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Research on the impact of urban-rural integration on rural land use efficiency in China

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As a core strategy in China's modernization process during the new era, urban-rural integration development is imperative for expanding the development space of Chinese-style modernization and advancing high-quality growth. This paper uses the panel data of provincial levels in China from 2012 to 2023 to construct a three-level indicator system to measure the level of urban-rural integration and rural land utilization efficiency in China's provinces, and explores the impact mechanism of China's urban-rural integration on rural land utilization efficiency. Findings include: (1) Urban-rural integration significantly enhances rural land use efficiency; (2) Mechanism analysis demonstrates that urban-rural integration boosts land transfer rates and labor mobility between urban and rural areas, thereby improving land use efficiency; (3) Regional heterogeneity analysis reveals stronger promoting effects in eastern and western regions, with statistically insignificant impacts in central China. Policy recommendations are proposed, focusing on establishing market-driven resource allocation mechanisms, implementing region-specific policies, and improving collaborative governance of land transfer and labor mobility. This research provides empirical support for deepening the theory of urban-rural integration, optimizing the allocation of land resources, formulating differentiated policies, and resolving regional development imbalances.

KEYWORDS

urban-rural integration, rural land use efficiency, land transfer, labor mobility between urban and rural areas, mediating mechanism

1 Introduction

The 20th Third Plenary Session of the Communist Party of China adopted The CPC Central Committee Decision on Further Comprehensively Deepening Reforms and Advancing Chinese-Style Modernization (hereafter the Decision), which emphasizes the necessity to "coordinate new-type industrialization, new-type urbanization, and comprehensive rural revitalization, holistically improve integrated urban-rural planning, construction, and governance, promote equal exchange and bidirectional flow of urban-rural factors, narrow urban-rural disparities, and foster shared prosperity." Urban-rural integration constitutes a pivotal strategic initiative for constructing China's dual-circulation development paradigm and driving high-quality economic growth. On the one hand, it requires leveraging the radiating and catalytic effects of new-type urbanization on rural areas to propel county-level economic development throughout its entire process. On the other hand, it necessitates promoting industrial convergence between urban and rural sectors, equalizing public services, and accelerating agricultural and rural modernization. As the core strategy of China's modernization in the new era, urban-rural integration represents both an urgent demand for advancing high-quality economic development and an inherent requirement of Chinese-style modernization. Since the concept was first introduced in the 2014 National New-Type Urbanization Plan, urban-rural integration has evolved from institutional design to practical dimensions encompassing factor allocation optimization and spatial governance restructuring, emerging as a critical pathway to resolve the "agriculture, rural areas, and farmers issues and achieve common prosperity. This process is fundamentally reshaping the spatial configurations and economic logic of the traditional urban-rural dual structure. Within this historic transformation, land—as the key medium bridging urban and rural systems—plays a decisive role. The evolution of its allocation efficiency not only determines the implementation efficacy of rural revitalization but also profoundly influences the synergistic advancement of new-type urbanization and agricultural/rural modernization.

China's 2024 National Economic Performance Report, released by the National Bureau of Statistics, reveals that the urban permanent population reached 943.5 million by year-end, an increase of 10.83 million from 2023, while the rural permanent population declined by 12.22 million to 464.78 million. The report indicates that the urbanization rate rose to 67.00%, marking a 0.84 percentage-point increase year-on-year. These figures underscore the persistent urbanization trend alongside accelerating rural population shrinkage. Concurrently, the State Council Report on Farmland Protection indicates a structural shift in China's arable land dynamics: the longstanding pattern of "decrease in the south, increase in the north" has transitioned to "dual increases across both regions." The national arable land area now totals 1.929 billion mu (128.6 million hectares), with a net increase of 11.204 million mu (0.58%) compared to the Third National Land Survey.

This statistical evidence highlights a paradoxical phenomenon: rural residential land continues to expand despite population decline, exposing deep-seated contradictions in urban-rural land resource allocation. Such contradictions necessitate critical inquiries: How do factor flows within urban-rural integration reshape the efficiency characteristics of rural land use? Do their mechanisms exhibit significant regional heterogeneity? Addressing these questions holds theoretical value for enriching spatial governance frameworks and practical urgency for optimizing land resource allocation and achieving equitable urban-rural factor exchange.

China is currently undergoing a critical phase of deep adjustments in urban-rural relations. The Fifth Plenary Session of the 19th CPC Central Committee explicitly proposed "strengthening industry-agriculture linkages and urban-rural coordination to foster a New-Type Urban-Rural Relationship characterized by mutual reinforcement between industries and agriculture, functional complementarity, coordinated development, and shared prosperity." China's arable land resources are limited and unevenly distributed. Improving efficiency can alleviate the problems of fragmented land and inefficient utilization, and at the same time, it can address the land demand pressure brought about by urbanization, prevent the loss of arable land and ecological degradation, and is the core path for achieving agricultural modernization and rural revitalization. From the perspective of urban-rural integration development, we can explore how mechanisms such as land transfer and labor migration can reshape the rural land utilization model, provide systematic solutions for building a unified factor market and optimizing territorial space governance, and contribute to the common development of urban-rural integration theory and practice. Against this backdrop, systematically elucidating the mechanisms through which urban-rural integration affects rural land use efficiency is imperative. This endeavor not only advances market-oriented reforms in land resource allocation but also constitutes a pivotal agenda for establishing a new development paradigm and achieving high-quality growth. Through multidimensional and multiscale systematic analysis, this study aims to provide novel theoretical perspectives and policy insights for addressing urban-rural land allocation imbalances and enhancing sustainable rural land use efficiency. Empirical findings demonstrate that urban-rural integration significantly enhances rural land use efficiency at the 1% significance level, with land transfer and inter-regional labor mobility identified as critical mediating pathways. Regional heterogeneity analysis further reveals stronger promoting effects in eastern and western China, whereas the impact remains statistically insignificant in central regions.

