Study on the Coupling Coordination Between Digital Economy and Agricultural Green Development in Arid Regions: A Case Study of Xinjiang (Postprint)

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Abstract

Enhancing the coupling coordination degree between digital economy and agricultural green development in arid regions is an inevitable requirement for promoting high-quality agricultural development. To investigate the coupling coordination between digital economy and agricultural green development in arid regions, this study selects panel data for the Xinjiang region from 2011 to 2020, employs a coupling coordination model to measure the coupling coordination degree between digital economy and agricultural green development in Xinjiang, and utilizes methods such as Kernel density estimation, standard deviation ellipse, and Dagum Gini coefficient to analyze the spatiotemporal evolution of their coupling coordination degree. The results show that: (1) Xinjiang's digital economy exhibits a "high center, low periphery" pattern, while agricultural green development shows a "high north, low south, high east, low west" pattern; from 2011 to 2020, Xinjiang's digital economy increased by as much as 131.618%, while agricultural green development increased by 33.922%. (2) The overall coupling coordination degree between the two in Xinjiang shows a gradual upward trend over time, with regional growth rates following the pattern: Eastern Xinjiang > Northern Xinjiang > Southern Xinjiang; based on Kernel density results, both Xinjiang as a whole and the three major regions exhibit certain characteristics of polarization effects; according to the standard deviation ellipse, from 2011 to 2015, the azimuth angle increased by 1.747°, while from 2015 to 2020, the azimuth angle decreased by 1.410°, indicating that the distribution center of the coupling coordination degree between digital economy and agricultural green development follows a back-and-forth swinging trajectory. (3) The overall level difference in coupling coordination degree shows a certain converging trend, with the mean inter-group difference being 0.403 and

the mean intra-group difference being 0.304.

Full Text

Preamble

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Coupling and Coordination of Digital Economy and Green Agricultural Development in Arid Regions: A Case Study of Xinjiang

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Abstract: Enhancing the coupling coordination between the digital economy and green agricultural development in arid regions is essential for promoting high-quality agricultural development. To investigate this relationship, this study employs panel data from Xinjiang spanning 2011–2020, utilizing a coupling coordination model to measure the degree of interaction between the digital economy and green agricultural development. Kernel density estimation, standard deviation ellipse, and Dagum Gini coefficient methods are applied to analyze the spatiotemporal evolution of coupling coordination. The results reveal: (1) Xinjiang's digital economy exhibits a "high center, low periphery" pattern, while green agricultural development shows a "high north, low south, high east, low west" distribution. The digital economy grew by 131.618% during the study period, whereas green agricultural development increased by 33.922%. (2) The overall coupling coordination degree demonstrates a gradual upward trend over time, with regional growth rates ranking as: East Xinjiang > North Xinjiang > South Xinjiang. Kernel density results indicate polarization effects in both Xinjiang overall and across its three major regions. Standard deviation ellipse analysis shows the azimuth angle increased by 1.747° from 2011–2015, then decreased by 1.410° from 2015–2020, revealing a back-and-forth oscillation in the distribution center of gravity. (3) The overall disparity in coupling coordination levels exhibits a convergence trend, with mean inter-group differences of 0.403 and intra-group differences of 0.304.

Keywords: arid zones; digital economy; green agricultural development; coupling and coordination; regional differences; Xinjiang

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1. Introduction

With the advancement of information technology and the internet, the digital economy has become increasingly integrated into green agricultural development, providing powerful momentum for intelligent and precision agriculture. This integration is crucial for achieving sustainable agricultural modernization.

In 2021, the central government issued the "Opinions on Comprehensively, Accurately, and Comprehensively Implementing the New Development Concept to Achieve Carbon Peak and Carbon Neutrality," which explicitly calls for accelerating green agricultural development and enhancing agriculture's carbon sequestration capacity, marking a new historical stage for China's agricultural green transition. Xinjiang, as a major base for grain and cash crops and an ecologically fragile arid region, faces particular challenges in stabilizing the coupling between its digital economy and green agricultural development.

