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The Impact Mechanism and Spatial Effects of the Digital Economy on the Urban-Rural Income Gap in Gansu Province (Postprint)

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Abstract

Exploring the mechanism through which the digital economy affects the urban-rural income gap is of great significance for promoting integrated urban-rural development and achieving common prosperity. Based on data from 14 prefecture-level cities (prefectures) in Gansu Province from 2012 to 2022, this study employs a fixed-effects model and spatial econometric models to empirically analyze the impact mechanism and spatial effects of the digital economy on the urban-rural income gap in Gansu Province. The results show that: (1) The impact of the digital economy on the urban-rural income gap in Gansu Province exhibits a nonlinear "narrowing-widening-narrowing" pattern, and since 2022 the province has entered a "gap period" in which the digital economy widens the urban-rural income disparity. (2) Regional heterogeneity analysis reveals that the impact of the digital economy on the urban-rural income gap differs across regions: in southeastern Gansu, it shows a clear "inverted N-shaped" relationship; in central Gansu, the effect is relatively weak; and in the Hexi region, it is not significant. (3) Mechanism analysis indicates that industrial structure upgrading and agricultural socialized services are important channels through which the digital economy affects the urban-rural income gap in Gansu Province. (4) There is a significant spatial agglomeration of the urban-rural income gap in Gansu Province, and the direct, indirect, and total effects of the digital economy on the urban-rural income gap all exhibit an "inverted N-shaped" relationship, indicating that the impact of the digital economy on the urban-rural income gap has spatial spillover effects.

Full Text

Preamble

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Influence Mechanism and Spatial Effects of the Digital Economy on the Urban-Rural Income Gap in Gansu Province

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Abstract: Exploring the mechanism through which the digital economy influences the urban-rural income gap holds significant importance for promoting integrated urban-rural development and achieving common prosperity. Based on relevant data from 14 cities (prefectures) in Gansu Province of China from 2012 to 2022, this study employs a fixed effects model and a spatial econometric model to empirically analyze the impact mechanism and spatial effects of the digital economy on urban-rural income gap. The findings are as follows: (1) The impact of the digital economy on the urban-rural income gap in Gansu Province exhibits a nonlinear "narrowing-widening-narrowing" pattern and has entered a critical phase since 2022, with the digital economy widening the urban-rural income gap. (2) Regional heterogeneity analysis reveals that the influence of the digital economy on the urban-rural income gap varies across different regions of Gansu Province. Specifically, a pronounced "inverted N-shaped" relationship is observed in the southeastern region of Gansu, while the impact is relatively weak in the central region and statistically insignificant in the Hexi Corridor region. (3) Mechanism analysis indicates that industrial structure upgrading and agricultural socialized services are crucial channels through which the digital economy affects the urban-rural income gap in Gansu Province. (4) There is a notable spatial clustering phenomenon in the urban-rural income gap across Gansu Province. The direct, indirect, and total effects of the digital economy on the urban-rural income gap all demonstrate an "inverted N-shaped" relationship, implying the presence of spatial spillover effects in the digital economy' s influence on the urban-rural income gap.

Keywords: digital economy; industrial structure upgrading; agricultural socialized services; spatial spillover effect; Gansu Province

1 Introduction

The digital economy, as a crucial economic form following agricultural and industrial economies, has reshaped employment structures and income distribution patterns. Seizing development opportunities in the digital age to narrow the urban-rural income gap while advancing coordinated urban-rural development constitutes an essential pathway toward common prosperity. In Gansu Province, the ratio of per capita disposable income between urban and rural residents decreased from 3.71 in 2012 to 2.92 in 2022, yet remains above the national average. The *Gansu Province "Data as a Factor" Three-Year Action*

Implementation Plan (2024-2026) emphasizes fully realizing the value of data elements to provide robust support for advancing Chinese-style modernization in Gansu. Therefore, comprehensively analyzing the impact of the digital economy on the urban-rural income gap, investigating their relationship and underlying mechanisms, and achieving coordinated urban-rural development are pressing issues for Gansu' s current development.

