattaneo et al., 2022; Chen et al., 2020). The insight that geography continues to matter in the integrated and sustainable development of urban and rural areas is potentially useful for improving the design, implementation, and effectiveness of policies.

To investigate the spatial disparities in URI challenges across different regions, we identified the lagging regions. As a result, a total of 742 counties were classified into eight categories. These counties are predominantly located in the mountainous regions of western China and at the geological transition zone, where significant topographical changes occur. This further substantiates the detrimental impact of topography on URI. We summarized the development status and challenges faced by these distinct lagging regions, focusing on aspects such as population, industrial development, urbanization level, infrastructure and public services, and local finances. We also classified the lagging regions based on diverse county-level URI and challenges. These findings provide crucial insights for policymakers and researchers, serving as valuable references. Meanwhile, we acknowledge that similar issues might arise from different underlying causes due to the substantial variations across counties. Therefore, targeted policies and measures should take the specific conditions of each region into account in order to facilitate the development of these areas.

4.2. Policy implications for URI

The results of this research have three policy implications. First, policymakers are strongly suggested to take geographical factors into consideration. This study reveals that the RDLS not only directly impacts the URI but also indirectly affects it through its influence on infrastructure distribution. Therefore, it is necessary to incorporate the differences in topographical variations when formulating policies aimed at promoting URI. For example, the 11 national URI pilot areas in China do not cover the mountainous areas where the lagging regions identified in this study are concentrated. This omission may diminish the replicability and scalability of the pilot area experience. Therefore, it is recommended that the impact of geographical factors in the establishment of the second batch of pilot areas shall be given due consideration.

Second, policymakers are recommended to optimize the distribution of infrastructure and carefully consider trade-offs among different sustainable development goals. Areas with undesirable geographical conditions tend to be less populated, so these areas may be neglected for infrastructure investment due to cost-effective considerations. However, the durable and immobile nature of infrastructure may lock in regional inequalities. Our results show that infrastructure development and public service provision double the negative impact of topography on URI. Given the current unprecedented levels of global investment in infrastructure, it is crucial for China and other countries to carefully consider the trade-offs among different goals to promote sustainable development and avoid further exacerbating disparities.

Third, achieving a high level of URI shall leverage modern technical and institutional conditions and local advantages. The successes of two case studies in this paper show the possibility of mitigating the constraints of the unfavorable physical geography condition on URI, which requires two necessary elements. On the one hand, it is necessary to fully explore and leverage each region's local characteristics and advantageous resources. On the other hand, it is important to empower the local characteristics with the help of modern technology and institutional means, such as the fueling of local industries through digitalization and the development of inclusive finance. The insights gained from our study could inform policy makers not only in China but also in other countries that face similar challenges about potential interventions in achieving URI.

4.3. Contributions and limitations

This research contributes to the existing literature mainly in two ways. First, we collect multi-source granular data to reveal the spatial pattern of URI in China at the county level rather than at the provincial level, which conveys a deeper understanding of how geography promotes or hinders URI through powerful large-scale data. To better reflect the urban-rural gap at the county level, we gather unique data on the disposable income of urban and rural residents from a sizable number of county-level statistical bulletins and official reports. Second, we highlight the important role of geography in URI through the perspective of direct and indirect effects, quantifying the mediating role of infrastructure and public services. And we also reveal that the combination of localized advantages and modern technical conditions could mitigate the negative impact of topography. These findings could provide new insights for both research and policy implications for China and other countries.

Although this study makes contributions to the literature, it has certain limitations. We acknowledge that it is insufficient to use the urban-rural income gap to reflect the development gap between urban and rural areas since other aspects, such as consumption, basic public services, and well-being may be neglected. However, this is a common limitation when studying at the county level due to the constraints of the current statistical system. Although the urban-rural gap is multidimensional, the income ratio of urban and rural residents can be an important and representative indicator. Even this imperfect proxy can aid in shedding light on the rural-urban gap nationwide. Future research should explore more aspects of urban-rural gap to gain more abundant insights.

