Spatiotemporal Pattern of the Urban-Rural Income Gap in the Yellow River Basin and Its Response to Urbanization: Postprint

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Abstract

Analyzing the spatiotemporal evolution characteristics of the urban-rural income gap and urbanization level in the Yellow River Basin and exploring their relationship is of great significance for addressing urban-rural and inter-regional development imbalances, narrowing the urban-rural income gap, and promoting integrated urban-rural development. Taking 76 regions in the Yellow River Basin as the research object and employing the Theil index, kernel density estimation, spatial econometric models, and GIS and mathematical analysis methods, this study analyzes the spatiotemporal evolution characteristics of the urban-rural income gap and urbanization level from 2005 to 2020, reveals the response degree of the former to the latter, and examines other influencing factors of the urban-rural income gap. The results show that: (1) From 2005 to 2020, the urban-rural income gap in the Yellow River Basin showed a narrowing trend; the urban-rural income gap across different zones exhibited a stepwise increasing pattern of "lower reaches < middle reaches < upper reaches"; and the urban-rural income gap among various regions demonstrated a trend of narrowing and convergence. At the regional level, the urban-rural income gap in 35 regions including Aba, Ankang, and Linfen exhibited an inverted U-shaped trend, while that in 35 regions including Anyang, Baoji, and Baotou showed a near-linear decreasing trend. In terms of spatial distribution, the urban-rural income gap in the Yellow River Basin showed an increasing trend from north to south and a decreasing trend from west to east. (2) From 2005 to 2020, the urbanization level in the Yellow River Basin exhibited characteristics of transformation from a relatively low level to a medium-high level, with a significant improvement in urbanization. (3) The impact of urbanization level on the urban-rural income gap in the Yellow River Basin demonstrated an inverted U-shaped nonlinear characteristic; after the urbanization level exceeded a certain threshold, its impact on the urban-rural income gap shifted from positive promotion to negative inhibition. The impact of urbanization level on the urban-rural income gap exhibited spatial heterogeneity characteristics: the impact of urbanization level on the urban-rural income gap in the upper and middle reaches of the Yellow River Basin showed an inverted U-shaped pattern, while that in the lower reaches displayed a negative linear characteristic. The urbanization level of neighboring regions exhibited spatial spillover effects, and both local urbanization level and neighboring regions' urbanization level had significant nonlinear inverted U-shaped relationships with the local urban-rural income gap. The research findings can provide reference and guidance for narrowing the urban-rural income gap in the Yellow River Basin and promoting urban-rural integration.

Full Text

Preamble

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Abstract: Analyzing the spatio-temporal evolution characteristics of urban-rural income disparity and urbanization level in the Yellow River Basin, and exploring their relationship, holds significant importance for addressing imbalanced development between urban and rural areas and across regions, narrowing the urban-rural income gap, and promoting integrated urban-rural development. This study examines 76 prefecture-level cities (prefectures, leagues, and municipalities) in the Yellow River Basin, employing the Theil index, kernel density estimation, spatial econometric models, GIS, and mathematical analysis methods to analyze the spatio-temporal evolution of urban-rural income disparity and urbanization level from 2005 to 2020. It reveals the response magnitude of the former to the latter and examines other influencing factors of urban-rural income disparity. Results show: (1) From 2005 to 2020, the urban-rural income gap in the Yellow River Basin exhibited a narrowing trend, with inter-zonal disparities showing a stepwise increasing pattern from downstream to upstream regions. Inter-regional income gaps demonstrated convergence. Regionally, 35 areas including Aba, Ankang, and Linfen displayed an inverted U-shaped trend, while 35 areas including Anyang, Baoji, and Baotou showed a nearly linear decreasing trend. Spatially, the income gap increased from north to south and decreased from west to east. (2) The basin's urbanization level transformed from predominantly low to medium-high, with significant improvement. (3) The impact of urbanization on income disparity showed a nonlinear inverted U-shaped pattern. After exceeding a certain threshold, urbanization's effect shifted from positive to negative. This impact exhibited spatial heterogeneity: upstream and midstream regions showed inverted U-shaped relationships, while downstream regions displayed negative linear relationships. Adjacent areas' urbanization levels generated spatial spillover effects, with both local and neighboring urbanization levels showing significant nonlinear inverted U-shaped relationships with local income gaps. These findings provide references for narrowing urban-rural income gaps and promoting urban-rural integration in the Yellow River Basin.

Keywords: urban-rural income; urbanization; spatial lag model; Yellow River Basin

Introduction

Since the reform and opening-up, China has experienced rapid urbanization, which has played a positive role in urban-rural development. However, constrained by urban-priority development strategies, citizen-biased distribution mechanisms, and heavy-industry-oriented industrial structures under the urban-rural dual system, urban-rural development imbalances remain prominent, with substantial income distribution gaps. After the 21st century, China successively implemented macro policies including coordinated urban-rural development, new rural construction, urban-rural integration, new urbanization, and urban-rural fusion to narrow urban-rural disparities.

