Rural E-Commerce Clusters: Spatiotemporal Evolution and Development Drivers for Taobao Villages in Cao County, Eastern China

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Abstract [**Objectives**] To explore the spatiotemporal evolution and development drivers for Taobao villages in Cao County. [**Methods**] This paper employs GIS spatial analysis methods such as standard deviation ellipse and kernel density to characterize the spatial distribution, agglomeration, and correlation features of Taobao villages in Cao County at the township scale. Additionally, geographic detectors are used to explore influencing factors. [**Results**] (i) The number of Taobao villages in Cao County exhibits phased characteristics, progressing through initial, rapid expansion, and stable development stages. (ii) Taobao villages are unevenly distributed, with significant clustering features, primarily concentrated in the southeastern part of the county. In recent years, they have expanded toward the central and northwestern regions, potentially forming a "multi-core" spatial pattern in the future. (iii) The number of garment industries and e-commerce industrial parks consistently remains the primary factor influencing the spatial distribution of Taobao villages. After 2020, the number of wood processing industries and specialty agricultural product processing industries also exerted considerable influence. The number of logistics parks began to have an impact after 2018, albeit a weak one. Other factors had minimal influence on the differentiation of Taobao villages. [**Conclusions**] The spatiotemporal evolution exhibited diffusion along the "northwest-southeast" axis, with strengthened regional clustering. Government policies and industries significantly influenced the differentiation of Taobao villages, with varying primary factors across different periods.

Key words Taobao village, Spatial-temporal distribution, Influencing factors, Cao County

0 Introduction

The *Report of the 19th National Congress of the Communist Party of China* emphasized that issues concerning agriculture, rural areas, and farmers are fundamental to the national economy and people's livelihoods. It stressed that resolving the "three rural" issues must always remain a top priority for the entire Party, and the strategy of rural revitalization should be implemented. In recent years, the emergence of numerous Taobao villages has brought positive significance to rural revitalization[1]. Taobao villages are a typical product of the "internet + rural economy"[2]. With the development of inclusive internet-based economies[3], Taobao villages, as the smallest units in rural e-commerce industrial clusters, have become a result of the rapid advancement of rural e-commerce development models and the spread of technological innovation[4]. The rise of Taobao villages has had a strong demonstration and driving effect on the development of e-commerce in rural areas, triggering profound changes in the division of labor between urban and rural industries and the functional transformation of rural regions[5]. The "Taobao village" model, formed during the development of China's rural e-commerce industry, provides an effective pathway for promoting rural industrial revitalization. Against this backdrop, studying the spatiotemporal distribution of Taobao villages and their influencing factors holds significant importance.

Both domestic and foreign research findings indicate that the development model of Taobao villages primarily drives rural revitalization by stimulating regional industrial growth, creating employment opportunities, and narrowing the urban-rural income gap. Taobao villages impact the development of rural e-commerce, with e-commerce penetration promoting the growth of the circulation industry and encouraging migrant workers to return home for employment[6]. This effectively redirects local agricultural labor toward industrial sectors, compensating for previous labor outflows at the overall employment level. Moreover, its employment effects are positively correlated with local infrastructure development[7], contributing to the reduction of income disparities between urban and rural residents in China[8]. Additionally, effective collaboration and active participation among multiple stakeholders are key to the success of Taobao villages[9].

Taobao villages exhibit distinct spatiotemporal distribution characteristics across different regions. For instance, Zhejiang Province has witnessed rapid growth in the number of Taobao villages, with expanding coverage, showing a distribution pattern where central, southeastern, and northwestern areas have higher concentrations, while northeastern and southwestern areas have lower. The clustering cores of Taobao villages have evolved from point-like to area-wide and from suburban to near-urban areas[10]. In Guangzhou, "Taobao villages" are mainly concentrated around the central urban areas, in regions with medium-to-low permanent and employed population densities, and tend to cluster where similar products are sold[11]. Jiangsu Province's e-commerce industry displays three basic clustering patterns: high-high, low-high, and low-low[12]. Regarding influencing factors for Taobao villages, in

Received: May 4, 2025 Accepted: July 26, 2025

Supported by National Natural Science Foundation of China (42171206 & 42071159).

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addition to government policies, population, internet access, and transportation development[13], rural residents' disposable income also positively contributes to their growth, while economic development levels and urbanization rates may have inhibitory effects[14]. Furthermore, Taobao villages closer to cities demonstrate greater effects, whereas in more remote areas, only when a significant level of clustering is achieved can urbanization levels be enhanced[15].

Research findings at national and provincial scales[16-19] indicate that China's Taobao villages have undergone three developmental stages: the initial phase, the growth phase, and the current rapid expansion phase[20]. The distribution of Taobao villages exhibits significant regional imbalance, showing a clustered pattern, with 98% concentrated in eastern coastal cities. Additionally, the distribution of Taobao villages aligns with changes in the distribution of medium and large cities. These villages are more likely to be located in areas with better resource endowments, convenient transportation, industrial clusters, and higher internet penetration rates[21]. Some scholars have also studied specific Taobao villages as case studies to explore underlying patterns[22-24]. At the provincial scale, research on Taobao villages in Shandong Province reveals that their spatial distribution is clustered, presenting a pattern of "relatively sparse overall but concentrated in southwestern Shandong". The spatiotemporal evolution of these villages shows axial diffusion along the "northeast-southwest" direction, with increasing agglomeration density[25]. The developmental characteristics of Taobao villages in Shandong Province are similar to those at a finer scale in Cao County, both exhibiting clustering features and axial diffusion trends. Regarding influencing factors, major factors vary across regions. In Jiangxi Province, the development of Taobao villages results from a combination of multiple factors, with economic foundation, transportation conditions, and platform support being the primary influences[26]. In Shandong Province, e-commerce environment support was the foremost factor affecting the spatial distribution of Taobao villages in 2020[27]. For Henan Province, the five most significant factors influencing Taobao village development are government policies, industrial foundation, logistics and courier services, transportation conditions, and economic conditions[28].