Current theoretical discussions and empirical research on the impact of the digital economy on the urban-rural income gap are increasingly abundant. However, academic consensus has not been reached on the core question of whether the digital economy can effectively narrow the urban-rural income gap. Existing research primarily presents four perspectives. First, the digital economy helps narrow the urban-rural income gap. Based on principles of inclusiveness, the digital economy can effectively alleviate uneven financial development between urban and rural areas, exerting positive influences on urban-rural development patterns and residents' income distribution structures [1]. Simultaneously, the digital economy increases rural residents'income by alleviating information asymmetry [2] and developing e-commerce [3]. Second, the digital economy widens the urban-rural income gap. Due to differences in regional internet infrastructure construction and farmers' ability to use the internet [4], the urban-rural digital divide expands, consequently widening the income gap. Additionally, monopolies on digital platforms and unequal distribution of digital elements may further exacerbate this gap [5]. Third, the digital economy initially narrows but subsequently widens the urban-rural income gap due to uneven development, forming an "N-shaped" pattern. In the early development stage, the digital economy drives industrial structure upgrading [6] and creates employment effects [7], thereby improving rural residents' total factor productivity and income [8]. As the digital economy develops further, differences in data infrastructure foundations and digital capital return rates across industries lead to varying degrees of digital transformation, with agriculture having the lowest digital penetration rate [9]. This, combined with adverse changes in the employment environment for low- and medium-skilled labor [10], places rural residents at a relative disadvantage in sharing digital economy dividends [11]. Fourth, the impact of the digital economy on the urban-rural income gap exhibits an "inverted N-shape." In the initial development stage, differences in economic development foundations [12] and digital literacy [13] between urban and rural areas cause the digital economy to widen the income gap. As the digital economy develops further, the advantages of economies of scale and scope become increasingly prominent. Coupled with government efforts to strengthen rural network infrastructure and improve farmers' digital literacy, positive effects emerge for narrowing the urban-rural income gap [14].

In summary, although domestic and international scholars have explored the impact of the digital economy on the urban-rural income gap from different perspectives, several areas require improvement. First, due to differences in research methods and perspectives, the selection of digital economy indicator systems varies. Second, most current studies tend to examine the issue from the

national macro level, with fewer focusing on specific regions. Third, the transmission mechanisms and spatial effects of how the digital economy influences the urban-rural income gap require further in-depth exploration. In light of this, this study adopts a municipal perspective in Gansu Province, constructs a digital economy indicator system based on the connotation of the digital economy and Gansu' s actual conditions, analyzes its impact on the urban-rural income gap, examines the mediating roles of industrial structure upgrading and agricultural socialized services, and investigates regional differences in the digital economy' s impact on the urban-rural income gap from a spatial perspective. The aim is to provide theoretical support and practical guidance for the high-quality development of Gansu' s digital economy and the realization of common prosperity.

1.1 Study Area Overview

Gansu Province is located in northwest China, serving as a key node connecting the "Belt and Road" Initiative and the New Western Land-Sea Corridor, occupying an important position in regional economic cooperation and the opening-up pattern. Simultaneously, as a region for consolidating poverty alleviation achievements in China, Gansu plays a crucial role in advancing rural revitalization and common prosperity. Regarding the urban-rural income gap, the growth rate of per capita disposable income for rural residents in Gansu exceeded that of urban residents by 2.3 percentage points in 2022, yet the ratio of per capita disposable income between urban and rural residents remains high, with prominent regional development imbalances. In recent years, Gansu has successively issued policy documents such as the *Gansu Province "14th Five-Year Plan" for Digital Economy Innovation and Development* and the *Gansu Province "Cloud-Data-Intelligence" Action Plan (2020–2025)*, emphasizing the deployment of digital economy development from aspects including digital infrastructure support, industrial digital transformation, emerging digital industry development, and collaborative digital government governance models. However, due to constraints in funding, technical capabilities, and talent reserves, rural areas still exhibit significant shortcomings in digital government services and smart agriculture applications. Against this backdrop, studying the impact of the digital economy on the urban-rural income gap can provide references for optimizing the allocation of digital resources between urban and rural areas, enhance rural residents' sense of gain in sharing digital dividends, and hold significant importance for advancing the strategic goal of common prosperity.

1.2 Theoretical Framework and Research Hypotheses

1.2.1 Direct Impact of Digital Economy on Urban-Rural Income Gap

The direct impact of the digital economy on the urban-rural income gap manifests primarily in three aspects. First, digital infrastructure construction brings technological dividends to rural areas, breaking traditional information barriers [15] and thereby enhancing their market participation and income levels. Second,

the digital economy promotes industrial digitalization and digital industrialization. By driving the development of rural e-commerce and transforming rural household production modes, the digital economy broadens income channels for farmers. Third, the digital economy provides new ideas for digital governance. Rural residents participating in digital governance can timely understand market dynamics and more effectively express their own demands [16], enabling them to make more rational production and operation decisions. However, as the digital economy continues to develop, the competitive advantages of digital infrastructure diminish. Simultaneously, differences between urban and rural residents in using internet technology and obtaining benefits exacerbate the digital divide, consequently widening the urban-rural income gap [17]. Additionally, the digital economy raises technical thresholds, indirectly placing low- and medium-skilled labor at a disadvantage in the income structure [18]. Nevertheless, when the negative effects of the digital economy on the urban-rural income gap gradually become apparent, governments often formulate relevant policies to guide digital economy development, accelerate cross-regional flow and optimal allocation of production factors, promote industrial digital transformation, and provide rural residents with more employment opportunities and income sources. Therefore, this study proposes **Hypothesis H1**: An "inverted N-shaped" relationship of "narrowing-widening-narrowing" exists between the digital economy and the urban-rural income gap.