The relationship between urban-rural income gap and urbanization has long been a focus of scholars worldwide. Kuznets hypothesized that with urbanization and industrialization progress, inter-sectoral income disparities would reach a turning point, with income inequality first rising then falling—forming an inverted U-shaped curve. Subsequent research has confirmed this hypothesis, showing that urban-rural income gaps transition from expansion to contraction as urbanization levels increase. Regional urbanization processes trigger labor mobility, which in turn affects income disparities. When income gaps exist, rural surplus labor migrates to modern non-agricultural sectors, raising incomes and narrowing the gap.

Domestic research on urban-rural income gaps and their relationship with urbanization has produced substantial results in three main areas. First, studies on spatio-temporal patterns employ long-term statistical data, using metrics such as urban-rural income ratio, coefficient of variation, Gini coefficient, and Theil index to analyze evolution characteristics. Research indicates significant regional differences in urban-rural income gaps across eastern, central, and western regions. Second, studies on influencing factors use linear regression and geographically weighted regression to identify drivers including population urbanization, government policies, infrastructure development, economic growth, and industrial structure. Some scholars have applied spatial econometric models to examine education and finance factors. Third, research on the urbanization-income gap relationship reveals varied effects: promotion, inhibition, or inverted U-shaped patterns across different spatio-temporal contexts. Regionally, urbanization correlates negatively with income gaps in developed areas but positively in less-developed regions with low urbanization and scarce agricultural labor. China has reached the Kuznets turning point, with urban-rural income gaps narrowing as wage income becomes the primary source of rural income growth.

However, existing research has limitations. Most studies focus on national or provincial scales, with insufficient attention to prefecture and county scales where macro-scale conclusions may not apply. Few studies incorporate geographic elements into models, largely neglecting spatial influences. The Yellow River Basin, a crucial natural unit for studying human-land relationships and an important agricultural base, faces pronounced urban-rural development imbalances. In 2020, the basin's urbanization rate was 60.24%, slightly below the national average of 63.88%, with both urban and rural per capita disposable incomes lower than national averages. Despite the basin's ecological protection and high-quality development strategy emphasizing coordinated urban-rural development, few studies have deeply analyzed the patterns, mechanisms, and processes of its urban-rural income gap or its relationship with urbanization.

Based on statistical panel data and integrated GIS and mathematical analysis, this study examines the spatio-temporal pattern of urban-rural income gaps and their response to urbanization in the Yellow River Basin. It analyzes the evolution of income disparity and urbanization from 2005 to 2020, and constructs spatial econometric models with spatial weight matrices to incorporate geographic elements, providing references for targeted policies to narrow income gaps and promote urban-rural integration.

1.1 Study Area

The Yellow River Basin flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong—nine provinces and autonomous regions—spanning eastern, central, and western China [Figure 1: see original paper]. This study defines 76 prefecture-level cities (prefectures, leagues, and municipalities) within the basin as the research area. By the end of 2020, the basin's permanent population reached 254 million, accounting for 17.99% of China's total population, with an urbanization rate of 60.24%, slightly below the national level of 63.88%. Both urban and rural per capita disposable incomes were lower than national averages.

1.2 Data Sources

Research data from 2005–2020 were obtained from provincial/municipal statistical bulletins, statistical yearbooks, *China City Statistical Yearbook*, CEInet Statistics Database (https://ceidata.cei.cn/), and China Economic and Social Big Data Platform (https://data.cnki.net/). Administrative boundary data came from the National Geomatics Center of China (https://www.ngcc.cn/).

1.3 Methods

1.3.1 Theil Index The Theil index, which accounts for population structure and income changes, is more reasonable and accurate than urban-rural income ratio or Gini coefficient for reflecting urban-rural income gaps. The formula is:

$$t = \sum_{j=1}^{2} \frac{p_{ij}}{p_i} \log\left(\frac{p_{ij}}{p_i} \cdot \frac{z_i}{z_{ij}}\right)$$

where $j = 1, 2$ represents urban and rural areas; p_i is total income in region i; p_{ij} is urban or rural total income in region i (population multiplied by per capita disposable income); z_{ij} is urban or rural population; z_i is total population; and t represents the Theil index, where smaller values indicate smaller gaps.

1.3.2 Kernel Density Estimation Kernel density estimation uses continuous density curves to characterize the distribution pattern of urban-rural income gaps. Comparing kernel density curves across years reveals dynamic evolution. The formula is:

$$f(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - y_i}{h}\right)$$

where $f(x)$ is the density function of random variable x; n is the number of regions; y_i is region i's Theil index; y is the mean Theil index; K and h represent the kernel function and bandwidth (Stata software defaults).