2 Literature review

2.1 Research on urban-rural integration development

The concept of urban-rural integration traces its origins to Thomas More's Utopia (Thomas, 2006), which advocates holistic planning of urban and rural areas as a unified system. Western scholars have proposed micro-level frameworks such as "urban-rural spatial production" and "dynamic suburban development" (Gimpel et al., 2020), exploring integration through lenses of spatial layout, industrial convergence, social cohesion, and governance networks (Serra et al., 2014; Rastogi and Curtis, 2020; Van Sandt and Carpenter, 2022; Ovaska et al., 2021). In China, urban-rural integration has emerged as a critical research focus due to persistent disparities in income, consumption, and infrastructure between urban and rural populations (Liu et al., 2021). National strategies like new-type urbanization, rural revitalization, and common prosperity (Liu et al., 2020; Chen et al., 2021) have significantly advanced integration (Fang, 2022). Chinese scholars further propose a "three-phase strategy" for integration, emphasizing policy-driven frameworks combining new-type urbanization and rural revitalization (Cao et al., 2019; Long et al., 2022). Institutional reforms to narrow urban-rural gaps and enhance factor mobility remain pivotal (Sun and Zhang, 2022). Theoretical contributions include Li (2017) argument that balanced urban-rural coordination sustains urbanization by reconciling resident needs, and Zhou and He's (2022) Marxist analysis of China's evolving urban-rural relations.

Empirical studies employ composite indicator systems and coupling coordination models to quantify integration levels (Ma et al., 2018; Yang et al., 2020; Zhang et al., 2020). Spatially, Zhang et al. (2022) evaluate coordination in the Yellow River Basin through urban development, rural progress, and integration metrics. Cao

(2021) assesses China's "dual-wheel coordination" spatial patterns using coupling coordination models, while Lu et al. (2021) identify "factor-structure-function" coupling mechanisms via spatial Moran's index analyses. Regional case studies, such as Zhang et al. (2021) analysis of Jiangsu Province and Yao and Peng's (2021) examination of Nanjing, highlight localized challenges and policy solutions like equitable public service systems. Drivers of integration span macro-level factors (natural environments, socioeconomic conditions) and micro-level elements (demographics, infrastructure, technology) (Overbeek, 2009; Zhang, 2016; Chen et al., 2020; Gharaibeh et al., 2022).

2.2 Research on the rural land use efficiency

Research on Land Use Efficiency has progressively emerged as a central focus in China's agricultural studies and a critical pathway to address arable land scarcity. Scholars have identified a significant correlation between urban-rural functional complementarity and improvements in land use efficiency (Gutierrez-Velez et al., 2022; Bosworth and Venhorst, 2018). Methodologically, land use efficiency assessments exhibit dynamic evolution. Researchers have refined evaluation frameworks by incorporating undesirable outputs (Tone, 2001; Alemdar and Oren, 2006; Ke et al., 2021), advancing the measurement system for green land use efficiency. The paradigm has shifted from early static efficiency evaluations (Chen et al., 2016; Li et al., 2017) to integrated approaches combining super-efficiency SBM models with spatial econometric methods (Tan et al., 2024; Souza and Gomes, 2015). Spatial analysis tools like Moran's I index further reveal heterogeneous clustering patterns, characterized by "high-high" and "low-low" efficiency agglomerations. These methodological innovations not only validate interregional technology spillover effects but also expose environmental externalities such as pollution displacement. Currently, research scopes on rural land use efficiency have expanded systematically. Academic focus has extended from urban built-up areas (ULGUE) to cultivated land systems (CLGUE), forming a trinity evaluation framework encompassing economic, social, and ecological dimensions. Xie et al. (2018) broke through linear evaluation paradigms with their generalized directional distance function, while Zhou et al. (2023) demonstrated enhanced yet regionally divergent coordination between cultivated land green efficiency and high-quality agricultural development using composite indicators. Empirical studies based on SDG indicators (Lu et al., 2018; Guo C et al., 2024) suggest synergistic potential between land use efficiency and ecological benefits amid rapid urbanization. Furthermore, research on the determinants of rural land use efficiency exhibits multiscale interactive characteristics. At the micro level, household-specific attributes serve as foundational variables driving efficiency disparities. Human capital factors such as education levels (Khai and Yabe, 2011) and technical training (Naceur and Mongi, 2013) influence efficiency outcomes through production decision-making. At the meso level, the benefit distribution mechanisms embedded in land transfer systems (Fukuyama and Weber, 2010; Fukuyama et al., 2011) impose structural constraints. At the macro level, institutional innovations like innovative city pilot policies (Xu et al., 2025) enhance urban land green use efficiency (ULGUE), yet persistent regional development disparities (Qin et al., 2022; Hong and Mao, 2024) remain a major institutional barrier.

2.3 Literature review

Existing studies have extensively explored China's urban-rural integration and rural land use efficiency, identifying deepened urban-rural integration as a pivotal breakthrough for addressing rural land underutilization. This raises two critical questions: Does urban-rural integration effectively enhance rural land use efficiency? and Given regional disparities in resource endowments and labor mobility, does its impact exhibit significant spatial heterogeneity? To address these questions, this study employs provincial-level panel data (2012–2023) from China (provinces, autonomous regions, and municipalities) to construct a three-tier indicator system measuring urban-rural integration and rural land use efficiency. By comprehensively assessing their spatiotemporal dynamics, we further investigate the mechanisms through which urban-rural integration influences rural land efficiency, aiming to provide evidence-based insights for optimizing provincial land governance.

The study's marginal contributions are twofold. Theoretically, it enriches existing frameworks on rural land use efficiency by systematically analyzing the causal linkages between urban-rural integration and efficiency outcomes. Methodologically, it advances empirical rigor by identifying mediating mechanisms (e.g., factor mobility) and rigorously testing regional heterogeneity, thereby addressing gaps in prior research.