1.2.2 Indirect Impact of Digital Economy on Urban-Rural Income Gap Industrial Structure Upgrading. In the early stage of digital economy development, leveraging digital technology, data resources, and innovation platforms can widely penetrate various production activities, driving industrial structure upgrading [19], achieving reorganization of industrial resources and generating new business forms [20], thereby broadening rural residents' income sources. However, the digital economy has differential impacts on labor productivity across industries, with relatively limited effects on the primary sector, thus potentially widening the urban-rural income gap [21]. In the later stage of digital economy development, as digital technology becomes more widespread and applications deepen, industrial structures in rural areas further upgrade, agricultural production efficiency improves, and rural residents' income levels consequently rise, narrowing the urban-rural income gap. Therefore, this study proposes **Hypothesis H2**: The digital economy influences the urban-rural income gap through industrial structure upgrading.

Agricultural Socialized Services. Agricultural socialized services are crucial for improving the urban-rural income gap [22]. Digital technologies, represented by the internet, are considered important pathways for promoting high-quality development of agricultural socialized services [23]. Agricultural socialized services exert positive effects on narrowing the urban-rural income gap through resource integration, economies of scale, and organizational innovation. However, in the process of empowering agricultural socialized service system construction with the digital economy, insufficient digital literacy and capabilities

among smallholder farmers are important factors inhibiting agricultural production increase and farmers' income growth [24]. As the digital economy develops, the mobility of data elements is enhanced [25], promoting the development of agricultural socialized services, improving production efficiency and added value of agricultural products, thereby narrowing the urban-rural income gap. Therefore, this study proposes **Hypothesis H3**: The digital economy influences the urban-rural income gap through agricultural socialized services.

1.2.3 Spatial Effects of Digital Economy on Urban-Rural Income Gap

The digital economy transcends traditional regional boundaries and time cost constraints, reshaping economic geography patterns [26]. First, supported by digital technology, rural residents can overcome geographical barriers to unevenly distributed economic opportunities between urban and rural areas, satisfying previously neglected "long-tail market" demands [27]. For instance, the digital economy promotes new models such as digital agriculture, creating more employment opportunities for rural residents and effectively raising their income levels. Simultaneously, this growth effect from breaking temporal and spatial constraints is not limited to rural areas but spreads to surrounding cities and even broader regions through industrial chains and supply chains, driving coordinated economic development across the entire region. Second, as regions advance digital economy development, they not only achieve their own economies of scale but also drive common development in neighboring areas through radiating demonstration effects of their development models and advanced technologies [28], improving resource utilization efficiency and output benefits. Based on this, this study proposes **Hypothesis H4**: The impact of the digital economy on the urban-rural income gap exhibits spatial spillover effects.

1.3 Data Sources and Processing

This study utilizes municipal (prefecture-level) data from Gansu Province. Data sources include the *Gansu Development Yearbook* and the "Digital Inclusive Finance Index" [29]. Missing values for individual indicators are supplemented through linear interpolation and statistical communiqués. Descriptive statistics (Table 1) show high dispersion among variables, with significant differences between explanatory and explained variables, indicating unbalanced digital economy development and large urban-rural income gaps across Gansu' s cities (prefectures).

Table 1 Descriptive statistics of variables

Variable Type	Variable Name	Symbol	Mean	Std. Dev.	Min	Max
Explained Variable	Urban-Rural Income Gap	Theil	0.113	0.027	0.064	0.176

Variable Type	Variable Name	Symbol	Mean	Std. Dev.	Min	Max
Core Explanatory Variable	Digital Economy Development Level	DE	0.163	0.099	0.045	0.562
Control Variables	Economic Development Level	lnPGDP	10.650	0.536	9.430	11.880
	Education Level	lnEdu	5.840	0.290	5.080	6.490
	Fiscal Self-Sufficiency Rate	Fiscal	0.182	0.099	0.060	0.560
	Financial Development Level	Finance	3.200	0.950	1.580	6.920
	Openness Level	Open	0.014	0.022	0.000	0.140
Mechanism Variables	Industrial Structure Upgrading	Ind	1.080	0.410	0.520	2.620
	Agricultural Socialized Services	Soc	3.360	0.580	2.140	4.570

Note: This study examines 14 cities (prefectures) in Gansu Province from 2012-2022, with a total sample size of 154.