1.3.3 Spatial Correlation Test Spatial econometric models require significant spatial correlation in the dependent variable. Moran's I tests this. Table 1 shows significant spatial correlation in the dependent variable.

1.3.4 Spatial Econometric Model Given the spatial correlation (Table 1), traditional methods may yield biased results, so spatial econometric models are used. The spatial lag model is:

$$Y_{it} = \rho W_{ij} Y_{it} + \beta_1 x_{it} + \beta_2 x_{it}^2 + \gamma W_{ij} x_{it} + \theta W_{ij} x_{it}^2 + \delta Z_{it} + \varepsilon_{it}$$

where Y_{it} is the dependent variable (log of Theil index); i, j are different regions; ρ is the spatial lag coefficient; W_{ij} is the spatial weight matrix; x_{it} is urbanization level; β_1, β_2 reflect urbanization level and its squared term; γ, θ are spatial lag coefficients; δ reflects control variables; Z_{it} represents other controls; and ε_{it} is the error term. The spatial weight matrix uses inverse geographic distance: $W_{ij} = 1/d_{ij}$.

1.3.5 Variable Selection **Dependent Variable:** The Theil index (log-transformed as $\ln theil$) measures urban-rural income gaps.

Core Explanatory Variable: Urbanization level, measured as the ratio of urban permanent population to total population (log-transformed as $\ln ui$).

Control Variables: Following previous studies, these include: - Industrial structure ($\ln esin$): ratio of secondary and tertiary industry value-added to GDP, representing non-agricultural development. - Fixed asset investment share in primary industry ($\ln faipi$): ratio of primary industry fixed asset investment to total fixed asset investment. - Public budget expenditure share for agriculture, forestry, and water affairs ($\ln pbea$): ratio in general public budget expenditure, reflecting government priorities. - Highway mileage ($\ln hmpa$): ratio of regional highway mileage to area, measuring transportation accessibility. All control variables are log-transformed.

2.1 Spatiotemporal Pattern of Urban-Rural Income Gap in the Yellow River Basin

From 2005 to 2020, the urban-rural income gap in the Yellow River Basin showed a narrowing trend. At the basin scale, the Theil index decreased from 0.141 in 2005 to 0.089 in 2020, indicating gradual gap reduction. At the zonal level, gaps exhibited heterogeneity, with a "downstream < middle < upstream" stepwise increase pattern related to regional economic development. Compared nationally, downstream gaps were below the national average in 2020, while upstream and middle reaches exceeded it.

To characterize regional heterogeneity, kernel density estimation reveals dynamic evolution [Figure 3: see original paper]. From 2005 to 2020, the kernel density curve shifted leftward, indicating narrowing gaps. The distribution transitioned from right-skewed to normal, with shrinking intervals and shifting from "broad peak" to "sharp peak" shapes, showing increasing peaks and steepening crests. This indicates converging income gaps across regions, with reduced inter-regional disparities.

Spatial heterogeneity is evident. Using ArcGIS 10.8, Theil indices for 2005, 2010, 2015, and 2020 were visualized [Figure 4: see original paper], classified into five levels: low (0.00–0.05), relatively low (0.05–0.10), medium (0.10–0.20), relatively high (0.20–0.30), and high (0.30–0.50). In 2005, gaps were high in most areas except Yan'an, Sanmenxia, Shizuishan, Guyuan, and Linxia. By

2020, gaps showed a north-south differentiation and zonal distribution: low in northern areas (Zhangye, Alxa League), medium in central areas (Zhongwei, Yulin, Jincheng), and high in southern areas (Yushu, Aba, Longnan, Ankang). Western (Xining, Zhangye, Yushu), southeastern (Xi'an, Luoyang, Zhengzhou, Nanyang), and northern (Bayannur, Baotou, Ordos) regions showed narrowing trends, while central and southern areas experienced varying degrees of expansion. By 2020, 44.74% of areas had low gaps, 26.32% relatively low, and 27.63% medium, with northern and eastern areas predominantly low/relatively low, and southwestern Qinghai and Gansu transitioning from relatively high to medium.

Trend analysis of 76 regions from 2005–2020 reveals 35 areas (Aba, Ankang, Linfen, etc.) with inverted U-shaped trends, peaking around 2010–2015 before declining [Figure 5: see original paper]. Another 35 areas (Anyang, Baoji, Baotou, etc.) showed nearly linear decreasing trends. The remaining six areas (Bayannur, Shizuishan, Yangquan, Linxia, Guyuan, Xianyang) had less distinct patterns. Global trend analysis shows the basin's east-west trend line slightly U-shaped but generally decreasing from west to east, while the north-south trend shows a near-linear increase from north to south [Figure 6: see original paper].