The digital economy promotes green agricultural development through multiple pathways. First, it reduces information asymmetry by enriching farmers' access to information channels through various digital technologies. Farmers can utilize digital tools to obtain market information, understand demand for green products, optimize planting practices, and promote green technologies. Digital technologies also guide scientific farming practices, standardize fertilizer application, and facilitate knowledge sharing, thereby improving farmer efficiency. Second, the digital economy optimizes resource allocation. Digital production elements are characterized by replicability, renewability, non-consumption, and shareability, enabling low-cost, unlimited replication that breaks traditional resource constraints. In agricultural digital transformation, shared production materials reduce energy consumption and optimize resource allocation. For instance, farmers can substitute organic fertilizers for chemical ones and employ agricultural robots instead of heavy machinery to mitigate soil compaction and prevent land degradation. Additionally, remote sensing technology helps detect crop diseases, enabling precise mapping of disease patterns and reducing pesticide application. Third, digital finance enhances agricultural technology innovation and capital deepening, improving total factor productivity and reducing carbon emissions. Simultaneously, the digital economy drives rapid development of rural e-commerce, promoting industrial integration and service enhancement. E-commerce platforms enable farmers to sell directly to consumers, reducing price spreads, improving circulation efficiency, and strengthening whole-process supervision. In response to growing demand for green products and regulatory transparency, farmers are incentivized to adopt green production methods, with e-commerce platforms establishing dedicated sections for green agricultural products.

Conversely, green agricultural development also drives digital economic growth. First, green agricultural transformation generates strong demand for digitalization, requiring land standardization, scaling, technological advancement, organizational development, and intensification—all of which rely on digital support. Modern green agriculture encompasses diverse, integrated fields including sightseeing agriculture, ecological agriculture, and facility agriculture, merging entertainment, elderly care, and leisure functions. This diversification accelerates agricultural digitalization and increases demand for digital tools and platforms that support efficient, precise management decisions. Second, green agricultural development fosters digital economy talent cultivation. Human capital represents a key driver of green agricultural development, yet high-quality agricultural talent remains in short supply, constraining industry progress. In agricultural digitalization, these talents play a principal role in driving advancement, leading new directions for both green agricultural development and digital economy talent training. Such individuals are valuable assets for rural cooperatives and agricultural processing enterprises, providing localized optimal solutions and helping explore suitable paths for smart agricultural development in their regions. By effectively utilizing digital technologies, they reduce the digital divide's constraints on agriculture and popularize green development concepts. Cultivating high-quality agricultural talent is thus crucial for enhancing agricultural competitiveness and promoting sustainable development.

However, current integration between the digital economy and green agricultural development remains insufficient, leading to digital divides and uneven resource allocation that hinder green agricultural development and affect socioeconomic progress. Therefore, clarifying the coupling coordination relationship between Xinjiang's digital economy and green agricultural development, identifying factors influencing coupling differences, and promoting their integration are essential for helping farmers and agricultural enterprises seize market opportunities and achieve sustainable development.

This study establishes a coupling coordination system for Xinjiang's digital economy and green agricultural development in arid regions, providing theoretical support for promoting their synergistic development through empirical analysis of their relationship and dynamic evolution trends.

1.1 Study Area Overview

Xinjiang Uygur Autonomous Region is located in northwestern China between 73°20 –96°25 E and 34°15 –49°10 N. The region's topography is characterized by "three mountains surrounding two basins," featuring rich natural resources and a unique geographical environment. Agriculture in Xinjiang is dominated by cotton, wheat, corn cultivation, and animal husbandry. According to the latest statistics, Xinjiang has 524.23$\times 10^{4}$ hectares of cultivated land, accounting for 3.15% of its total area. The primary irrigation method is oasis irrigation agriculture, while natural factors such as water resource scarcity and ecological fragility constrain green agricultural development.

1.2 Data and Methods

1.2.1 Data Sources Considering data availability, this study selected 14 prefectures and cities in Xinjiang (excluding Karamay) as research objects. Data were obtained from the *Xinjiang Statistical Yearbook* (2012–2021), the *Digital Inclusive Finance Index*, and government work reports. Missing values were supplemented using linear interpolation.

1.2.2 Evaluation Index System Construction For green agricultural development, the evaluation framework encompasses four dimensions: environmental friendliness, ecological protection, resource conservation, and benefit output. For the digital economy, considering data availability and referencing existing research, a comprehensive digital economy indicator system was established. Specific indicators are shown in , with the entropy method used for measurement.

1.3 Methodology

1.3.1 Coupling Coordination Model Following relevant literature, the coupling coordination model was constructed with the following formulas:

$$C = 2 \times \frac{w(y) \times e(z)}{[w(y) + e(z)]^2}$$

$$D = \sqrt{C \times T}$$

$$T = \alpha w(y) + \beta e(z)$$

where:
- C represents the coupling degree between the digital economy and green agricultural development systems;
- D denotes the coupling coordination degree between the digital economy and green agricultural development;
- T is the comprehensive coordination index of the two subsystems, reflecting their contributions to coordination;
- $w(y)$ and $e(z)$ are the digital economy index and green agricultural development index, respectively;
- α and β are weights representing each subsystem's impact on social development, set as equal in this study.