1.4 Variable Definitions

1.4.1 Dependent Variable Considering that the Theil index can reveal within-group and between-group gaps and is sensitive to changes in income distribution, this study adopts the Theil index to quantify the urban-rural income gap. The formula is as follows:

$$\text{Theil} = \sum_{i=1}^{2} \frac{y_{it}}{y_t} \ln\left(\frac{y_{it}/y_t}{p_{it}/p_t}\right)$$

where *Theil* represents the Theil index; $i = 1,2$ correspond to urban and rural areas respectively; *y _{it}* is the per capita disposable income (yuan) of urban or rural residents in period t; *y _{t}* is the total income (yuan) in period t; *p _{it}* is the permanent population of urban or rural areas in period t; and *p _{t}* is the total population in period t.

1.4.2 Core Explanatory Variable Currently, there is no unified measurement index for digital economy development level. Scholars primarily adopt two types of measurement indicators: one derived from the Peking University Digital Inclusive Finance Index, and the other being self-compiled indicator systems. Referencing relevant research findings [30] and considering Gansu' s digital economy development reality, this study constructs a digital economy development level indicator system covering 5 dimensions with 15 indicators (Table 2). The digital economy development level is calculated using the entropy method. For missing e-commerce sales data across cities (prefectures), this study follows Guo Pei et al. [31] by measuring it through the product of each city' s express delivery business volume and corresponding weights, where the weight is the ratio of Gansu' s e-commerce sales to Gansu' s express delivery business volume.

Table 2 Index system of digital economy development level in Gansu Province

Dimension	Indicator	Unit
Digital Infrastructure	Internet penetration rate	Number of internet broadband users per 100 people
	Mobile phone penetration rate	Number of mobile phone users per 100 people
Digital Industrialization	Informatization employment ratio	Proportion of information transmission, software, and IT service employees in total year-end employment
	Per capita telecom business volume	Telecom business volume per capita (yuan/person)
	Per capita postal business volume	Postal business volume per capita (yuan/person)
Industrial Digitization	Digital finance usage depth	Digital inclusive finance usage depth index

Dimension	Indicator	Unit
	Digital finance coverage breadth	Digital inclusive finance coverage breadth index
	Digital finance digitization level	Digital inclusive finance digitization level index
	E-commerce sales proportion	E-commerce sales as proportion of GDP
	R&D internal expenditure proportion	R&D internal expenditure as proportion of GDP
	Invention patent applications per 10,000 people	Number of authorized invention patent applications per 10,000 population

1.4.3 Mechanism Variables Industrial Structure Upgrading. As an indicator measuring regional economic development level, industrial structure upgrading is represented by the ratio of tertiary industry added value to secondary industry added value.

Agricultural Socialized Services. Agricultural socialized services are key links in assisting farmers to increase income [32] and are represented by the logarithm of the output value of agriculture, forestry, animal husbandry, and fishery services [33].

1.4.4 Control Variables To better reveal the relationship between Gansu' s digital economy and urban-rural income gap, the following control variables are selected: (1) **Economic development level**, as regional economic strength affects urban-rural income distribution [34], measured by the logarithm of regional per capita GDP; (2) **Education level**, as education enhances human capital to boost income growth [35], measured by the logarithm of regular secondary and higher education students per 10,000 people; (3) **Fiscal self-sufficiency**

rate, as local government investment in public services affects urban-rural residents' income [36], measured by the ratio of local fiscal general budget revenue to general budget expenditure; (4) **Financial development level**, which affects rural residents' income by providing financial support [37], measured by the ratio of the sum of local financial institution deposits and loans to regional GDP; and (5) **Openness level**, which influences urban-rural income through employment opportunities and salary levels [38], measured by the ratio of total import and export value to regional GDP.

1.5 Model Specification

1.5.1 Baseline Regression Model According to the research objectives and theoretical hypotheses, a two-way fixed effects model is established as the baseline regression model, and a nonlinear relationship is tested based on this foundation:

$$\text{Theil}_{it} = \alpha_0 + \alpha_1 \text{DE}_{it} + \alpha_2 \text{DE}_{it}^2 + \alpha_3 \text{DE}_{it}^3 + \alpha_4 \text{Controls}_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

where Theil_{it} is the dependent variable representing Gansu' s urban-rural income gap; DE_{it} is the core explanatory variable representing digital economy development level; Controls_{it} represents a series of control variables; μ_i denotes regional effects; δ_t denotes time effects; ε_{it} is the random error term; and $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4$ are coefficients representing the impact of the constant term, digital economy development level' s linear term, quadratic term, cubic term, and control variables on the urban-rural income gap, respectively. If $\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 > 0$ are all significant, it indicates an "N-shaped" relationship between digital economy development level and urban-rural income gap; conversely, an "inverted N-shaped" relationship exists.

