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Probing Influence Factors of Implementation Patterns for Sustainable Land Consolidation: Insights from Seventeen Years of Practice in Jiangsu Province, China

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Abstract: Land consolidation is a key measure in the implementation of agricultural sustainability and has a strategic importance in farmland fragmentation reduction and rural revitalization. In order to understand spatiotemporal patterns of land consolidation implementation and their influences at a large scale, a comprehensive evaluation of 1046 land consolidation projects was conducted in Jiangsu Province, China. The results of this study showed that the construction scale (CS) and investment amount (IA) rose in waves in Jiangsu province during the period 2001–2017, while the newly increased farmland rate (NIFR) continued to decline. Spatial patterns of land consolidation aggregated, whereas the scale and the kernel density of the newly increased farmland area (NIFA) was differentiated in different time periods. In addition, the regional differentiation was significant. The gravity center of CS, IA, and NIFA moved with an overall trend from South Jiangsu to North Jiangsu, and finally stopped at the Li-Xia River plain area in North Jiangsu. The key factors that promoted land consolidation included natural farmland quality and the proportion of the primary industry production in GDP. The potential of NIFA, the farmland production amount, and the income of the financial transferring payment were also important factors. Spatial patterns were initially influenced by natural conditions and were later influenced more significantly by economic and policy conditions. In the future, differentiated land consolidation policy oriented by public involvement should be formulated to improve new frameworks of system implementation, as well as to provide evidence for spatial configuration, district cooperation, policy adjustment, and the systematic improvement of sustainable land consolidation.

Keywords: land consolidation; dynamic balance of cultivated land; grain production capacity; spatiotemporal pattern; regional differentiation

1. Introduction

Since 1978, China's industrialization and urbanization have developed rapidly, occupying a large percentage of high-quality farmland, coupled with inappropriate utilization. This has caused large-scale soil erosion, soil pollution, and land degradation, all of which seriously threaten food security and sustainable economic development [1–6]. However, since 1996, the central government has launched a series of policies to carry out organized land consolidation work on a national scale [7,8]. The objectives of the policies were to protect farmland through rational utilization with maximum output benefit and to keep a dynamic balance of cultivated land area. Over a span of 10 years, China has invested CNY 30 billion per year into land consolidation. The cumulative consolidated land area has exceeded 40 million ha [9–11]. Land consolidation, which is an effective measure of sustainable farmland management policy [12–16], had important functions to realize. These were the requisition–compensation balance of farmland [10], the enhancement of farmland quality and grain production capacity [17–20], the safeguarding of national food safety [21,22], and the promotion of rural revitalization [23–25].