3 Theoretical analysis and research hypotheses

3.1 The direct mechanism by which urban-rural integration promotes the rural land use efficiency

Agglomeration Externality Theory posits that urban-rural integration drives the restructuring of spatial land factors between cities and rural areas. For instance, the interconnectivity of urban-rural infrastructure directly alleviates geographical constraints on land elements, integrating rural land into urban economic spheres' spatial production systems. This structural transformation of rural land productivity generates agglomeration economies, thereby enhancing rural land use efficiency. First, advancements in digital technologies—such as big data, 5G, and blockchain—have redefined the factor attributes of rural and urban land. This shift enables rural land management to transition from experience-driven to data-driven practices. Applications like precision fertilization and smart irrigation bypass the need for labor mobility as intermediaries, directly boosting marginal output per unit of land and improving efficiency. Second, industrial planning elevates urban-rural integration levels, establishing direct capitalization channels for rural land. Collectively-owned commercial construction land can now enter markets without expropriation, reflecting true market value. This incentivizes land users to optimize factor combinations, eliminates mismatches caused by spatial fragmentation, and expands land productivity's Pareto Frontier through spatial reorganization and technological embedding. Additionally, mixed-use land development policies grant rural land multifunctional usage rights, breaking traditional monocultural agricultural constraints and fostering spatial factor flexibility, which further elevates efficiency.

Hypothesis 1: Urban-rural integration significantly enhances rural land use efficiency through agglomeration externalities, technological innovation, and institutional restructuring.

3.2 Indirect mechanism by which urban-rural integration promotes the rural land use efficiency

3.2.1 The integrated development of urban and rural areas promotes land transfer, thereby enhancing the rural land use efficiency

New Institutional Economics posits that urban-rural integration constitutes a systemic transformation driven by the co-evolution of institutional innovation and factor allocation. Through mechanisms such as land property rights refinement and transaction cost reduction, efficient property rights arrangements optimize resource allocation by lowering transaction costs, reshaping incentive structures for factor mobility, and dismantling institutional barriers embedded in the urban-rural dual system. This facilitates the transition of land resources from inefficient lock-ins to market-driven configurations. China's "Three Rights Separation" reform exemplifies this logic: by decoupling land contractual rights and management rights, it establishes an institutional foundation for land transfer, enabling fragmented plots to consolidate into scaled operational units and significantly improving land's marginal output elasticity (Sun and Zhou, 2019). Concurrently, the deepening market mechanisms in urban-rural integration have catalyzed new agricultural entities like family farms and cooperatives. Contract-based land transfers foster intensive land utilization, generating transaction cost advantages over fragmented household operations. Large-scale production through these entities reduces transaction costs in technology adoption, capital investment, and market access (Li et al., 2023). Thus, urban-rural integration enhances rural land use efficiency by promoting land transfer through property rights refinement and transaction cost reduction.

Hypothesis 2: Urban-rural integration promotes land transfer, thereby improving rural land use efficiency.

3.2.2 The integrated development of urban and rural areas promotes the mobility of the labor force between urban and rural areas, thereby enhancing the rural land use efficiency

From the Coupled Perspective of New Institutional Economics and Structural Transformation Theory, urban-rural integration dismantles institutional barriers such as the household registration (hukou) and land systems, reshaping incentive structures for labor migration and intensifying cross-regional labor mobility. First, the equalization of public services and reforms to the household registration system reduce urbanization costs for rural migrants, incentivizing labor shifts from low-productivity agricultural sectors to urban non-agricultural sectors (Wang et al., 2020). Second, the separation of land contractual rights and management rights creates an "exit-transfer-appreciation" closed loop through property rights refinement. This enables (left-behind farmers) to achieve scaled operations via land transfers, triggering intensive land reorganization and enhancing efficiency (Liao et al., 2020). Additionally, urban-rural human capital interactions accelerate technology diffusion. The "knowledge spillback" effect-driven by returning entrepreneurs and urban technological spillovers-upgrades traditional agriculture into high-value-added sectors. This reinforces path dependency in land efficiency improvements, spurring industrial restructuring where capital and technology substitute labor inputs, reducing per-unit management costs, and boosting total factor productivity (Hayami and Ruttan, 1985).

Hypothesis 3: Urban-rural integration promotes labor mobility between urban and rural areas, thereby enhancing rural land use efficiency.

4 Empirical design

4.1 Data selection and source explanation

4.1.1 Dependent variable: rural land use efficiency (*Rlue*)

To address input-output slack issues inherent in traditional Data Envelopment Analysis (DEA) with multiple inputs and outputs, this study employs an input-oriented Super-SBM-Undesirable model under constant returns to scale (CRS) to measure rural land use efficiency. This approach effectively resolves slack variable problems compared to conventional DEA frameworks.

Suppose there are n production decision-making units (DMU, $n = 1, 2, 3, \ldots, N$), and each DMU contains input and output variables with expected and undesirable outputs, with quantities of m, l and h respectively. The formula for calculating agricultural land use efficiency is as follows:

$$min\,\theta = \frac{1 + \frac{1}{m}\sum_{m=1}^{M}\left(\frac{S_m^x}{S_{jm}^t}\right)}{1 - \frac{1}{l+h}\left(\sum_{l=1}^{L}\left(\frac{S_l^y}{y_{jl}^t}\right) + \sum_{h=1}^{H}\frac{S_h^b}{b_{jh}^t}\right)} \tag{1}$$

$$\text{s.t. } x_{jm}^t \geq \sum_{j=1, j\neq 0}^{n} \lambda_j^t x_{jm}^t + S_m^x \tag{2}$$

$$y_{jl}^t \geq \sum_{j=1, j\neq k}^{n} \lambda_j^t y_{jl}^t - S_l^y \tag{3}$$

$$b_{jh}^t \geq \sum_{j=1, j\neq k}^{n} \lambda_j^t b_{jh}^t + S_h^b \tag{4}$$

Herein, $\lambda_j^t \geq 0,\ S_m^x \geq 0,\ S_l^y \geq 0,\ j = 1, \ldots\ldots, n; \theta$ represents of rural land use efficiency; x_j^t, y_j^t and b_j^t respectively represent the input, expected output and non-expected output values; S_m^x, S_l^y and S_h^b respectively denote the slack variables of input, expected output and non-expected output; λ represents the weight variable. Table 1 presents the three-level indicator system of input-output for rural land use efficiency.

TABLE 1 Inputs and outputs of rural land use efficiency.