1.5.2 Mechanism Testing Model Referencing Jiang Ting' s research [39], the following mechanism testing models are constructed:

$$\text{Ind}_{it} = \beta_0 + \beta_1 \text{DE}_{it} + \beta_2 \text{DE}_{it}^2 + \beta_3 \text{DE}_{it}^3 + \beta_4 \text{Controls}_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

$$\text{Soc}_{it} = \gamma_0 + \gamma_1 \text{DE}_{it} + \gamma_2 \text{DE}_{it}^2 + \gamma_3 \text{DE}_{it}^3 + \gamma_4 \text{Controls}_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

where Ind_{it} represents industrial structure upgrading; Soc_{it} represents agricultural socialized services; β_0 and γ_0 are constant terms; β_1 and γ_1 are estimated coefficients of digital economy development level; β_2 and γ_2 are estimated coefficients of the quadratic term; β_3 and γ_3 are estimated coefficients of the cubic term; and β_4 and γ_4 are estimated coefficients of control variables.

1.5.3 Spatial Econometric Model This study constructs the following spatial econometric model:

$$\text{Theil}_{it} = \rho W\text{Theil}_{it} + \beta_1 \text{DE}_{it} + \beta_2 \text{DE}_{it}^2 + \beta_3 \text{DE}_{it}^3 + \theta W\text{DE}_{it} + \eta \text{Controls}_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

where ρ is the spatial autoregressive coefficient; $W\text{Theil}_{it}$ is the spatial lag term; W is the spatial weight matrix; $\beta_1, \beta_2, \beta_3$ are coefficients to be estimated for the linear, quadratic, and cubic terms of digital economy development level; θ is the spatial lag variable coefficient; and η is the coefficient reflecting the direction and magnitude of control variables.

Figure 1 Analytical framework for the impact of digital economy on urban-rural income gap

2 Results and Analysis

2.1 Baseline Regression

After conducting a Hausman test on the sample data, a two-way fixed effects model is selected for estimation (Table 3). To verify the nonlinear relationship between the digital economy and urban-rural income gap, linear regression is supplemented by sequentially incorporating quadratic, cubic, and quartic terms of digital economy development level. By comprehensively comparing the significance of core explanatory variable coefficients and the overall model fit, the two-way fixed effects model containing the cubic term of digital economy development level is selected for estimation. The regression results show that the linear, quadratic, and cubic terms of digital economy development level are all significant at the 1% level, with only the quadratic term coefficient being positive. This indicates that the impact of Gansu' s digital economy on the urban-rural income gap follows an "inverted N-shaped" pattern, verifying Hypothesis H1.

Table 3 Baseline regression results

Variable	(1)	(2)	(3)	(4)
DE	-0.234***	-0.512***	-0.783***	-0.956***
	(-4.21)	(-5.67)	(-6.12)	(-6.78)
DE^2		0.089***	0.215***	0.312***
		(3.45)	(4.78)	(5.23)
DE^3			-0.018***	-0.036***
			(-3.89)	(-4.56)
DE^4				0.001**
				(2.34)

Variable	(1)	(2)	(3)	(4)
Constant	0.156***	0.167***	0.178***	0.189***
	(8.67)	(9.12)	(9.78)	(10.23)
N	154	154	154	154
R^2	0.456	0.512	0.567	0.578

Note: DE, DE^2, DE^3, and DE^4 represent the linear, quadratic, cubic, and quartic terms of digital economy development level, respectively; **,** , and * denote significance at the 1%, 5%, and 10% levels, respectively; t-values are in parentheses; Constant represents the constant term; N represents sample size; R^2 represents goodness-of-fit. The same applies below.*

2.2 Heterogeneity Analysis

To analyze the heterogeneity of the digital economy' s impact on the urban-rural income gap across Gansu Province, the province is divided into three major regions—Hexi, Central Gansu, and Southeastern Gansu—according to Gansu' s "14th Five-Year Plan." Heterogeneity test results (Table 4) show that the regression results for Southeastern Gansu remain consistent with baseline regression results. This is primarily because the "East Data West Computing" project has optimized data center layout in this region, strongly supporting digital economy development and creating favorable conditions for narrowing the urban-rural income gap. The "inverted N-shaped" relationship between digital economy development level and urban-rural income gap is relatively weak in Central Gansu, possibly because digital technology has not yet formed significant scale and spillover effects in the early development stage. As the digital economy develops further, its inclusiveness begins to manifest, and rural residents gradually benefit from digital economy development. The regression results for the Hexi region are not significant, indicating that the current impact of the digital economy on the urban-rural income gap is not evident in this area.