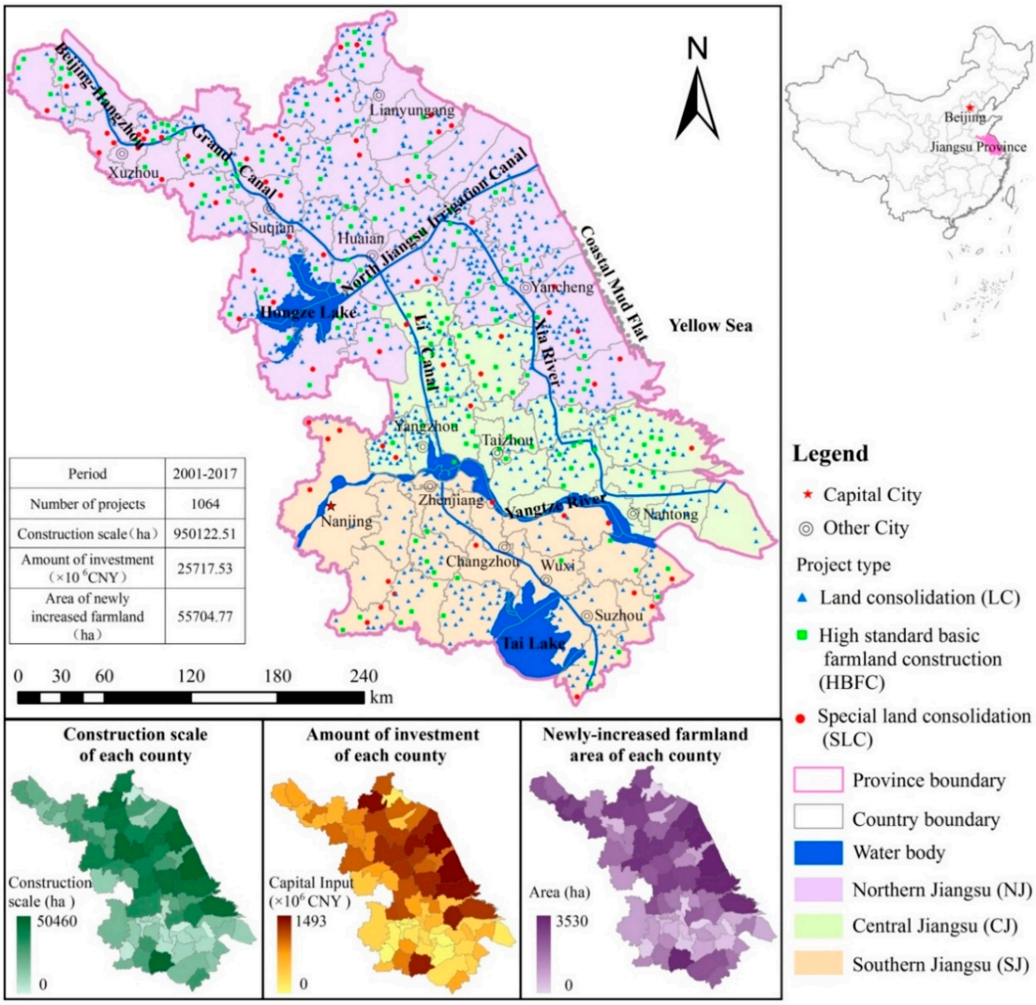
Land consolidation is employed as an effective tool for reducing farmland fragmentation [26–34], enhancing agricultural competition [35–39], and promoting social equity [40] and sustainable rural renewal [41]. Meanwhile, improvement of the environment, the management of risks, the realization of infrastructure projects, and the creation of recreational areas are essential parts of land consolidation projects [42–46]. However, the benefits of land consolidation in Europe and America, such as reducing land fragmentation, are more concerned with the newly increased farmland rate [15,16,18,19,42]. The emergence of land consolidation in China originated from the requirements of a number of social and economic development strategies. These consisted of an initial target of increasing farmland quantity, exploiting unutilized land resources [47], and satisfying the requirement of farmland requisition–compensation balance [48]. Subsequently, the policy turned towards the enhancement of crop production capacity with high-standard basic farmland construction (HBFC) [49]. In China, previous studies have been plentiful and were more focused on the spatial differentiation of land consolidation [50,51] and the spatiotemporal characteristics of the newly increased farmland [40,47]. Investment efficiency and regional division [52,53], and the coupling relationship between land consolidation and economic development or rural renewal [54,55], were also subjects that were focused on. In addition, topics such as NIFR at a small scale, energy efficiency, landscape effect, environmental influence, and social effects were also considered [56–58]. The methods involved included the gravity center model, spatial self-related analysis, the variation coefficient, the Gini coefficient, the geological centralization degree, and the standard deviation index [50–53]. However, the social development status in China was converted dramatically to preferential targets for maintaining a beautiful natural and living environment, as well as ecological safety. Therefore, land consolidation for ecological society construction [59–61], rural transformation [62–70], and low carbon development [71,72] have all been paid greater attention to by researchers. The concept of land consolidation, particularly focusing on quantity and energy production, has been transformed, mainly to provide ecological system services [73].