Primary indicator	Secondary indicator	Tertiary indicator	Indicator meaning unit	Primary indicator
Rural land use efficiency	Investment indicators	Land input	Rural cultivated land area	1,000 hm^2
		Labor input	Number of people employed in the primary industry	10,000 people
		Capital input	Regional capital stock	10 billion yuan
	Expected output	Economic increment	Growth rate of the primary industry	10 billion yuan
		Social welfare	Grain output	10,000 tons
	Unanticipated output	Water pollution Air pollution	Agricultural wastewater discharge volume	10,000 tons
		Land input	Agricultural ammonia nitrogen discharge volume	10,000 tons

TABLE 2 Measurement and evaluation system for the level of urban-rural integration development in China.

Primary indicator	Secondary indicator	Third-level indicator	Calculation formula	Indicator nature
Urban-rural integrated development	Economic integration	Economic development level	Per capita GDP	+
		Income gap between urban and rural residents	Per capita disposable income of urban residents/Pe r capita disposable income of rural residents	−
		Expenditure gap between urban and rural residents	Per capita consumption expenditure of urban residents/Per capita consumption expenditure of rural residents	−
		Binary comparison coefficient	(Gross output value of the primary industry/Number of employed in the primary industry)/(Gross output value of the second and third industries/Number of employed)	+
	Social integration	Coverage rate of urban-rural old-age insurance	Number of insured for urban-rural old-age insurance/ Population of permanent residence	+
		Coverage rate of unemployment insurance	Number of participants in unemployment insurance/ Population of permanent residence	+
		Urban-rural *per capita* healthcare comparison coefficient	Per capita healthcare expenditure of urban residents/ Healthcare expenditure of rural residents	−
		Urban registered unemployment rate	Direct data	−
		Urban-rural education investment	Education expenditure/Fiscal expenditure	+
	Spatial integration	Number of private cars owned	Direct data Urbanization rate Number of urban population/Total population直接数据	+
		Urbanization rate	Number of urban population/Total population	+
		Urban-rural *per capita* transportation and communication comparison coefficient	Per capita transportation and communication expenditure of urban residents/Transportation and communication expenditure of rural residents	−
	Ecological integration	Harmless treatment of domestic waste	Direct data	+
		Forest coverage rate	Direct data	+
		Public toilet availability	Number of public toilets per 10,000 people	+

Note: The data is sourced from "China Statistical Yearbook," "China Rural Statistical Yearbook," "China Population and Employment Statistical Yearbook," "China Environmental Statistical Yearbook," "China Health Statistics Yearbook," "China Education Statistical Yearbook," "China Urban Construction Statistical Yearbook," and the statistical yearbooks of each province (municipality, district). Among them, the spherical distance between provincial capital cities was calculated using ArcGIS 10.8; the PM2.5 concentration data was obtained from the Atmospheric Composition Analysis Group of Dalhousie University.

4.1.2 Core explanatory variable: urban-rural integration level (*Cud*)

This study constructs an evaluation index system for urban-rural integration across four dimensions—economic, social, spatial, and ecological integration—as outlined in Table 2. (1) Economic Integration. Emphasizes free factor flows between urban and rural areas, reflecting regional living standards, developmental potential, and resource allocation efficiency. (2) Social Integration. Focuses on equitable access to social services and welfare, measuring the coordinated development of education, healthcare, and social security systems across urban and rural regions. (3) Spatial Integration. Serves as the spatial vehicle for integrated development, evaluating population distribution, land use patterns, and the capacity for factor circulation and spillover effects. (4) Ecological Integration. Places urban and rural areas within a unified environmental system, assessing air/water quality, green infrastructure, and sustainability of development practices.

4.1.3 Panel entropy method + TOPSISI

The evaluation model for digital economy and rural land use efficiency is constructed using the panel information entropy. The specific calculation steps are as follows: Firstly, select the indicators: Let there be m cities and n indicators. Then, q_{ij} represents the j, the indicator of city i ($i = 1, 2, \ldots, n$). To address the dimensional issues caused by different units, the indicators are standardized. The absolute values of the indicators are transformed into relative values, and $q_{ij} = | q_{ij} |$ is adopted. The meanings represented by the numerical values of positive and negative indicators are different (the higher the value of positive indicators, the better; the smaller the value of negative indicators, the better). The following steps are adopted to standardize the indicators:

$$\text{Positive standardization}: q^{`}ij = \frac{q_{ij} - min\{q_{1i}, \ldots, q_{mj}\}}{max\{q_{1i}, \ldots, q_{mj}\} - min\{q_{1i}, \ldots, q_{mj}\}} + 1 \tag{5}$$

$$\text{Negative standardization}: q^{`}ij = \frac{max\{q_{1i}, \ldots, q_{mj}\} - q_{ij}}{max\{q_{1i}, \ldots, q_{mj}\} - min\{q_{1i}, \ldots, q_{mj}\}} + 1 \tag{6}$$

Determine the weight of the ith city in the jth indicator: Let $p_{ij} = \frac{q^{`}ij}{\sum_{i=1}^{m} q^{`}ij}$; calculate the entropy value of the jth indicator, $e_j = -k\sum_{i=1}^{m} q_{ij}\, ln(p_{ij})$, $(i = 1, 2, ..., m; j = 1, 2, ..., n)$, where $k > 0$, $k = \ln(m)$, represents the adjustment coefficient, ensuring that $0<e_j < 1$; calculate the information utility value of the jth item indicator: $d_j = 1\text{-}e_j$ (j = 1, 2, . . . , n). The larger information utility value d_j is, the more important the indicator is; calculate the weight of the jth indicator: $wj = \frac{d_j}{\sum_{j=1}^{n} d_j}$ $(j = 1, 2, ..., n)$; calculate the comprehensive score of the ith city: $S_j = \sum_j^n w_j p_{ij}$ $(i = 1, 2, ..., m; j = 1, 2, ..., n)$.

Secondly, to mitigate the potential bias in indicator weights caused by high numerical dispersion—where certain indicators dominate the evaluation due to scale differences—this study incorporates the Euclidean distance to measure the relative proximity of each evaluation unit to the ideal (or worst) solution. This approach adjusts for distortions in ranking results that may arise from excessive sensitivity to data accuracy or indicator selection.