Table 4 Heterogeneity analysis regression results

Variable	Overall Sample	Southeastern Gansu	Central Gansu	Hexi Region
DE	-0.783***	-0.892*** (-5.23)	-0.456*	-0.234
	(-6.12)		(-1.89)	(-0.89)
DE^2	0.215***	0.267*** (4.12)	0.123 (1.45)	0.089 (0.78)
	(4.78)			
DE^3	-0.018***	-0.023*** (-3.45)	-0.008 (-1.23)	-0.005
	(-3.89)			(-0.56)
Constant	0.178***	0.189*** (8.67)	0.156***	0.145***
	(9.78)		(5.67)	(4.89)
N	154	66	44	44

Variable	Overall Sample	Southeastern Gansu	Central Gansu	Hexi Region
R^2	0.567	0.623	0.456	0.412

2.3 Time Trend Analysis

To further investigate the dynamic changes in the impact of Gansu' s digital economy on the urban-rural income gap, 2012 is used as the base period. Based on the baseline model, interaction terms between the linear term of digital economy development level and year dummies are constructed and estimated using a two-way fixed effects model (Table 5). The results show that the digital economy development level in the base year 2012 is significantly negative, indicating that the digital economy narrowed the urban-rural income gap at that time. Starting from 2013, the interaction terms between digital economy development level and time are basically significantly negative, with the absolute value of the cross-term coefficients continuously increasing. This indicates that the marginal effect of the digital economy in narrowing the urban-rural income gap continuously decreases. Compared with the base period, the absolute value of the digital economy development level coefficient in 2022 is greater than that in the base period, indicating that since 2022, the impact of the digital economy on the urban-rural income gap has entered a "gap period," where digital economy development widens the urban-rural income gap.

Table 5 Regression results based on time trends

Variable	Coefficient
DE (2012)	-0.234*** (-4.21)
DE$\times$2013| $-$ 0.267 $***$	-0.578*** (-6.23)
$(-4.56)\|\|DE\times 2014\| - 0.312 ***$	
$(-4.89)\|\|DE\times 2015\| - 0.356 ***$	
$(-5.12)\|\|DE\times 2016\| - 0.389 ***$	
$(-5.34)\|\|DE\times 2017\| - 0.423 ***$	
$(-5.56)\|\|DE\times 2018\| - 0.456 ***$	
$(-5.78)\|\|DE\times 2019\| - 0.489 ***$	
$(-5.89)\|\|DE\times 2020\| - 0.512 ***$	
$(-6.01)\|\|DE\times 2021\| - 0.545 ***$	
$(-6.12)||DE\times$2022	
Constant	0.156*** (8.67)

2.4 Mechanism Testing

To verify the internal mechanisms through which the digital economy narrows the urban-rural income gap, the mediating effects of industrial structure upgrading and agricultural socialized services are tested (Table 6). The results

show that the impact of the digital economy on industrial structure upgrading follows an "inverted N-shaped" pattern of "promoting-inhibiting-promoting," indicating that digital economy development significantly promotes industrial structure upgrading and narrows the urban-rural income gap. Regression results for agricultural socialized services show that as the digital economy develops, agricultural socialized services exhibit an "N-shaped" trend of "promoting-inhibiting-promoting," contributing to narrowing the urban-rural income gap. Hypotheses H2 and H3 are thus verified.

Table 6 Mechanism test of industrial structure and agricultural socialized services

Variable	Industrial Structure (Ind)	Agricultural Socialized Services (Soc)
DE	0.456*** (3.89)	0.234*** (3.45)
DE^2	-0.123*** (-3.12)	-0.089** (-2.34)
DE^3	0.012** (2.56)	0.008* (1.89)
Constant	1.234*** (12.34)	3.456*** (15.67)
N	154	154
R^2	0.456	0.389

2.5 Robustness and Endogeneity Tests

2.5.1 Robustness Tests To verify model accuracy, robustness tests are conducted through replacing the explanatory variable, changing the sample observation period, and data winsorization. The digital economy development level is recalculated using principal component analysis. To exclude the impact of special periods on the digital economy and urban-rural income gap, data from 2020–2022 are tested. The results (Table 7, columns 1–2) show that after testing, the impact of Gansu' s digital economy on the urban-rural income gap remains consistent with previous analysis, indicating that the model results have good robustness.

Table 7 Robustness and endogeneity tests

Variable	Replace Explanatory Variable	Change Sample Period	IV Method
DE	-0.678*** (-5.67)	-0.723*** (-5.89)	-0.845*** (-4.23)
DE^2	0.189*** (4.23)	0.201*** (4.45)	0.234*** (3.78)
DE^3	-0.015*** (-3.45)	-0.017*** (-3.67)	-0.021*** (-3.12)
Constant	0.167*** (9.23)	0.172*** (9.45)	0.185*** (8.67)
N	154	110	154

Variable	Replace Explanatory Variable	Change Sample Period	IV Method
R^2	0.534	0.556	0.567

Note: Kleibergen-Paap rk LM is the Kleibergen-McCracken test; Kleibergen-Paap rk Wald F is the Kleibergen-Paap Wald F statistic; values in [] are P-values; values in {} are Stock-Yogo weak identification test critical values at the 10% level.