Overall, scholars have conducted relatively comprehensive research on large scales such as the national and provincial levels, as well as micro-scale village-level studies, but there is a lack of research focusing on township-level analyses within the broader context of county-wide studies. Taobao villages inherently exhibit significant clustering effects, and studying their influencing factors can better reveal their spatial distribution characteristics and agglomeration patterns across different geographical regions. This helps to understand how Taobao villages achieve economies of scale in specific areas and how spatial optimization can enhance efficiency and competitiveness. It also allows for an in-depth exploration of the reasons behind the formation and development of Taobao villages in specific regions, uncovering their internal clustering mechanisms. The study area, Cao County, serves as a typical example of an "inland agricultural county + Taobao village cluster". Its spatiotemporal evolution model can supplement theories on the regional adaptability of rural e-commerce in non-coastal areas, revealing the differentiated mechanisms of e-commerce industry agglomeration under varying geographical conditions. As a populous county (with a registered population of about 1.7 million) and an agricultural hub, Cao County has long faced challenges such as labor outmigration and a singular industrial structure. The rise of Taobao villages has driven local employment and industrial upgrading, making it the second-largest "super-large Taobao village cluster" in China. Studying its development path can provide a practical paradigm of "e-commerce-driven rural revitalization" for similar counties in central and western China, particularly in areas such as the digital transformation of traditional industries and returning entrepreneurship. This model, leveraging local resources (*e. g.*, traditional handicrafts, specialty agricultural products) combined with e-commerce to overcome geographical limitations and achieve economic growth in non-coastal regions, holds practical significance for the national rural revitalization strategy, especially in "developing localized specialty industries." It offers policymakers decision-making insights regarding industrial support, infrastructure development (*e. g.*, logistics, internet), and other relevant areas. Therefore, this paper focuses on Cao County's Taobao villages as the research subject, conducting a township-level study to analyze their spatiotemporal evolution characteristics, predict future development trends, and explore influencing factors, which holds significant importance.

1 Material and methods

1.1 Kernel density estimation It can visualize the distribution of each type of land use in the study area[24], and the higher the value of kernel density, the greater the degree of clustering. The formula is as follows:

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

where $f_n(x)$ is the kernel density function; $k\left(\frac{x - x_i}{h}\right)$ is the kernel function; n is the sample size; $h > 0$ is a smoothing parameter called bandwidth; $(x - x_i)$ denotes the distance from the center point of the raster to a known point. In this paper, kernel density estimation is used to analyze the clustering of Taobao villages.

1.2 Standard deviation elliptic analysis (SDEA) It is used to express the direction of the distribution of spatial data, the center point of the ellipse indicates the mean center of the spatial distribution of the research object, the long axis indicates the dominant direction of the spatial elements, and the short axis indicates the centripetal force of the data. Among them, the larger the ratio of the long to short axes, the more obvious the directionality of the spatial distribution is indicated, and the azimuth represents the main trend direction of the spatial distribution[25]. The calculation formulas are as follows:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{X})^2}{n}} \quad (2)$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \overline{Y})^2}{n}} \quad (3)$$

$$\tan\theta = \frac{(\sum_{i=1}^{n}\overline{x_i^2} - \sum_{i=1}^{n}\overline{y_i^2}) + \sqrt{(\sum_{i=1}^{n}\overline{x_i^2} - \sum_{i=1}^{n}\overline{y_i^2})^2 + 4(\sum_{i=1}^{n}\overline{x_i y_i})^2}}{2\sum_{i=1}^{n}\overline{x_i y_i}} \quad (4)$$

where θ is the rotation angle; n is the sample size; SDE_x denotes the short axis of the standard deviation ellipse; SDE_y denotes the long axis of the standard deviation ellipse.

1.3 Geodetector Geodetector is a tool for detecting and utilizing spatial variability. Among them, divergence and factor detection is used to detect the spatial divergence of Y and to detect how much a factor X explains the spatial divergence of attribute Y. The expression is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \quad (5)$$

The value domain of q is [0, 1], the larger the value indicates that the spatial differentiation of Y is more obvious; if the stratification is generated by the independent variable X, the larger the value of q indicates that 3 the independent variable X explains the attribute Y more strongly, and vice versa. In the extreme case, a q-value of 1 indicates that factor X completely controls the spatial distribution of Y, a q-value of 0 indicates that factor X has no relationship with Y, and a q-value indicates that X explains $100 \times q\%$ of Y[26]. In this paper, Geodetector is used to calculate the explanatory power of each factor on Taobao village divergence, and then determine the geographic rootedness.

1.4 Data sources In this study, the annual list of Taobao villages in Cao County was sourced from the Ali Research Institute (http://www.aliresearch.com/). Relevant indicator data were compiled from the *China Rural Statistical Yearbook* (Township Volume) and the enterprise information platform Qichacha. Government policy documents and other information were obtained from the official websites of the Cao County People's Government (http://www.caoxian.gov.cn/) and the Heze Municipal People's Government (http://www.heze.gov.cn/). Spatial vector data for each Taobao village were extracted using the maplocation geographic information application tool.