5. Conclusions

This research establishes a URI framework and evaluates China's county-level URI across dimensions of regional economy, rural development, urban-rural linkage, and urban-rural income gap. Apart from previous studies, this study incorporates indicators reflecting urban-rural interdependence and mutual interactions. Moreover, multi-source data unveils the spatial pattern of URI in China at the county level rather than provincial level as in earlier studies. The results show a lower URI index in west China's mountainous regions, physically overlapping with regions with a high relief degree of land surface. Structural equation modeling reveals topography's direct and indirect effects on URI, the latter through infrastructure and public service influence. Additionally, case studies propose leveraging local advantages, digital technologies, and inclusive rural financing to mitigate the negative effects of topography on URI. Finally, we identified 742 lagging counties, illustrating the regional imbalance and URI challenges in specific regions. Overall, this study deepens our understanding of URI dynamics by uncovering that topography impacts URI through infrastructure. This insight contributes to a more profound grasp of the intricate interplay between geography and sustainable development.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was funded by the National Natural Science Foundation of China (Grants No. T2261129477 and 41971220), and the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDA23070300).

References

Breiman, L., 2001. Random forests. Mach. Learn. 45 (1), 5–32.
Cattaneo, A., Nelson, A., McMenomy, T., 2021. Global mapping of urban-rural catchment areas reveals unequal access to services. Proc. Natl. Acad. Sci. U.S.A. 118, e2011990118.
Cattaneo, A., Adukia, A., Brown, D.L., Christiaensen, L., Evans, D.K., Haakenstad, A., McMenomy, T., Partridge, M., Vaz, S., Weiss, D.J., 2022. Economic and social development along the urban–rural continuum: New opportunities to inform policy. World Dev. 157, 105941.
Chen, K., Long, H., Liao, L., Tu, S., Li, T., 2020. Land use transitions and urban-rural integrated development: Theoretical framework and China's evidence. Land Use Policy 92, 104465.
Chen, M., Chen, L., Cheng, J., Yu, J., 2022. Identifying interlinkages between urbanization and sustainable development goals. Geogr. Sustain. 3 (4), 339–346.
Chen, S., Li, Y., Pan, W., Wang, W., Jin, F., 2022. Evolution of China's overland transportation dominance and its economic effect: A county-level analysis. Acta Geogr. Sin. 77, 1937–1952 (in Chinese).
Combes, P.P., Démurger, S., Li, S., Wang, J., 2020. Unequal migration and urbanisation gains in China. J. Dev. Econ. 142, 102328.
Feng, Z., Tang, Y., Yang, Y., Zhang, D., 2008. Relief degree of land surface and its influence on population distribution in China. J. Geogr. Sci. 18, 237–246.
Fu, B., 2020. Promoting geography for sustainability. Geogr. Sustain. 1 (1), 1–7.
Genuer, R., Poggi, J.M., Tuleau-malot, C., 2010. Variable selection using random forests. Pattern Recognit. Lett. 31, 2225–2236.
Grace, J.B., Anderson, T.M., Seabloom, E.W., Borer, E.T., Adler, P.B., Harpole, W.S., Hautier, Y., Hillebrand, H., Lind, E.M., Pärtel, M., Bakker, J.D., Buckley, Y.M., Crawley, M.J., Damschen, E.I., Davies, K.F., Fay, P.A., Firn, J., Gruner, D.S., Hector, A., Knops, J.M.H., MacDougall, A.S., Melbourne, B.A., Morgan, J.W., Orrock, J.L., Prober, S.M., Smith, M.D., 2016. Integrative modelling reveals mechanisms linking productivity and plant species richness. Nature 529 (7586), 390–393.
Guo, F., Wang, J.Y., Wang, F., Kong, T., Zhang, X., Cheng, Z.Y., 2020. Measuring China's digital financial inclusion: Index compilation and spatial characteristics. China Econ. Q. 19 (4), 1401–1418 (in Chinese).
Guo, D., Jiang, K., Xu, C., Yang, X., 2022. Industrial clustering, income and inequality in rural China. World Dev. 154, 105878.
Lagakos, D., 2020. Urban-rural gaps in the developing world: Does internal migration offer opportunities? J. Econ. Perspect. 34, 174–192.
Li, Y., Wang, J., Liu, Y., Long, H., 2014. Problem regions and regional problems of socioeconomic development in China: A perspective from the coordinated development