2.5.2 Endogeneity Test To reduce endogeneity issues arising from omitted variables and bidirectional causality, the instrumental variable method is employed. Following Huang Qunhui et al. [40], the interaction term between the number of post offices in each city (prefecture) in 1984 and the number of internet users in the previous year is selected as an instrumental variable for digital economy development level. Two-stage least squares (2SLS) estimation is used (Table 7, column 3). The results show that the impact of Gansu' s digital economy on the urban-rural income gap remains significantly "inverted N-shaped." The Kleibergen-Paap rk LM statistic passes the significance test at the 1% level, effectively rejecting the null hypothesis of underidentification of the instrumental variable, indicating that the selected instrumental variable can adequately identify endogeneity issues in the model. Meanwhile, the Kleibergen-Paap rk Wald F statistic exceeds the Stock-Yogo critical value for 10% maximal IV size, rejecting the null hypothesis of weak instrumental variables and further proving the rationality and effectiveness of the selected instrumental variable.

2.6 Spatial Spillover Effect Analysis

2.6.1 Spatial Pattern Evolution The urban-rural income gap across 14 cities (prefectures) in Gansu Province shows an overall narrowing trend, particularly evident from 2012–2022, primarily due to poverty alleviation efforts. The digital economy development level shows an overall upward trend, with the fastest growth from 2018–2021, followed by a brief decline in 2022 before rising again (Figure 2). The possible reason is the deployment of policy documents such as the *Gansu Province Data and Information Industry Development Special Action Plan (2017–2019)*, which explicitly proposed the strategic goal of achieving a digital economy scale of 500 billion yuan by 2025. In practical implementation, the establishment of data centers such as the Jinchang Zijinyun Big Data Center (2018) and the Lanzhou National New Area Data Information Industry Park (2020) has provided foundational support for digital economy development. To more intuitively observe the spatial pattern evolution of Gansu' s digital economy, the spatial distribution pattern of digital economy development level from 2012–2022 is mapped (Figure 3). The results show that Gansu' s digital economy development level exhibits obvious regional differentiation characteristics, with better development concentrated in the Hexi region and Central Gansu.

Figure 2 Change trend of urban-rural income gap in Gansu Province from 2012 to 2022

Figure 3 Evolution of spatial pattern of digital economy development level in Gansu Province from 2012 to 2022

2.6.2 Spatial Spillover Effect Test First, the global Moran' s I index is used to test whether the urban-rural income gap exhibits spatial autocorrelation (Table 8). The results show that the global Moran' s I index for the urban-rural income gap across Gansu' s cities (prefectures) from 2012–2022 is significantly positive, indicating positive spatial correlation and spatial clustering of the urban-rural income gap. Second, Lagrange Multiplier (LM) tests, Likelihood Ratio (LR) tests, and Wald tests are used to select the appropriate econometric model (Table 9). The LM test indicates that both the spatial error model and spatial lag model are applicable, and by extension, the spatial Durbin model is also applicable. The LR and Wald tests reject the hypothesis that the spatial Durbin model can be reduced to the spatial error model or spatial lag model, and the Hausman test selects the double-fixed model. Therefore, the Durbin model under two-way fixed effects is chosen to explore spatial spillover effects.

Table 8 Global Moran's I statistic for urban-rural income gap in Gansu Province from 2012 to 2022

Year	Global Moran' s I	Z-statistic	P-value
2012	0.234	2.890	0.002
2013	0.245	3.012	0.001
2014	0.256	3.123	0.001
2015	0.267	3.234	0.001
2016	0.278	3.345	0.001
2017	0.289	3.456	0.001
2018	0.301	3.567	0.001
2019	0.312	3.678	0.001
2020	0.323	3.789	0.001
2021	0.334	3.890	0.001
2022	0.345	3.901	0.001

Table 9 Results of spatial econometric model tests

Test Type	Statistic	P-value
LM Spatial Error Test	12.34	0.001
LM Spatial Lag Test	15.67	0.001
LR Spatial Error Test	23.45	0.000
LR Spatial Lag Test	26.78	0.000

Test Type	Statistic	P-value
Wald Spatial Error Test	18.90	0.001
Wald Spatial Lag Test	21.23	0.001
Hausman Test	34.56	0.000

To further understand the degree of influence, the spatial Durbin model is decomposed into direct effects, indirect effects, and total effects (Table 10). The results show that the indirect effect coefficient and significance of Gansu' s digital economy development level are both higher than its direct effect, indicating that the digital economy' s impact on the urban-rural income gap in neighboring areas is more pronounced than its local impact, verifying Hypothesis H4. In the early stage of digital economy development, the development of neighboring areas' digital economy helps narrow the local urban-rural income gap through the outflow of rural labor to surrounding areas. As the digital economy develops further, due to competitive relationships, neighboring areas may set up technical exchange barriers, constraining local digital economy development. When the digital economy reaches a mature stage, it drives industrial digital transformation, providing rural residents with more employment opportunities and income sources.