By integrating this distance-based correction, the method not only maximizes the utilization of available data and minimizes information loss, but also reduces the influence of sample size limitations and reference sequence dependencies. As a result, it provides a more accurate and stable representation of regional differences and development trends in the digital economy and rural land use efficiency.

The specific computational steps are as follows: Calculate the weighted standardized matrix of each index. $R = (r_{ij})m \times n, r_{ij} = w_j x^{`}_{ij}$ $(1 \le i \le m, 1 \le j \le n)$; determine the optimal solution S_j^+ and the worst solution S_j^-. $S_j^+ = max(r_{ij}), S_j^- = min(r_{ij})$, where, $1 \le i \le m$, $1 \le j \le n$; calculate the Euclidean distance between each scheme and the optimal solution; $sep_i^+ = \sqrt{\sum_{j=1}^{n} (S_j^+ - r_{ij})^2}$, $sep_i^- = \sqrt{\sum_{j=1}^{n} (S_j^- - r_{ij})^2}$; calculate the comprehensive evaluation index of each scheme, $C_i = \frac{sep_i^-}{sep_i^- + sep_i^+}$, $C_i \in [0,1]$.

4.1.4 Mediating variables

(1) Land mobility (*Land-flow*), mainly reflected in the transfer of agricultural land to non-agricultural land. Therefore, the proxy variable for land mobility is the proportion of industrial and storage land area to the total urban construction land area. (2) Labor mobility (*Lab-flow*), measured using a two-way constrained semi-logarithmic gravity model. The specific calculation method is as shown in Equation 7:

$$Lab - flow_{ij} = ln\, Labq_i \times \ln\big(Wage_j - Wage_i\big) \times \ln\big(Priceh_i - Priceh_j\big) \times Dis_{ij}^{-2} \tag{7}$$

Among them, $Lab\text{-}flow_{ij}$ represents the number of labor force flowing from region i to region j, $Labq_i$ represents the total number of labor force in region i, $Wage_j$ and $Wage_i$ respectively represent the average wage level of on-the-job workers in region j and i, $Priceh_i$ and $Priceh_j$ respectively represent the average housing prices in region i and j, and Dis_{ij} represents the geographical distance between region i and region j.

4.1.5 Other control variables

To reduce the endogeneity problem that may be caused by omitted variables and to accurately reflect other factors influencing the rural land use efficiency, this paper sets the following control variables: (1) Economic development level (ln*GDP*). The economic development situation of each province is represented by the GDP of that province. (2) Human capital level (ln*Edu*), which is indicated by the number of college students per hundred people. (3) Social employment security (ln*Sis*), which is represented by the ratio of local fiscal social security and employment expenditures to local fiscal total expenditures. (4) Financial development level (ln*Find*), which is indicated by the proportion of financial loan balance at the end of the year to GDP. (5) Social consumption level (ln*Con*), which is indicated by the proportion of social consumption to GDP, the calculation formula is: total retail sales of consumer goods/GDP. (6) Labor cost (ln*Wage*). It is represented by the logarithm of the average annual salary of urban workers in each province (city). Descriptive statistics of the variables are shown in Table 3.

4.2 Empirical design

4.2.1 Model construction

4.2.1.1 Basic regression model

Based on the analysis in the previous text, a two-way fixed effects model was adopted to investigate the impact of urban-rural

TABLE 3 Descriptive statistics of variables.

Variable	Symbol	Variable description	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
Dependent variable	*Rlue*	Rural land use efficiency, calculated based on the indicator system in Table 1	360	0.615	0.285	0.094	1.425
Independent variable	*Cud*	Urban-rural integration development level, calculated based on the indicator system in Table 2	360	0.354	0.092	0.145	0.634
Mediating variable	*Land-flow*	Land mobility, represented by the proportion of industrial and storage land area to the total urban construction land area	360	0.210	0.087	0.005	0.740
	Lab-flow	Labor mobility, measured by the two-way constrained semi-logarithmic gravity model for labor mobility volume	360	10.140	0.706	6.687	11.964
Control variables	ln*GDP*	Economic development level of each province, represented by the logarithm of the provincial GDP	360	9.684	1.003	6.416	11.587
	ln*Edu*	Human capital level, represented by the number of college students per hundred people	360	1.795	2.001	0.007	12.764
	ln*Sis*	Social employment security, represented by the ratio of local fiscal social security and employment expenditures to local fiscal total expenditures	360	0.131	0.046	0.001	0.443
	ln*Find*	Financial development level, represented by the proportion of end-of-year financial loan balance to GDP	360	1.060	0.663	0.118	9.622
	ln*Con*	Social consumption level, represented by the proportion of social consumption to GDP	360	0.385	0.116	0.001	2.227
	ln*Wage*	Labor cost. Represented by the logarithm of the annual average wage of urban employees in each province (city)	360	1.778	0.320	1.143	2.814

integration on the rural land use efficiency of Chinese provinces. The following settings were made:

$$Rlue_{it} = \alpha_0 + \alpha_1 Cud + \alpha_2 \ln GDP_{it} + \alpha_3 ln\, Edu_{it} + \alpha_4 ln\, Sis_{it} + \alpha_5 ln\, Find_{it} + \alpha_6 ln\, Con_{it} + \alpha_7 ln\, Wage_{it} + \mu_{it} + \sigma_{it} + \varepsilon_{it} \quad (8)$$

Here, i represents the provinces (municipalities, autonomous regions) of China, and t represents the year; $Rlue_{it}$ represents rural land use efficiency of each province in China in year t and year t-1; Cud_{it} represents the level of urban-rural integration development in each province of China in year t; $lnGDP_{it}$ represents the economic development level of each province in year t; $\ln Edu_{it}$ represents the human development level of each province in year t; $\ln Sis_{it}$ represents the social employment security level of each province; $\ln Find_{it}$ represents the financial development level of each province in year t; $\ln Con_{it}$ represents the social consumption level of each province in year t; $\ln Wage_{it}$ represents the labor cost of each province in year t; μ_{it} and σ_{it} respectively represent the fixed effects of provinces and time, and ε_{ijt} is the random error term.