1.3.2 Kernel Density Estimation This study employs Kernel density estimation to analyze the distribution dynamics of coupling coordination between Xinjiang's digital economy and green agricultural development. For a random variable x with observations $x_1, x_2, \dots, x_n$, the Kernel density function is:

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

where n is the number of observations, h is the bandwidth, and K is the kernel weighting function measuring the distance between x and x_i.

1.3.3 Standard Deviation Ellipse The standard deviation ellipse is a statistical technique that estimates data distribution through variance and covariance calculations. It describes the geographic distribution characteristics of coupling coordination degrees, making it suitable for spatial data comparison and statistical analysis. While intuitive and flexible, its application requires attention to data quality and interpretive limitations. This method clearly reveals the movement of the coupling coordination distribution center and spatial element change trends. Based on calculated coupling coordination degrees, the center of gravity was computed to reflect spatial pattern changes using:

$$\bar{X} = \frac{\sum_{i=1}^{a} w_i p_i}{\sum_{i=1}^{a} w_i}, \quad \bar{Y} = \frac{\sum_{i=1}^{a} w_i q_i}{\sum_{i=1}^{a} w_i}$$

where (p_i, q_i) represents the spatial location of the ith research object, a is the number of research objects, and w_i is the weight.

1.3.4 Dagum Gini Coefficient The Dagum Gini coefficient extends the traditional Gini coefficient by addressing its limitation in capturing data crossover and overlap. This study employs the Dagum Gini coefficient (G) for analysis:

$$G = \frac{1}{2n^2\bar{y}} \sum_{j=1}^{k} \sum_{h=1}^{k} \sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|$$

where y_{ji} and y_{hr} represent the coupling coordination degree composite scores for prefecture i in region j and prefecture r in region h, respectively; $\bar{y}$ is the average composite score; n is the total number of prefectures; k is the number of regions; and n_j and n_h are the numbers of prefectures in regions j and h. The overall Xinjiang Gini coefficient is further decomposed into inter-group differences (G_{nb}), intra-group differences (G_w), and transvariation density (G_t).

2. Results and Analysis

2.1 Spatiotemporal Characteristics of Xinjiang's Digital Economy and Green Agricultural Development

Using the entropy method, this study measured Xinjiang's digital economy and green agricultural development indices, with results shown in . ArcGIS 10.6 software was used to classify the indices into five levels via natural breaks: low, relatively low, medium, relatively high, and high value zones, with spatial evolution patterns illustrated in [Figure 1: see original paper].

2.1.1 Digital Economy Xinjiang's digital economy index grew significantly from 0.089 in 2011 to 0.206 in 2020, representing a 131.618% increase. While all prefectures showed upward trends, regional disparities became increasingly pronounced, with an expanding range. In terms of level changes, the number of prefectures in the relatively low and low value zones decreased from 10 to 6, indicating overall improvement. Spatially, Xinjiang's digital economy exhibits significant spatial differentiation, with high-value areas concentrated in the central region, demonstrating strong spatial agglomeration characteristics. This concentration likely relates to the central region's well-developed transportation, infrastructure, and talent reserves, which provide a solid foundation for digital economy development.

2.1.2 Green Agricultural Development Xinjiang's green agricultural development index increased from 0.216 in 2011 to 0.289 in 2020, a 33.922% rise. Although the overall trend is upward, the growth rate is substantially lower than that of the digital economy, indicating insufficient attention to green agricultural development. Spatially, high-value areas for green agricultural development show a pattern of high in the north and east, low in the south and west. This may be attributed to Xinjiang's geographical characteristics as an arid/semi-arid region where precipitation concentrates in the Tianshan Mountains area. Eastern regions, facing relatively scarce precipitation, have prioritized efficient water use, driving continuous upgrades in water-saving technologies that support green agricultural development. Western regions, benefiting from more abundant precipitation, have paid less attention to water-saving technology development, limiting their green agricultural development potential.

2.2 Coupling Coordination Degree Analysis

2.2.1 Spatiotemporal Evolution Trends Using data from 14 prefectures across 2011–2020, this study calculated coupling coordination degrees through the coupling model, dividing Xinjiang into three major regions: North Xinjiang, South Xinjiang, and East Xinjiang. Results are presented in and [Figure 2: see original paper].

The overall coupling coordination degree in Xinjiang shows a fluctuating upward trend, increasing from 0.382 in 2011 to 0.511 in 2020, reflecting strengthening synergies between the digital economy and green agricultural development. Notably, a temporary decline occurred in 2018, primarily due to decreased coupling coordination in North Xinjiang, while the 2019 decline stemmed mainly from South Xinjiang.

Regionally, East Xinjiang exhibited the largest growth in coupling coordination (0.222), followed by North Xinjiang (0.129) and South Xinjiang (0.106). East Xinjiang's exceptional growth likely reflects its relatively low initial coordination level at the study's outset, providing substantial room for improvement.