2 Study site

Cao County is located in the southwestern part of Shandong Province, China, and is a county under the jurisdiction of Heze City, Shandong Province, with a long history. The county lies on the alluvial plain of the Yellow River, with terrain sloping from the southwest to the northeast. It has been honored with titles such as one of China's Top Ten Counties for E-commerce Development, a National Comprehensive Demonstration County for E-commerce in Rural Areas, one of China's Top 100 Counties for Online Sales, and one of China's Top 100 Counties for the Food Industry. It is also renowned as the "Hometown of Hanfu (Traditional Han Chinese clothing)", "Hometown of Willow Weaving", "Hometown of Asparagus", and "Hometown of Poplar Wood Processing" in China. In 2023, the county's GDP reached 58.204 billion yuan, with the industrial structure ratio of the primary, secondary, and tertiary sectors approximately at 1∶4∶5. In the same year, Cao County's cultivated land for planting exceeded 26 666 ha, and it had 441 industrial enterprises above the designated size, ranking first in Heze City.

Cao County is home to the largest Taobao village cluster in China and the largest in the northern Jiangsu region. The integration of e-commerce with traditional industries such as Cao County's performance costume sector has led to the formation of industrial clusters characterized by performance apparel and other specialties[27]. As of 2022, details regarding Taobao villages in Cao County: 176 Taobao villages, 21 Taobao towns, 30.5 billion USD sales revenue, more than 5 000 e-commerce enterprises, more than 60 000 online stores, 6 stores with revenue more than one billion USD, more than 100 stores with revenue more than one million USD, 249 Alibaba cross-border e-commerce enterprises, 77 Amazon cross-border e-commerce companies, and 4 e-commerce industry clusters (Hanfu, performance clothes, wood products, agricultural products).

3 Results and analysis

3.1 The phased evolution of Taobao villages in Cao County In terms of temporal evolution, Fig. 1 illustrates significant changes in the number of Taobao villages in Cao County from 2014 to 2022. In 2014, there were only 7 Taobao villages, but by 2022, the number surged to 176. The distribution of Taobao villages, initially concentrated in Daji Town, gradually expanded across the entire county.

From Fig. 2 and Table 1, it can be observed that since the emergence of the first Taobao villages in Cao County's Daji Town in 2013, the development of Taobao villages in Cao County has undergone an evolutionary process consisting of three stages: the budding stage, the rapid expansion stage, and the stable development stage. Specifically, before and during 2014, the number of Taobao villages was relatively small and confined to Daji Town and its surrounding areas, with significant fluctuations in the ratio of the major to minor axes of the ellipse, marking the exploratory phase of Taobao village development, the budding stage. In 2015, new Taobao villages appeared in the central and northwestern regions of the county, and from 2015 to 2020, the number of Taobao villages grew rapidly, with both the major and minor semi-axes of the ellipse generally increasing, representing the rapid expansion stage. From 2021 onwards, the growth rate of Taobao villages began to slow down, with the values of the major and minor semi-axes and their ratio gradually stabilizing, indicating the stable development stage.