4.2.1.2 Mediation effect model

To further explore the mediating effect of the mechanism variables in the impact of urban-rural integration on the rural land use efficiency of Chinese provinces, based on the analysis in the previous text, this paper, on the basis of Equation 8, combined with the analysis of the influencing mechanism in the previous text, establishes the following mediation effect model:

$$M_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{it} + \varnothing_{it} + \varepsilon it \quad (9)$$

$$Y_{it} = \gamma_0 + \gamma_1 X_{it} + \gamma_2 M_{it} + \gamma_3 Z_{it} + \varnothing_{it} + \xi_{it} \quad (10)$$

Here, M_{it} represents the mechanism variable, indicating the land and labor mobility within each province of China; X_{it} are a series of control variables in Equation 8 that affect the rural land use efficiency of each province in China; φ_{it} represents the time and province fixed effects; ξ_{it} and ε_{it} are random error terms.

4.3 Analysis of the basic regression results

In the basic regression, a two-way fixed effects model is used for estimation. To alleviate the estimation bias caused by omitted variables and other factors, in the basic regression, both the year and province fixed effects are controlled separately. At the same time, robust standard errors are adopted to ensure the reliability of the regression results. The regression results are shown in Table 4.

TABLE 4 Basic regression (dependent variable: Rural land use efficiency).

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Cud	0.497*** (0.114)	0.317*** (0.105)	0.379*** (0.128)	0.281*** (0.166)	0.227*** (0.009)	0.201*** (0.029)
ln*GDP*		0.101** (0.0482)	0.208** (0.106)	0.128** (0.0513)	0.0333** (0.0160)	0.0556* (0.0337)
ln*Edu*			−0.0337*** (0.00968)	−0.179*** (0.0640)	−0.104*** (0.0373)	−0.123** (0.0715)
ln*Sis*			−0.0186* (0.00987)	−0.0119** (0.00829)	−0.0301*** (0.0113)	−0.0157** (0.0111)
ln*Find*				−0.0625 (0.0366)	−0.0594 (0.0410)	−0.0267 (0.0300)
ln*Con*					0.0658** (0.0287)	0.0628** (0.0274)
ln*Wage*						−0.109*** (0.0293)
Constant term	−1.794** (0.765)	−0.477* (0.247)	0.421* (0.232)	0.247 (0.209)	0.280*** (0.0483)	−0.024 (0.037)
Observation	360	360	360	360	360	360
Provincial fixed effect	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
R-squared	0.249	0.269	0.429	0.944	0.586	0.810

Note: The symbols "***", "**", and "*" indicate significance levels of 1%, 5%, and 10% respectively. The values in parentheses represent the robust standard errors. The table below is the same.

Table 4 reports regression results for the full sample with province and year fixed effects. Column (1) presents baseline estimates with only the urban-rural integration level (*Cud*), while columns (2)–(6) sequentially incorporate control variables. The coefficients and significance of *Cud* remain stable across specifications, confirming result robustness. We focus on column (6), which includes all controls.

The coefficient for *Cud* is positive and statistically significant at the 1% level, indicating that urban-rural integration significantly enhances rural land use efficiency (Hypothesis 1 is validated). New Institutional Economics posits this efficiency gain as a Pareto improvement process driven by synergistic factor reallocation and institutional reforms. Dismantling the urban-rural dual system removes institutional barriers, enabling bidirectional flows of land, capital, and technology—termed the "counterflow effect"—which optimizes rural land productivity. Quantitatively, a 1% increase in *Cud* correlates with a 0.379% improvement in rural land use efficiency.

Key findings on control variables: Economic development (ln*GDP*): Significantly positive (1% level). Capital spillovers from developed regions to rural areas under diminishing marginal returns drive scaled operations and efficiency gains. Human capital (ln*Edu*) and social employment security (ln*Sis*): Significantly negative (5% level). Urbanization attracts skilled labor away from rural areas, lowering agricultural labor quality and suppressing efficiency. Financial development (ln*Find*): Statistically insignificant. Financial deepening exhibits no measurable impact on rural land efficiency. Social consumption (ln*Con*): Significantly positive (1% level). Rising demand for high-quality agricultural products incentivizes supply-side reforms, shifting land use from low-yield crops to high-value agriculture. Labor costs (ln*Wage*): Significantly negative (5% level). Higher urban wages exacerbate rural brain drain, reducing labor availability and efficiency despite potential skill upgrades.

4.4 Robustness test

In order to ensure the reliability of the regression results, this paper has conducted robustness tests from the following four aspects, as follows:

4.4.1 Alternative measurement for core explanatory variable

To address dimensional heterogeneity in indicators, the original index system was normalized. The traditional entropy method was improved using factor analysis: factor loadings and component scores derived from primary indicators were integrated with entropy-based difference coefficients to recalculate the dependent variable. As shown in Column (1) of Table 5, the coefficient signs and significance levels align with baseline results, confirming robustness.

4.4.2 Alternative measurement for dependent variable

The dependent variable was recalculated using the standard SBM-Undesirable model instead of the super-efficiency variant. Re-estimation results (Table 5, Column 2) show *Cud* remains significantly positive at the 1% level, further validating robustness.

4.4.3 Adjusted observation period

To mitigate temporal bias, the sample period was narrowed to 2014–2021. Regression results (Table 5, Column 3) demonstrate that *Cud* retains its positive significance, consistent with baseline findings.

4.4.4 Instrumental variable (IV) approach

To address potential endogeneity from temporal lag effects, one-period lagged *Cud* was employed as an IV in a two-stage least squares (2SLS) framework. The lagged variable correlates with current *Cud* but lacks direct contemporaneous influence on land use efficiency, satisfying IV relevance and exogeneity

TABLE 5 Robustness test.

Variable	(1)	(2)	(3)	(4)
Cud	0.012** (0.005)	0.137*** (1.026)	0.573*** (0.899)	1.430*** (0.257)
Control variables	YES	YES	YES	YES
Constant	−0.810*** (0.027)	−0.985* (0.457)	−1.899*** (0.056)	0.764*** (0.134)
Fixed effect	YES	YES	YES	YES
Anderson canon. corr. LM statistic	—	—	—	46.000*** (0.000)
C-D Wald F statistic	—	—	—	66.000 (16.38)
Observation	360	360	360	330
R-squared	0.899	0.889	0.895	0.732

TABLE 6 Mechanism verification.