Currently, there is a severe lack of high-quality farmland, in addition to significant farmland protection pressure. The low implementation of land consolidation remains a significant problem faced by China and other countries. Thus, there is motivation to carry out relevant studies related to achieving a range of aims, such as how to reasonably arrange projects of land consolidation, realize the maximization of capital usage efficiency, promote the spatial configuration optimization of resources, establish land consolidation patterns in new periods, and realize the collaborative development of reserved farmland resources and land consolidation. In China, natural conditions, socioeconomic development, and policy implementation capacity are reflected in different problems in different regions due to large regional inequalities [15,56]. Thus, it is urgent that implementation patterns, mechanisms, and different reasons for land consolidation at a larger, regional scale should be ascertained. In view of this, 1064 land consolidation projects with approved financial investment implemented by Jiangsu province were investigated using index analysis (Table 1) and redundancy analysis in this study. The aims of this study are as follows: (1) Clarify the spatial pattern evolution of land consolidation from 2001 to 2017; (2) Assess whether the investment amount (IA) and cultivated land agglomeration zone match, and whether site selection of the project and the reserved land resource are consistent; and (3) Identify the key factors that influence land consolidation implementation, and see if these change over time. This study will help China and other countries provide for strategic top-level design and macro decisions aimed at the better promotion of implementation efficiency.

2. Materials and Methods

2.1. The Study Area

Jiangsu province is located on China's eastern coast at 116°18′–121°57′ E and 30°45′–35°20′ N (Figure 1). Its terrain is flat, with plains, water, and hills accounting for 70.2%, 15.5%, and 14.3% of the total area, respectively. The total land area is 107,200 km^2, with a population of 80.7 million (2019) and an urbanization rate of 65.2%. Its weather is warm and it spans semitropical zones. The annual temperature range and precipitation are 13–16 °C and 1000 mm, respectively. Land use is mainly cultivated land, accounting for 42.7%, followed by built-up areas, which account for 20.4%. Wetland accounts for 19.6%, forested land for 14.6%, and other uses for only 2.7%. Thus, an obvious contradiction between humans and land prevails in this area. In Jiangsu province, the per capita farmland allocation in 2018 was only 0.06 ha. Even though Jiangsu Province is an important industrial base and is known as a main food production area, with dense population density and high levels of economic output, industrialization, and urbanization, intra-provincial socioeconomic development is not balanced. The ratio of per capita GDP between South, Central, and North Jiangsu is 4:2:1. Therefore, the problems and objectives of land use in South Jiangsu, Central Jiangsu, and North Jiangsu are different. In addition, the reserved farmland resources of Jiangsu province are scarce. Coastal mud flats and the wetland of the Li-Xia River are protected by the red line of ecological protection. Thus, there is an urgent need for land consolidation that could increase farmland area, improve food production, and enhance the carrying capacity of the regional ecological environment.



Period	2001-2017
Number of projects	1064
Construction scale (ha)	950122.51
Amount of investment (×10^{6}CNY)	25717.53
Area of newly increased farmland (ha)	55704.77

Figure 1. The study area and the sampling data map.

2.2. Data Sources

For the present study, the principal data sources are those relating to land consolidation and the social economy. Land consolidation data were obtained from the database of "the monitoring and management information system of rural land consolidation in Jiangsu province", from the Land Consolidation Centre of Jiangsu Province. During the period from 2001 to 2017, there were 1064 government-funded land consolidation projects. These projects were of three types: land consolidation projects (LC) (focusing on adding new cultivated land, thus, landfilling ponds and land leveling are the most important tasks, and some farmland water conservancy facilities are supported); high-standard basic farmland construction (HBFC) projects (focusing on increasing farmland production capacity, thus, the most important task is the support of field infrastructure, including roads, shelterbelts, and farmland water conservancy facilities); and comprehensive land consolidation (SLC) projects (including soil pollution remediation projects, mine reclamation projects, and whole village restructuring projects). Data for each project, including coordinates, type, CS, NIFA, and IA were gathered (Figure 1).

Eleven socioeconomic indicators (namely, population; GDP; farmland area; fertilizer application amount; area of the newly increased construction land; number of rural employees; land lending revenue; the proportion of primary, secondary, and tertiary industries; the proportion of agricultural investment to total investment; and the income of financial transferring payment; see Table 2) were obtained from the statistical yearbook of different districts and countries (city, district) (2002–2018). The source of farmland data, such as natural quality degree [10], was a data CD entitled "the investigation and evaluation of Chinese farmland quality grade" (Jiangsu volume).