The development of Taobao villages in Cao County has expanded

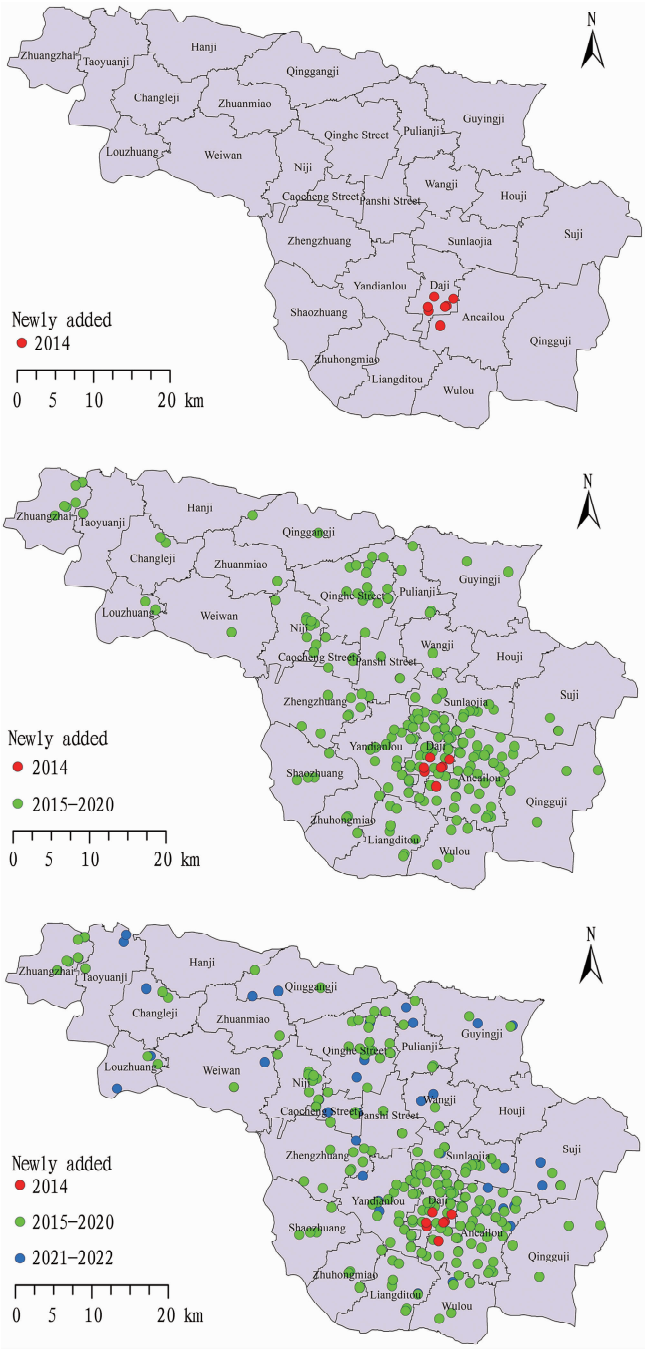


Fig. 1 Distribution of Taobao villages in Cao County from 2014 to 2022

from its initial base in Daji Town to the entire county and city, evolving from a "wild growth" phase to a more clustered and industrialized direction. The earliest Taobao villages in Cao County were Dinglou Village and Zhangzhuang Village in Daji Town, which were recognized as Taobao villages in 2013 and included in the national list of Taobao villages. In 2014, five additional Taobao villages emerged around Dinglou and Zhangzhuang. From 2015 to 2020, the number of Taobao villages grew rapidly, adding a total of 117 new villages. The spatial evolution of Taobao villages in Cao County demonstrates a pattern of close-range diffusion, ultimately forming the largest cluster centered around Daji Town, a second major cluster in the Pulanji-Qinghe Subdistrict area, and scattered distributions in other townships.

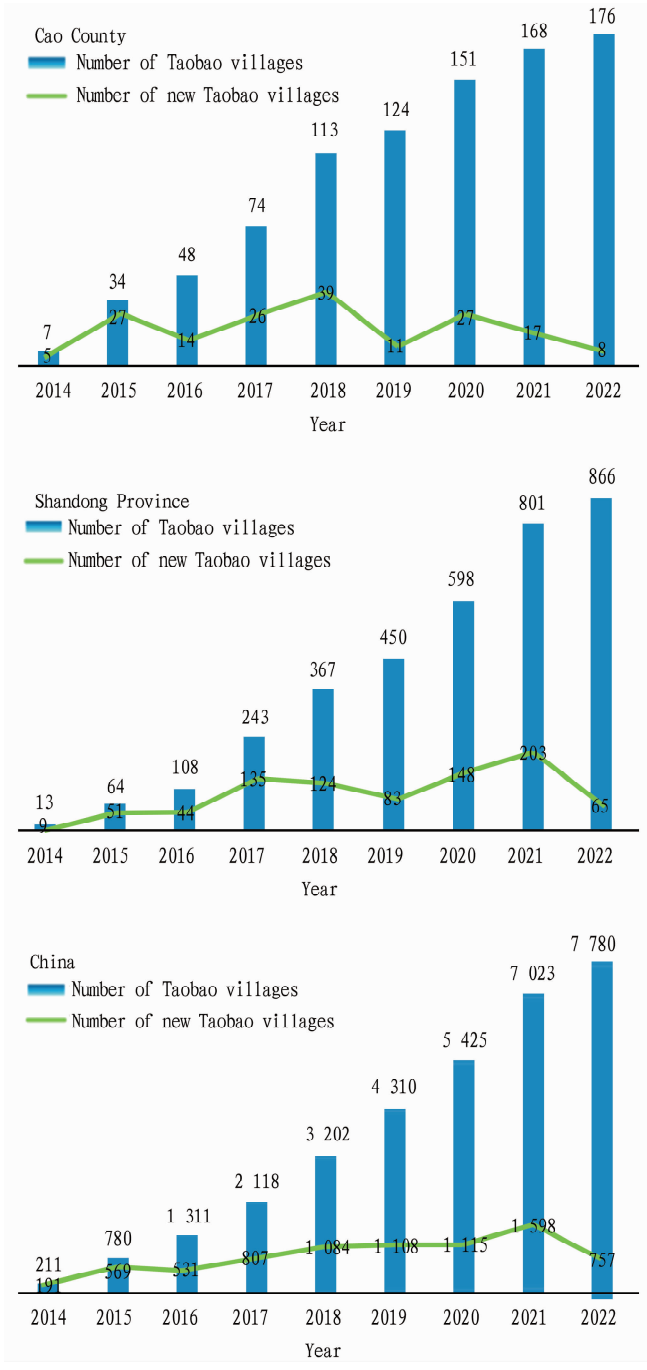


Fig. 2 Changes in the total number of Taobao villages in Cao County, Shandong Province and China from 2014 to 2022

From Fig. 2, it can be observed that the changes in the number of Taobao villages in Shandong Province and nationwide can also be divided into three similar development stages: the initial stage before and including 2014, the rapid growth stage from 2015 to 2019, and the stable development stage after 2021. There is a significant similarity in the development stages between the two,

leading to the conclusion that the temporal evolution of Taobao villages in Cao County follows the general pattern of Taobao village development over time. Based on the temporal patterns of Taobao village development in Shandong Province and nationwide, it is predicted that future changes in the number of Taobao villages in Cao County may be minimal, with a continued decline in the number of newly added Taobao villages.