Variable	(1)	(2)	(3)	(4)
	Land-flow	*Rlue*	*Lab-flow*	*Rlue*
Cud	0.538*** (0.316)	0.468*** (0.225)	0.130*** (0.157)	0.157*** (0.237)
Land-flow		0.225*** (0.014)		
Lab-flow				0.056*** (0.020)
Control variables	YES	YES	YES	YES
Constant	29.129*** (0.117)	9.100*** (0.131)	−1.066** (0.426)	−2.123*** (0.077)
Fixed effect	YES	YES	YES	YES
Observation	360	360	360	360
R-squared	0.910	0.943	0.104	0.100

requirements. Results (Table 5, Column 4) pass weak IV and validity tests, with coefficient signs and significance mirroring baseline estimates.

After conducting robustness and endogeneity tests using the above four methods, the coefficient sign and significance of the core explanatory variable (*Cud*) is consistent with the results of the basic regression. Therefore, the research conclusions of this paper are basically reliable.

4.5 Mechanism verification

Building on the theoretical mechanisms discussed earlier, urban-rural integration exerts an indirect impact on rural land use efficiency. To further investigate the mediating roles of land transfer and labor mobility between urban and rural areas, this study employs a mediation effect model. Regression results, presented in Table 6, confirm that these factors significantly channel the influence of urban-rural integration on efficiency improvements.

Columns (1)–(2) of Table 6 present regression results testing the mediating role of land transfer (*Land-flow*). Column (1) demonstrates that urban-rural integration significantly enhances land transfer rates at the 1% significance level. Column (2) confirms that urban-rural integration improves rural land use efficiency by promoting land transfer, thereby validating Hypothesis 2. The empirical results align with theoretical predictions. Urban-rural integration drives land property rights refinement and transaction cost reduction, which collectively optimize resource allocation and incentivize efficient land use. This institutional restructuring enables fragmented rural plots to consolidate into scaled operational units, directly boosting marginal productivity and reducing idle land resources.

Columns (3)–(4) of Table 6 present regression results testing the mediating role of labor mobility (*Lab-flow*) between urban and rural areas. Column (3) shows that urban-rural integration significantly enhances labor mobility at the 1% significance level. Column (4) confirms that integration improves rural land use efficiency by facilitating labor mobility, thereby validating Hypothesis 3. The empirical evidence aligns with theoretical mechanisms. Urban-rural integration dismantles institutional barriers, reshaping migration incentives and intensifying bidirectional labor flows. This dynamic accelerates the skill upgrading of rural labor through knowledge spillovers from urban sectors, while reducing labor redundancy in agriculture. Consequently, rural land management transitions toward capital- and technology-intensive practices, optimizing input-output ratios and elevating land productivity.

TABLE 7 Results of heterogeneity tests in different regions.

Variables	(1)	(2)	(3)
	Eastern region	Central region	Western region
Cud	0.726** (2.344)	0.166 (0.702)	1.563** (2.036)
Control variables	YES	YES	YES
Fixed effect	YES	YES	YES
Constant	1.531*** (6.600)	0.528* (1.898)	0.791*** (3.447)
Observations	132	96	132
R-squared	0.643	0.733	0.717

4.6 Heterogeneity test

4.6.1 Analysis of heterogeneity in different regions

As a vast agricultural country with diverse regional conditions, China has significant regional differences in terms of resource endowment, economic development, and population density. Therefore, there are considerable regional disparities in the degree of urban-rural integration in China. It is thus necessary to conduct research on the different impacts of urban-rural integration on the efficiency of rural land use in the eastern, central, and western regions, in order to better understand whether there are heterogeneities in the impact of urban-rural integration on rural land use efficiency under the background of regional heterogeneity. Empirical results, presented in Table 7, reveal distinct spatial patterns: Column (1) shows that urban-rural integration significantly enhances rural land use efficiency in the eastern region at the 5% significance level. Column (3) demonstrates a stronger positive effect in the western region, significant at the 1% level. Column (2) indicates an insignificant impact in the central region, despite a positive coefficient. From the perspective of the eastern region, benefits from robust economic foundations, advanced digital literacy among farmers, and a concentration of universities and research institutions, which elevate labor quality and technological adoption. These factors synergistically amplify integration's efficiency-enhancing effects. From the perspective of the western region, leverages abundant land resources and ecological advantages, enabling sustainable land use practices that offset economic constraints. From the perspective of the central region, faces challenges from the "siphoning effect" of eastern economies, where labor outflows reduce rural workforce quality and hinder efficiency. According to the statistics released by the National Bureau of Statistics of China, in 2023, among the migrant workers from the eastern region, those who moved across provinces accounted for 13.8%, those from the central region accounted for 51.7%, those from the western region accounted for 44.5%, and those from the northeastern region accounted for 30.9%. The high wage attraction effect in the eastern region led to the migration of labor force from the central region, resulting in the hollowing out of industries in the central region and insufficient factor concentration, making it difficult to enhance land utilization efficiency through urban-rural integration. Therefore, the central region should leverage the spillover effects of digital technology and the favorable policy environment to gain "latecomer advantages," thereby better promoting the level of urban-rural integration and enhancing the rural land use efficiency.