of industrialization, informatization, urbanization and agricultural modernization. J. Geogr. Sci. 24, 1115–1130.
Li, Y., Long, H., Liu, Y., 2015. Spatio-temporal pattern of China's rural development: A rurality index perspective. J. Rural Stud. 38, 12–26.
Lichter, D.T., Brown, D.L., 2011. Rural America in an urban society: Changing spatial and social boundaries. Annu. Rev. Sociol. 37, 565–592.
Lichter, D.T., Ziliak, J.P., 2017. The rural-urban interface: New patterns of spatial interdependence and inequality in America. Ann. Am. Acad. Polit. Soc. Sci. 672, 6–25.
Liu, Y., Li, Y., 2017. Revitalize the world's countryside. Nature 548 (7667), 275–277.
Liu, Y., Lu, S., Chen, Y., 2013. Spatio-temporal change of urban-rural equalized development patterns in China and its driving factors. J. Rural Stud. 32, 320–330.
Liu, Y., Schen, C., Li, Y., 2015. Differentiation regularity of urban-rural equalized development at prefecture-level city in China. J. Geogr. Sci. 25, 1075–1088.
Liu, W., Dunford, M., Song, Z., Chen, M., 2016. Urban–rural integration drives regional economic growth in Chongqing, Western China. Area Dev. Policy 1 (1), 132–154.
Liu, Y., 2018. Introduction to land use and rural sustainability in China. Land Use Policy 74, 1–4.
Ma, L., Liu, S., Fang, F., Che, X., Chen, M., 2020. Evaluation of urban-rural difference and integration based on quality of life. Sustain. Cities Soc. 54, 101877.
Nordhaus, W.D., 2006. Geography and macroeconomics: New data and new findings. Proc. Natl. Acad. Sci. U.S.A. 103 (10), 3510–3517.
Nunn, N., 2020. The historical roots of economic development. Science 367 (6485), eaaz9986.
Pan, W., Wang, J., Lu, Z., Liu, Y., Li, Y., 2021. High-quality development in China: Measurement system, spatial pattern, and improvement paths. Habitat Int. 118, 102458.
Pandey, B., Brelsford, C., Seto, K.C., 2022. Infrastructure inequality is a characteristic of urbanization. Proc. Natl. Acad. Sci. U.S.A. 119, e2119890119.
Sovacool, B.K., Newell, P., Carley, S., Fanzo, J., 2022. Equity, technological innovation and sustainable behaviour in a low-carbon future. Nat. Hum. Behav. 6, 326–337.
Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., Hall, J.W., 2019. Infrastructure for sustainable development. Nat. Sustain. 2 (4), 324–331.
UN DESA, 2020. World social report 2020: Inequality in a rapidly changing world. United Nations Department of Economic and Social Affairs.
UN DESA, 2021. World social report 2021: Reconsidering rural development. United Nations Department of Economic and Social Affairs.
Wan, G., Zhou, Z., 2005. Income inequality in rural China: Regression-based decomposition using household data. Rev. Dev. Econ. 9 (1), 107–120.
Wan, G., Wang, X., Zhang, R., Zhang, X., 2022a. The impact of road infrastructure on economic circulation: Market expansion and input cost saving. Econ. Model. 112, 105854.
Wan, G., Zhang, X., Zhao, M., 2022b. Urbanization can help reduce income inequality. npj Urban Sustain. 2, 1.
Xu, Z., Chau, S.N., Chen, X., Zhang, J., Li, Yingjie, Dietz, T., Wang, J., Winkler, J.A., Fan, F., Huang, B., Li, S., Wu, S., Herzberger, A., Tang, Y., Hong, D., Li, Yunkai, Liu, J., 2020. Assessing progress towards sustainable development over space and time. Nature 577 (7788), 74–78.
Yang, Y., Bao, W., Wang, Y., Liu, Y., 2021. Measurement of urban-rural integration level and its spatial differentiation in China in the new century. Habitat Int. 117, 102420.
Young, A., 2013. Inequality, the urban-rural gap, and migration. Q. J. Econ. 128, 1727–1785.
Yuan, Y., Wang, M., Zhu, Y., Huang, X., Xiong, X., 2020. Urbanization's effects on the urban-rural income gap in China: A meta-regression analysis. Land Use Policy 99, 104995.
Zhou, Q., Shi, W., 2022. How does town planning affect urban-rural income inequality: Evidence from China with simultaneous equation analysis. Landsc. Urban Plan. 221, 104380.