2.2.2 Kernel Density Estimation Results To visually demonstrate the development levels of coupling coordination, this study employed Matlab R2022a for Kernel density analysis of Xinjiang's overall and regional coordination degrees from 2011–2020, with results shown in [Figure 3: see original paper].

For Xinjiang overall, the Kernel density distribution center shifted rightward, indicating rising coupling coordination. The peak gradually increased while overall width expanded, suggesting growing development disparities. The distribution showed a clear "multi-peak" pattern in 2020, with side peaks weaker than the main peak but revealing polarization effects.

Regionally, all three areas showed rightward shifts in their Kernel density curves, consistent with Xinjiang's overall trend. However, distinct multi-peak patterns emerged in 2020 for North, East, and South Xinjiang, indicating that while coupling coordination improved, development remained uneven across regions.

2.2.3 Center of Gravity Migration and Directional Evolution To analyze spatial evolution patterns, this study used ArcMAP to calculate the center of gravity, standard deviation ellipse, and parameters for coupling coordination degrees in 2011, 2015, and 2020, with results shown in [Figure 4: see original paper] and .

In 2011, the coupling coordination center of gravity was located northwest of Bayingolin Mongol Autonomous Prefecture. The center moved southward then back northward, demonstrating dynamic changes in coordination patterns. The standard deviation ellipse area first decreased from 687,470.056 km^2 to 677,500.769 km^2, then expanded to 688,257.246 km^2, reflecting fluctuating spatial distributions.

The long axis first increased then decreased, with a slight overall increase, while the short axis first decreased then increased, with a slight overall decrease. These changes indicate spatial distribution imbalances and directional development differences. The azimuth angle increased by 1.747° from 2011–2015, then decreased by 1.410° from 2015–2020, showing a fluctuating growth pattern that reflects rotational trends in spatial distribution and dynamic changes in the relative levels of digital economy and green agricultural development across Xinjiang.

2.2.4 Regional Disparities and Sources The Dagum Gini coefficient and its decomposition for Xinjiang's coupling coordination degree are presented in and [Figure 5: see original paper].

Overall disparity showed a fluctuating decline trend, with the Gini coefficient decreasing from 0.458 in 2011 to 0.389 in 2020, indicating converging differences among prefectures. Inter-group differences among East, South, and North Xinjiang also declined steadily, suggesting synchronized development.

Specifically, differences between North and South Xinjiang were smallest (mean Gini = 0.337), followed by South and East Xinjiang (0.403), while North and East Xinjiang showed the largest disparity (0.468). Intra-group Gini coefficients showed volatile patterns, with East Xinjiang exhibiting the largest internal differences (0.354), followed by South Xinjiang (0.292), and North Xinjiang the smallest (0.267).

Decomposition results show inter-group differences contributed most to overall disparity (mean contribution rate = 45.7%), followed by intra-group differences (30.4%), with transvariation density lowest (23.9%). The combined contribution of inter-group and intra-group differences exceeds 76%, indicating these are the primary sources of disparity. The substantial variation in inter-group contribution rates reflects heterogeneity in natural environments, soil quality, agricultural infrastructure, and technological innovation across the three major regions.

3. Discussion

Unlike previous studies focusing solely on the digital economy's impact on green agricultural development, this research examines their mutual interaction, representing the first investigation of coupling coordination in arid regions. Xinjiang's water scarcity and environmental vulnerability make green agricultural development particularly critical. Analyzing coupling coordination helps identify key constraints on synergistic development and inform targeted policies to promote deep integration.

Our findings align with Fei et al. regarding the overall upward trend in coupling coordination, though the growth patterns differ. Their national-level study showed coupling coordination first narrowing then widening, while Xinjiang exhibits a slow, steady rise. This discrepancy likely stems from regional differences in data and geographic characteristics.

4. Conclusions

1) **Spatial Distribution**: Xinjiang's digital economy shows a "center-to-periphery" diffusion pattern, while green agricultural development exhibits "high north, low south, high east, low west" polarization. Temporally, both indices increased from 2011–2020, but green agricultural development's growth rate (33.922%) lagged far behind the digital economy's (131.618%).

2) **Coupling Coordination Trend**: The coupling coordination degree shows a gradual upward trend over time. Regionally, East Xinjiang experienced the largest growth, followed by North Xinjiang and South Xinjiang. The distribution center of gravity oscillated between north and south, reflecting dynamic spatial relationships.

3) **Regional Disparities**: Differences in coupling coordination levels show convergence trends. Inter-group differences contribute most to overall disparity (mean = 0.403), followed by intra-group differences (0.304), making them the primary sources of regional variation in Xinjiang's digital economy and green agricultural development coupling coordination.

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