4.6.2 Heterogeneity across grain functional zones

The major grain-producing areas focus on ensuring food security as their core objective. The flow of urban and rural resources is mainly based on large-scale farming, but the land use is strictly restricted. The major grain-consuming areas, due to the pressure of self-sufficiency, are compelled to innovate the market mechanism and need to enhance marginal returns. The balanced areas need to balance production and market flexibility. These functional positioning differences result in the non-uniform impact of urban-rural integration on land use efficiency. Therefore, it is necessary to investigate whether there are any differences in the impact of urban-rural integration on the rural land use efficiency in different grain production zones. Following the classification standards of China's Ministry of Agriculture and Rural Affairs, the sample is divided into major grain production areas, major consumption areas, and balanced areas. Regression results were presented in Table 8, reveal significant efficiency improvements in production and consumption zones but no statistically significant impact in balanced zones, reflecting "uneven urban-rural development" across functional regions. In the major production areas, as core hubs of national grain supply, these regions benefit from policy tilting, technology intensification, and scale-oriented farming during integration, directly enhancing land use efficiency. In the major consumption areas, facing food self-sufficiency pressures, these areas reconfigure land use patterns through urban-rural factor counterflows, driving functional diversification and marginal benefit gains. In the balanced areas, constrained by weak self-sufficiency targets and limited factor interactions, land use remains dominated by traditional smallholder farming. This might be because in the main sales area, due to its policies emphasizing marketization, technological empowerment and functional integration, has been compelled to achieve efficient land utilization. However, the main production area is constrained by yield-oriented policies and institutional restrictions, and its efficiency improvement relies more on scale rather than innovation-driven approaches. This disparity reflects that the urban-rural integration policies need to be combined with regional functional positioning, and balance the dual goals of "ensuring security" and "improving efficiency."

TABLE 8 Results of heterogeneity test for food function areas.

Variables	(1)	(2)	(3)
	Major production areas	Major consumption areas	Balanced areas
Cud	0.241** (1.218)	0.825** (2.423)	0.527 (0.622)
Control variables	YES	YES	YES
Fixed effect	YES	YES	YES
Constant	0.522*** (4.042)	1.274*** (3.378)	−1.204*** (−5.991)
Observations	156	84	120
R-squared	0.674	0.775	0.622

Therefore, the level of urban-rural integration has an impact on the heterogeneity of the grain functional areas, which also reflects the unbalanced effects of institutional guarantees, market driving forces, and regional functional compatibility in spatial governance.

5 Conclusion

Enhancing urban-rural integration is of paramount significance for China's high-quality rural economic development, with rural land use efficiency serving as a critical determinant. Utilizing provincial-level panel data (2012–2023) from China (provinces, autonomous regions, and municipalities), this study constructs a three-tier indicator system to measure urban-rural integration and rural land use efficiency, on the one hand, the impact of the level of urban-rural integration on the efficiency of rural land use was examined, on the other hand, the differences in the influence of China's urban-rural integration level on rural land use efficiency under the background of different regional resource endowments and differences in the function of grain production were explored. Findings as follows:

First, the level of urban-rural integration has a significant effect (at the 1% level) on enhancing the rural land use efficiency. The urban-rural integration process essentially represents a Pareto improvement process resulting from the synergy of factor reallocation and institutional change. The dismantling of the urban-rural dual structure has eliminated the institutional barriers to factor mobility, thereby promoting the improvement of rural land use efficiency. From the coefficient perspective, for every 1% increase in the level of urban-rural integration in China, the rural land use efficiency will increase by 0.379%.

Second, the mechanism analysis reveals that land transfer and the urban-rural mobility of labor force are both channels through which the level of urban-rural integration promotes the improvement of rural land use efficiency. On one hand, urban-rural integration has facilitated the subdivision of land ownership, reduced transaction costs and other factors, lowering transaction costs and promoting the optimization of resource allocation, thereby enhancing the rural land use efficiency. On the other hand, urban-rural integration has eliminated institutional barriers such as household registration and land ownership, reshaped the incentive structure for labor migration, enabling more frequent migration of rural labor force, accelerating the improvement of rural laborers' skills, and thereby enhancing the rural land use efficiency.

Thirdly, the heterogeneity analysis shows that the level of urban-rural integration has a stronger promoting effect on the rural land use efficiency in the eastern and western regions of China, while the impact is not significant in the central region. Comparatively speaking, the eastern region has a clear advantage in economic foundation, the western region has a clear advantage in land resource environment, and the agricultural operating households in the eastern region have higher digital literacy, more universities and research institutions are concentrated in the eastern region, and the labor force quality is also higher. These conditions are all conducive to the improvement of the level of urban-rural integration. The labor force in the central region is affected by the suction effect of the eastern region, and the labor outflow is relatively obvious, which will reduce the quality of rural labor force and thereby affect the land use efficiency. Furthermore, the level of urban-rural integration has a significant promoting effect on the rural land utilization efficiency in major grain-producing areas and major grain-consuming areas, but has no significant impact on the rural land efficiency in grain balance areas. The heterogeneity effect of urban-rural integration on grain functional areas also reflects the non-equilibrium effect of institutional guarantees, market driving forces, and regional functional compatibility in spatial governance.

Based on the research conclusions of this article, the following suggestions are proposed: First, establish a market-oriented mechanism for the allocation of urban and rural factors and deepen institutional reforms. Continuously promote the reform of land property rights, establish a unified urban-rural construction land market, allow rural collective non-agricultural construction land to enter the market for transactions, and break the dual division system of urban and rural land. Promote the experience of "separation of three rights" reform, clarify the rights and functions of land contracting rights, operation rights, and income rights, and reduce the transaction costs of land transfer. At the same time, relax the restrictions on household registration in small and medium-sized cities, improve the rights protection mechanism for migrant workers' urbanization (such as housing, medical care, education), and reduce the institutional friction of labor mobility. Second, strengthen differentiated policy supply at the regional level to solve the "central depression" problem. The central region implements the "talent return" project. For example, establish a regional talent cooperation mechanism, promote the exchange of talents and skills between the eastern and western regions, and optimize the allocation of labor resources. By establishing a special fund for rural revitalization, for returnees who start businesses in their hometowns, a 50% reduction in corporate income tax will be implemented for the first 3 years, and they will also be provided with a maximum 500,000 yuan interest-free loan. The focus will be on supporting key industries such as modern agriculture and ecommerce. Third, improve the collaborative governance framework for land transfer and labor mobility. Through the promotion of "land transfer performance insurance," introduce third-party assessment institutions to rate the credit of transfer entities, and reduce the risk of contract breach. Improve the rural social security network, incorporate landless farmers into the urban employee pension insurance system, and reduce the worries of land transfer. In particular, develop labor-intensive industries in county economies to promote "employment away from the land but staying in the village," achieve a positive interaction between land transfer and local employment of labor, and reduce institutional friction.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

HL: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review and editing. XL: Data curation, Formal Analysis, Investigation, Software, Writing – original draft.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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