2.2 Spatiotemporal Pattern of Urbanization Level in the Yellow River Basin

From 2005 to 2020, urbanization levels increased significantly, from 37.62% to 60.28% [Figure 2: see original paper]. Visualized in ArcGIS 10.8 and classified into five levels (0.00–0.20, 0.20–0.40, 0.40–0.60, 0.60–0.80, 0.80–1.00), the spatial pattern shifted from predominantly low/relatively low (63.16% in 2005) to medium/relatively high (84.21% in 2020) [Figure 7: see original paper]. In 2005, low-level urbanization clustered in the basin, with medium levels only in northern areas. By 2020, most central and southern areas increased, showing clustered distributions of medium/relatively high levels, reflecting rapid economic growth and new urbanization strategies. However, upstream areas with lagging economies and large agricultural populations (Guoluo, Longnan, Dingxi, Linxia, Wuzhong) maintained low urbanization.

2.3 Impact of Urbanization on Urban-Rural Income Gap

Using 2005–2020 data, Lagrange multiplier tests selected the optimal spatial econometric model among SLM, SEM, and SDM . Results rejected the null hypothesis in Hausman tests, indicating fixed effects suitability. Likelihood ratio tests confirmed significant time fixed effects, supporting a time-fixed SLM. Comparing OLS and SLM results , SLM showed better fit (higher R-squared, lower AIC/BIC), confirming spatial autocorrelation and SLM appropriateness.

The impact of urbanization on income gaps shows an inverted U-shaped nonlinear feature. Without controls, urbanization level ($\ln ui$) and its squared term ($(\ln ui)^2$) are significantly negative, indicating an inverted U-shaped relationship where urbanization first expands then narrows gaps after a threshold. With controls , coefficients remain stable, confirming this nonlinear impact. Results show urbanization initially expands income gaps; only after reaching a threshold does its gap-narrowing effect emerge.

Control variables show: primary industry fixed asset investment share ($\ln faipi$) is significantly negative, indicating rural infrastructure investment improves productivity and incomes; public budget expenditure for agriculture, forestry, and water affairs ($\ln pbea$) is significantly negative, as policies like subsidies, insurance, and training stabilize rural incomes; highway mileage ($\ln hmpa$) is significantly negative, as improved transport networks enhance factor mobility and narrow gaps.

Heterogeneity tests across upstream, middle, and downstream regions show upstream and middle reaches exhibit inverted U-shaped relationships (significant negative $(\ln ui)^2$), while the economically developed downstream region shows a negative linear relationship (insignificant $(\ln ui)^2$).

Spatial spillover analysis reveals that both local and neighboring urbanization levels have significant inverted U-shaped relationships with local income gaps, though neighbor effects (indirect effects) are smaller than local effects (direct effects). This reflects labor mobility patterns where rural workers often prefer local or nearby employment due to place attachment, making local urbanization more influential.

3.1 Conclusions

This study analyzed 76 prefecture-level cities in the Yellow River Basin from 2005–2020, examining spatio-temporal patterns of urban-rural income gaps and urbanization, and testing urbanization's impact effects. Key findings:

(1) The urban-rural income gap narrowed, with zonal heterogeneity showing a downstream $<$ middle $<$ upstream pattern. Regional gaps converged. Thirty-five areas showed inverted U-shaped trends, while 35 showed linear decreasing trends. Spatially, gaps increased from north to south and decreased from west to east.

(2) Urbanization levels shifted from predominantly low to medium-high, with significant improvement.

(3) Urbanization's impact on income gaps exhibited an inverted U-shaped nonlinear feature, shifting from positive to negative after a threshold. This impact showed spatial heterogeneity: upstream and middle reaches displayed inverted U-shaped patterns, while downstream regions showed negative linear relationships. Spatial spillover effects existed, with both local and neighboring urbanization levels showing significant inverted U-shaped relationships with local gaps, though neighbor effects were smaller.

3.2 Recommendations

Narrowing urban-rural gaps and promoting integration are key to high-quality development in the Yellow River Basin. Policy implications include:

(1) Further increase urban population to strengthen urbanization's role in narrowing income gaps. Urbanization does not automatically reduce gaps; its effects vary temporally and spatially. Most basin areas have entered the stage where urbanization inhibits gaps, so continued urbanization promotion is beneficial.

(2) Strengthen regional coordination. Besides local urbanization, neighboring areas' urbanization indirectly affects local gaps. Policies should account for cross-regional spillover effects, encourage multi-regional cooperation, accelerate regional integration, and relax household registration restrictions to facilitate labor mobility.

(3) Recognize complex influencing factors. Besides urbanization, primary industry investment, public budget expenditure, and highway mileage significantly affect gaps, indicating government policy preferences matter. With gaps already narrowing, continued agricultural support is necessary.

Further research should explore how urbanization affects gaps across different economic development levels and the mechanisms of spatial spillover effects.

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