3.2 The spatial clustering of Taobao villages in Cao County

As shown in Fig. 3 and Table 1, (i) the distribution of Taobao villages in Cao County exhibits distinct clustering characteristics. Initially centered around a "single core", the Taobao villages have gradually evolved into a "dual-core" model. The earliest Taobao villages were primarily concentrated in the southeastern part of the county, forming the first major cluster centered around Daji Town (including Yandianlou Town and Ancailou Town, which served as the birthplace of Taobao village development in Cao County and specialized in performance costumes). After 2016, a second major cluster began to emerge and develop in the central part of the county, particularly in towns and subdistricts such as Pulianji and Qinghe Subdistrict, focusing on wood product processing. In later stages of development, new agglomerations appeared in the northwestern part of the county, specifically in Zhuangzhai Town and Taoyuanji Town, with expanding scope and intensity. This suggests the potential emergence of a third major cluster in the future, also centered around wood product processing. (ii) Currently, the spatial distribution of Taobao villages in Cao County is uneven, generally following a pattern of "more in the southeast, fewer in the northwest". High-density concentrations have formed in the southeastern region, while a low-density concentration area has developed in the central part. Notably, Taobao villages are densely distributed around Daji Town and Ancaolou Town within the high-density cluster. (iii) The development of Taobao villages in Cao County has progressed from point-like to linear and then to areal distribution. Initially centered around Daji Town, the villages expanded eastward and westward to Yandianlou Town and Ancailou Town, subsequently driving the formation of an areal industrial cluster in the eastern part of the county. In the northwestern townships, where wood product processing dominates, agglomerations of Taobao villages have already begun to appear, indicating potential for future development that could spur overall growth in the western part of the county.

3.3 Development trend of Taobao villages in Cao County

From Fig. 4 and Table 2, we found that: (i) The coordinates of the ellipse's center of gravity gradually shift northwestward, indicating that the overall spatiotemporal evolution of Taobao villages follows an axial diffusion pattern along the "northwest-southeast" direction, with regional clustering intensity continuously increasing. (ii) Changes in the major and minor axes reflect that Taobao villages in Cao County initially developed in a point-like manner before transitioning to directional diffusion. (iii) Except for 2014, the ratio of the major to minor axes was generally higher in the early stages, while in later periods, the ellipse tended to become more circular, with a lower and more stable axis ratio, suggesting an increasingly uniform overall distribution of Taobao villages. (iv) Taobao villages in Cao County are consistently expanding toward the northwest region, potentially forming a third major Taobao village cluster centered on wood product processing in the northwest, thereby creating a "tri-core" development pattern.

Table 1 Standard deviation ellipse attributes

Year	Coordinates of the center of gravity	Long semi-axis	Semi-axis	Azimuth	Aspect ratio
2014	34.670° N – 115.634° E	0.161	0.134	46.11°	1.2 : 1
2015	34.727° N – 115.600° E	0.157	0.065	137.77°	2.4 : 1
2016	34.740° N – 115.594° E	0.191	0.070	132.66°	2.7 : 1
2017	34.753° N – 115.601° E	0.178	0.068	136.32°	2.6 : 1
2018	34.763° N – 115.596° E	0.188	0.080	131.96°	2.4 : 1
2019	34.762° N – 115.597° E	0.188	0.084	132.76°	2.2 : 1
2020	34.761° N – 115.591° E	0.200	0.086	131.88°	2.3 : 1
2021	34.762° N – 115.590° E	0.201	0.083	131.87°	2.4 : 1
2022	34.774° N – 115.583° E	0.213	0.088	130.34°	2.4 : 1

3.4 Analysis of influencing factors

Taobao villages typically focus on selling products with absolute competitive advantages and low costs. The goods produced within these industrial clusters often have cost advantages, leading to spatial differentiation and industrial agglomeration in the development of Taobao villages, which reflects their typical geographical embeddedness[28]. The growth of Taobao villages is primarily influenced by two key factors: products and logistics. They often rely on local specialty industries and advantageous resources to form industrial clusters of a certain scale. These clusters, connected through e-commerce platforms, achieve integrated online and offline development, driving the transformation, upgrading, and sustainable growth of the local economy.

In this study, we take the number of Taobao villages in each township of Cao County across different years as the dependent variable (Y), with the number of courier companies (X_1), logistics parks (X_2), e-commerce industrial parks (X_3), wood processing industries (X_4), garment manufacturing industries (X_5), and agricultural product processing industries (X_6) as explanatory variables. It aims to explore the main factors influencing the development of Taobao villages in Cao County for each respective year, assess the varying degrees of impact of these factors, and analyze the temporal changes in their influence. The indicators are detailed in Table 2.

Table 2 Influencing factors and indicators selected

Factor	Norm
Logistics and transportation conditions	Number of courier companies (X_1)
	Number of logistics parks (X_2)
Government policy	Number of e-commerce industrial parks (X_3)
Industrial condition	Number of garment manufacturing industries (X_4)
	Number of wood processing industries (X_5)
	Number of agro-processing industries (X_6)

The geographical detector was used to analyze each indicator, and the results are shown in Table 3.

Table 3 Results of geographic detectors for each indicator

Year	Value	X_1	X_2	X_3	X_4	X_5	X_6
2014	q statistic	0.023 3	0.004 1	0.972 7	1.000 0	0.101 7	0.207 4
	p value	0.977 0	0.951 7	0.000 0	0.000 0	0.996 0	0.277 5
2015	q statistic	0.034 7	0.007 2	0.865 8	0.964 7	0.489 2	0.110 1
	p value	0.875 3	0.926 6	0.000 0	0.000 0	0.880 4	0.680 1
2016	q statistic	0.082 9	0.008 6	0.919 2	0.990 5	0.459 4	0.169 0
	p value	0.612 4	0.911 3	0.000 0	0.000 0	0.989 0	0.638 6
2017	q statistic	0.135 3	0.009 7	0.804 4	0.977 2	0.513 4	0.321 8
	p value	0.818 9	0.901 5	0.000 0	0.000 0	0.982 0	0.631 8
2018	q statistic	0.129 7	0.008 8	0.611 4	0.973 6	0.766 8	0.758 7
	p value	0.842 8	0.913 4	0.078 7	0.011 4	0.586 3	0.130 7
2019	q statistic	0.170 8	0.371 9	0.877 8	0.959 2	0.387 9	0.574 6
	p value	0.746 8	0.020 7	0.000 0	0.040 4	0.998 7	0.832 0
2020	q statistic	0.123 4	0.586 1	0.877 6	0.964 8	0.577 8	0.946 3
	p value	0.929 1	0.003 7	0.000 0	0.011 9	0.992 7	0.042 7
2021	q statistic	0.095 8	0.447 5	0.567 1	0.972 8	0.996 0	0.992 5
	p value	0.985 8	0.013 7	0.120 7	0.004 8	0.000 0	0.000 0
2022	q statistic	0.714 5	0.366 8	0.499 7	0.881 6	0.999 0	0.811 5
	p value	0.071 2	0.060 8	0.008 4	0.000 0	0.000 0	0.772 5