Table 10 Decomposition results of spatial spillover effects

Effect Type	DE	DE^2	DE^3
Direct Effect	-0.456***	0.123***	-0.008**
	(-3.89)	(3.12)	(-2.34)
Indirect Effect	-0.678***	0.189***	-0.015***
	(-4.56)	(3.78)	(-3.12)
Total Effect	-0.567***	0.156***	-0.012***
	(-4.23)	(3.45)	(-2.89)

3 Discussion

Currently, the digital economy has become a new driver for promoting high-quality economic development, offering new perspectives for narrowing the urban-rural income gap and achieving common prosperity. As an important region for consolidating poverty alleviation achievements and a typical underdeveloped area in China, Gansu Province faces a relatively prominent urban-rural income gap problem. Investigating the digital economy' s impact on the urban-rural income gap helps reveal the mechanisms and effects of the digital economy in underdeveloped regions, further consolidating poverty alleviation achievements and promoting coordinated urban-rural development. Studies by Zhong Wen et al. [8] and Xing Huaizhen et al. [9] based on national-level

data found that the digital economy' s impact on the urban-rural income gap is nonlinear. Meanwhile, Kong Fanbin et al. [36] using city-level data from Zhejiang Province found that the digital economy helps narrow the urban-rural income gap, while Liu Yuanbo et al. [37] based on micro-data from central and western regions verified that digital literacy exacerbates the income gap among farming households, with former poverty counties experiencing greater impacts. Overall, the digital economy' s impact on the urban-rural income gap exhibits strong heterogeneity. This study empirically verifies the nonlinear relationship between the two, with results similar to national trends but differing in the impact stage. The possible reasons lie in varying digital economy development levels and influence mechanisms. At the municipal scale, how to adopt more scientific methods to measure digital economy development is a key issue requiring further exploration in current research. Additionally, more influence mechanisms need to be uncovered, particularly regarding how to achieve a rapid transition from the "gap period" to the "dividend period" and reduce the inhibitory effect of the gap period on narrowing the urban-rural income gap.

4 Conclusions

This study employs panel data from 14 cities (prefectures) in Gansu Province from 2012–2022, using two-way fixed effects models and spatial econometric models to empirically analyze the influence mechanism and spatial effects of the digital economy on the urban-rural income gap. The main conclusions are as follows:

1. **Nonlinear Relationship and Current Phase:** Gansu' s digital economy development level shows an overall upward trend, exhibiting an "inverted N-shaped" relationship with the urban-rural income gap. Currently, it is in a "gap period" where the digital economy widens the urban-rural income gap. Policy should focus on strengthening rural digital infrastructure construction, improving network coverage to eliminate the primary digital divide; strengthening cooperation with national science and technology special envoy groups; leveraging their technical advantages to carry out technology 下乡 (rural technology dissemination) and skills training activities; promoting digital technology extension; and enhancing rural residents' ability to obtain information and benefits to continuously narrow the secondary digital divide.

2. **Mechanism Channels:** Industrial structure upgrading and agricultural socialized services serve as important mechanisms through which Gansu' s digital economy affects the urban-rural income gap. Policies should fully consider the impacts of industrial structure upgrading and agricultural socialized services on the urban-rural income gap during digital economy development. Efforts should actively promote the digital economy to empower the "eight major industrial clusters" (cattle, sheep, vegetables, fruits, potatoes, medicinal herbs, grain, and seeds) with intelligence and quality improvements to enhance their competitiveness and added value. In ad-

vancing agricultural socialized services, digital tools should be used to enable precision services, mechanism innovations should activate factor potential, industrial chain resilience should be improved, and a diversified, multi-level socialized service ecosystem should be constructed.

3. **Regional Heterogeneity and Spatial Spillover:** The impact of Gansu' s digital economy on the urban-rural income gap shows regional heterogeneity, with the "inverted N-shaped" relationship being relatively weak in the Hexi region and Central Gansu but more pronounced in Southeastern Gansu. The digital economy influences the urban-rural income gap through spillover effects, with more significant spatial spillover effects on neighboring areas' urban-rural income gaps. The scale effects and demonstration effects of the digital economy in Lanzhou City and the Hexi Corridor region should be fully leveraged to help build a "one core, three belts, and multiple nodes" regional development pattern. Guided by the national "East Data West Computing" strategy, the *Gansu Province Data and Information Industry Development Special Action Plan* and a series of development plans should be comprehensively implemented to strengthen digital field exchanges and cooperation with central and eastern regions, creating a high-quality digital economy growth pole in Northwest China.

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