By combining Table 3 and Fig. 5, the analysis can be divided into three stages:

First, during the 2014 – 2018, the explanatory power of each indicator for the spatial differentiation of Taobao villages ranked from high to low as follows: X_4, X_3, X_5, X_6, X_1, X_2. Among these, only the p-values of X_3 and X_4 passed the significance test at the 0.05 level, indicating that during this stage, the number of e-commerce industrial parks (X_3) and the number of garment industries (X_4) had relatively strong explanatory power for the spatial differentiation of Taobao villages. Therefore, it can be concluded that the number of e-commerce industrial parks and garment industries were the main factors influencing the spatial distribution of Taobao villages in Cao County during this period.

During the 2018 – 2020, taking 2019 as an example, the explanatory power of each indicator for the spatial differentiation of Taobao villages ranked from high to low as follows: X_4, X_3, X_6, X_5, X_2, X_1. Among these, only the p-values of X_2, X_3, and X_4 passed the significance test at the 0.05 level, indicating that the number of e-commerce industrial parks (X_3) and garment industries (X_4) still had relatively strong explanatory power for the spatial differentiation of Taobao villages during this time, while the explanatory power of the number of logistics parks (X_2) increased. Thus, the number of e-commerce industrial parks, garment industries, and logistics parks were the main factors influencing the spatial distribution of Taobao villages in Cao County during this period.

In the 2020 – 2021, the explanatory power of each indicator for the spatial differentiation of Taobao villages ranked from high to low as follows: X_6, X_4, X_5, X_3, X_2, X_1. Among these, the p-values of X_2, X_4, X_5, and X_6 passed the significance test at the 0.05 level, indicating that the number of garment industries (X_4) still had relatively strong explanatory power for the spatial differentiation of Taobao villages, while the explanatory power of the number of e-commerce industrial parks (X_3) slightly declined. The explanatory power of the number of logistics parks (X_2), wood processing industries (X_5), and specialty agricultural product processing industries (X_6) increased, with the explanatory power of specialty agricultural product processing industries (X_6) even surpassing that of garment industries (X_4). Therefore, the number of garment industries, logistics parks, wood processing industries, and specialty agricultural product processing industries were the main factors influencing the spatial distribution of Taobao villages in Cao County during this period, with an increase in the number of key influencing factors.

In the 2021 – 2022, the explanatory power of each indicator for the spatial differentiation of Taobao villages ranked from high to low as follows: X_5, X_4, X_6, X_1, X_3, X_2. Among these, the p-values of X_2, X_3, X_4, and X_5 passed the significance test at the 0.05 level, indicating that the number of garment industries (X_4) still had relatively strong explanatory power for the spatial differentiation of Taobao villages, while the explanatory power of the number of e-commerce industrial parks (X_3) continued to decline. The explanatory power of the number of wood processing industries (X_5) reached a relatively high level and gradually stabilized, while the explanatory power of the number of logistics parks (X_2) continued to decline. Therefore, the number of garment industries, e-commerce industrial parks, and wood processing industries were the main factors influencing the spatial distribution of Taobao villages in Cao County during this period.

Overall, in terms of influencing factors, the number of e-commerce industrial parks and garment industries consistently remained the main factors affecting the spatial distribution of Taobao villages in Cao County over time, indicating that the garment industry is the pillar industry for the development of local Taobao villages. The declining trend in the explanatory power of the number of e-commerce industrial parks reflects the increasing maturity of government policy support for Taobao villages. In recent years, the number of wood processing industries and specialty agricultural product processing industries has also become a main factor influencing the spatial distribution of Taobao villages, reflecting the diversification of local Taobao villages into multiple industries and fields, with industrial factors gradually becoming the main driving force for their development. The explanatory power of logistics and transportation conditions (X_1, X_2) remained relatively low but showed a fluctuating upward trend overall, also reflecting the growing demand for logistics and transportation enterprises due to the expansion of the Taobao industry, although these factors are not the main determinants of Taobao village locations.

As shown in Fig. 6, when examining the interaction effects of the factors, any two factors exhibited an enhancing relationship. All interactive factors showed a two-factor enhancement, with no nonlinear enhancement, independence, or weakening relationships. This conclusion is based on the observation that $q(X_1 \cap X_2) > \max[q(X_1), q(X_2)] \cdots q(X_5 \cap X_6) > \max[q(X_5), q(X_6)]$, indicating that the influence of the interaction between two factors is greater than that of any single factor. Therefore, the interaction between different influencing factors can enhance the explanatory power for the embeddedness of Taobao villages. Among these, the

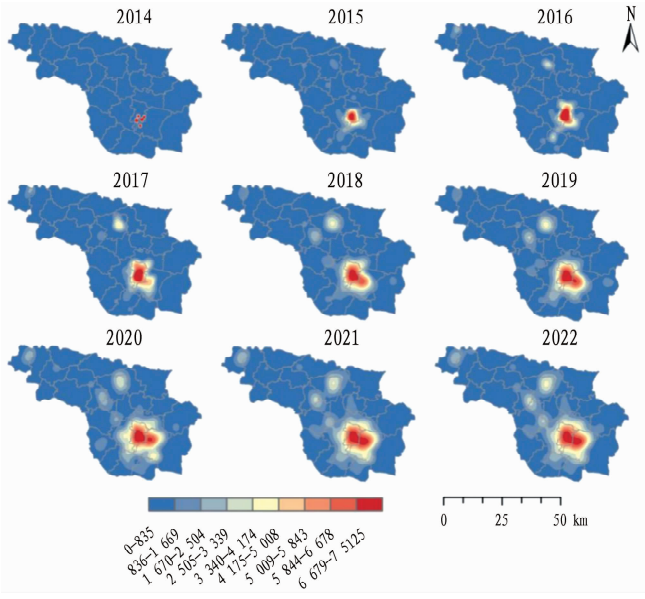


Fig. 3 Kernel density analysis of Taobao village in Cao County from 2014 to 2022

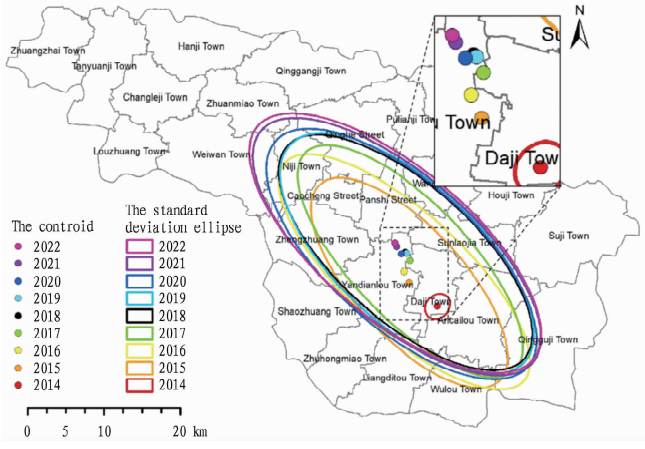
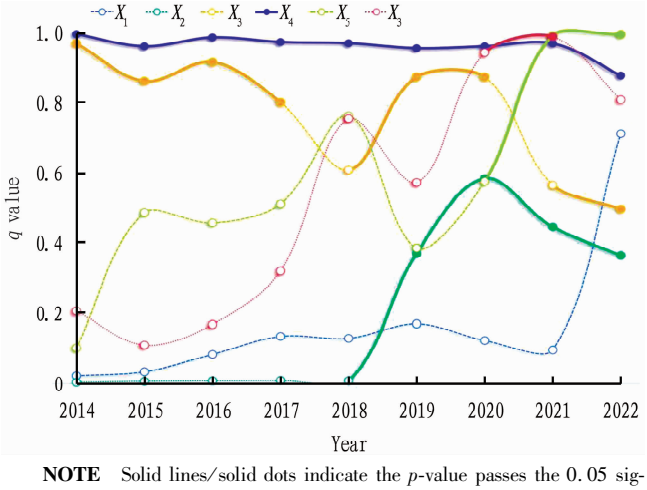


Fig. 4 Standard deviation ellipse analysis of Taobao village in Cao County (2014 – 2022)



NOTE Solid lines/solid dots indicate the *p*-value passes the 0.05 significance test.

Fig. 5 Temporal variation of *q*-value

number of garment industries (X_4), wood processing industries (X_5), and specialty agricultural product processing industries (X_6) were the most influential factors in the interaction detection. The strong influence of these industrial quantity factors suggests that Taobao villages in Cao County are highly dependent on specialized industrial clusters, with significant synergy or complementarity between industries.

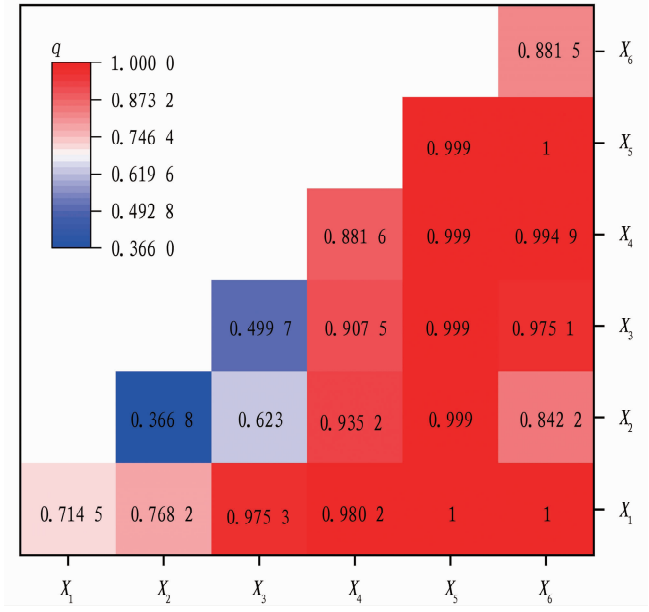


Fig. 6 Heat map of *q* value of each interaction factor

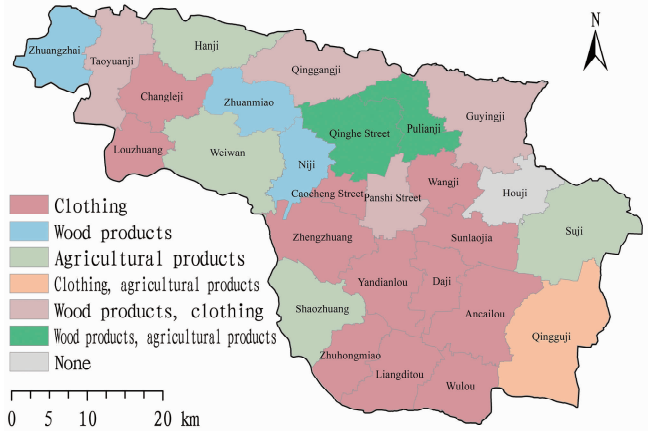


Fig. 7 Main types of commodities in Taobao villages in each township of Cao County

As seen in Fig. 7, Taobao villages specializing in Hanfu, performance costumes, and other clothing items are mainly concentrated in Daji Town and its surrounding areas, where Taobao villages emerged earlier. In contrast, towns in the northwest primarily focus on wooden products, benefiting from the local robust wood processing industry. Today, the main products of Cao County's Taobao villages are no longer limited to Hanfu and performance costumes but have diversified significantly. The industrial chain of Cao County's Taobao has evolved into a diversified and large-scale development pattern, transitioning from a single focus to multiple sectors and from decentralization to clustering. Cao County's

Taobao villages have formed several relatively complete industrial chains, covering raw materials to processing and sales logistics: the clothing industry chain, the wooden products industry chain, and the agricultural products industry chain. In the early stages, Cao County's Taobao industrial chain was primarily concentrated in the clothing sector, particularly performance costumes and Hanfu. With the continuous development of e-commerce platforms and the expansion of the market, the industrial chain gradually expanded into wooden products, agricultural products, and other fields. Initially, e-commerce businesses in Cao County were scattered across various villages without forming a well-integrated industrial chain. However, with strong government support and the construction of e-commerce industrial parks, these businesses, along with supporting industries like logistics, began to cluster, creating economies of scale and cluster effects.

In the early stages of Cao County's Taobao villages, development was just beginning, with relatively singular industries and raw material procurement primarily relying on local sourcing, making them locally productive Taobao villages. During the mid-term, Taobao villages expanded rapidly, with the increasing number of merchants and growing demand for raw materials leading to large-scale external procurement, gradually transitioning into mixed-production Taobao villages. In the later stages, the methods of raw material acquisition in Cao County's Taobao villages became relatively mature and diversified, including local procurement, external procurement, and online procurement. Hanfu, performance costumes, and timber raw materials mainly relied on both local production and external procurement, while agricultural and specialty product raw materials were mostly sourced locally, classifying them as mixed-production Taobao villages. In the future, the number of Taobao villages in Cao County is expected to stabilize, and the methods of raw material acquisition will continue to diversify and move toward greener practices.

4 Conclusions and discussion

By studying the Taobao villages in Cao County from 2014 to 2022, the phased characteristics of their temporal development were clarified, including three developmental stages, which align with the developmental phases of Taobao villages in Shandong Province and the whole country. Kernel density analysis revealed significant spatial clustering features, presenting an overall pattern of "more in the southeast, less in the northwest", with emerging aggregation points in the northwest expected to drive overall development in the western region. Using the standard deviation ellipse analysis method, the developmental trend was assessed, showing the ellipse's center of gravity shifting northwestward. The spatio-temporal evolution exhibited diffusion along the "northwest-southeast" axis, with strengthened regional clustering. After initial point-based development, directional diffusion emerged, and changes in the ellipse's axis ratio reflected the developmental process, higher ratios in early stages, becoming more circular and stable later, indicating increasingly uniform distribution.

Government policies and industries significantly influenced the differentiation of Taobao villages, with varying primary factors across different periods. Overall, the garment manufacturing industry remained the dominant influencing factor, while the explanatory power of other industries also increased, leading Taobao villages to diversify into multiple sectors and fields. The diffusion dynamics of Taobao villages also evolved: early stages were dominated by homogeneous competitive diffusion driven by social network relationships and demonstration effects, while later stages saw industrial chain extension making economic factors and industrial development conditions the primary drivers.

The methods of raw material procurement continuously evolved. Initially, it was locally sourced and locally produced. As demand expanded in the mid-term, procurement shifted externally, transitioning to a mixed production model. Later stages saw diversified procurement methods, with future trends pointing toward stable numbers and increasingly diversified and greener procurement approaches.

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panding the livelihood space of farmers and promoting the gradual transformation of their livelihoods.

3.5 Strengthening livelihood risk warning management and improving the stability of farmers' livelihoods The ecological environment in the ecological development area of northern Guangdong is fragile, and its economic development is lagging behind. The livelihoods of farmers are highly vulnerable to various risks such as natural risks, health risks, market risks, and policy risks, and their livelihood stability is relatively poor. Against this backdrop, preventing livelihood risks, strengthening livelihood risk early warning management, and enhancing the stability of farmers' livelihoods are crucial for ensuring the sustainable development of farmers' livelihoods.

In the future, it is necessary to strengthen the monitoring of farmers' livelihood risks, establish a dynamic monitoring and prevention mechanism for farmers' livelihood risks, conduct dynamic monitoring of farmers' production and living conditions, income sources, and household income and expenditure situations, accurately identify the risk points of different types of farmers' livelihoods, and take timely measures to eliminate them. In addition, it is necessary to strengthen livelihood risk early warning management, classify and intensify follow-up support and assistance work based on the early warning results, establish a livelihood risk prevention system, and enhance farmers' ability to cope with livelihood risks, ensuring the stable and sustainable development of farmers' livelihoods.

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