The administrative county is the basic unit that is used when assessing land administrative statistics in China. Considering the implementation status of land consolidation and the data availability, municipal administrative districts with few cultivated land areas, such as Nanjing City and Suzhou City, were merged from 96 county level districts to 69 evaluation units, and the projects were merged according to the adjustment of the evaluation units. These 69 evaluation units were determined according to the county level districts belonging to: South Jiangsu, including 5 prefecture-level cities (such as Nanjing City); Central Jiangsu, including 3 prefecture-level cities (such as Yangzhou City); and North Jiangsu, including 5 prefecture-level cities (such as Xuzhou City).

2.3. The Study Methods

2.3.1. Index Analysis

In this study, the nearest neighbor index, kernel density analysis, and the gravity center transferring model were used to explore the spatial pattern differentiation of land consolidation in Jiangsu province. The coordinates of each project were used as the origin, and the CS, IA, and NIFA of land consolidation were used as input variables. Spatial assignment was calculated according to Equations (1)–(6). The equations are as follows:

$$\mathrm{NNI} = \frac{r_{obs}}{r_{exp}} \tag{1}$$

$$r_{obs} = \sum_{i=1}^{n} \frac{\min\left(d_{ij}\right)}{n} \tag{2}$$

$$r_{exp} = 0.5\sqrt{A/n} \tag{3}$$

$$f(x) = \frac{1}{nh^d}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{4}$$

$$x_j = \sum_{i=1}^{n} \frac{E_{ij} \times X_i}{\sum_{i=1}^{n} E_{ij}} \tag{5}$$

$$y_j = \sum_{i=1}^{n} \frac{E_{ij} \times Y_i}{\sum_{i=1}^{n} E_{ij}} \quad (6)$$

where r_{obs} is the average observed distance of the land consolidation project; r_{exp} is the expected observed distance of the land consolidation project; $min\ (d_{ij})$ is the distance between each point and the nearest neighbor; n is the total number of studying points; and A is the total area of the research district. Generally, $NNI < 1$ indicates an aggregated distribution; $NNI = 1$ indicates a random distribution; and $NNI > 1$ indicates an even distribution [38]. K is the kernel function; x_i represents the data points; n is the number of data points; d is the dimension of the data; and h is the core band width of the searching diameter. The default band width generated automatically by ArcGIS was 1/30 of the minimum width or length of the data set. The large district of consolidation was composed of n sub-districts, wherein the geometrical center coordination of the ith consolidation sub-district was (X_i, Y_i). The measuring value of the element property of land consolidation in the ith sub-district in the jth year was E_{ij} (the construction scale, the investment amount, the newly increased farmland area). The gravity center coordinates of the element property of land consolidation in the large districts of consolidation in the jth year was p_j (x_j, y_j) (the construction scale, the investment amount, the newly increased farmland area). In this work, n refers to the number of sub-districts in the large district of land consolidation and j is the year (2001, 2002, ... 2017).

The above methods were implemented using the analysis tool in ArcGIS 10.2 (ESRI, San Diego, CA, USA). The detailed index definitions and applicability are presented in Table 1.

Table 1. The key parameters of the research methods.

Methods	Meaning and Applicability
Nearest neighbor index (NNI)	In NNI, the distance between each target and its corresponding nearest neighbor is compared with the expected distance of the nearest neighbor in a random distribution. NNI describes the adjacent extent between targets in geological space [74,75]. This method was realized using the Average Nearest Neighbor of Spatial Statistical Tool in ArcGIS 10.2. It has been widely used in the spatial statistical analysis of pattern types [75].
Kernel density analysis	This is a non-coefficient method to calculate the density of an element in the peripheral neighborhood, which has been widely used for spatial data inquiry analysis [76,77]. In the present work, the Kernel Density of Spatial Analyst Tool in ArcGIS 10.2 was used to analyze the spatial distribution characteristics of different property values (construction scale (CS), investment amount (IA), and newly increased farmland area (NIFA)).
Gravity center transferring model	In the present work, based on the Gravity Center Analysis Tool of ArcGIS 10.2 and Excel 2017, the gravity center position of elements in land consolidation projects at different layers in different years was calculated. Then, transfers of barycenter diagrams were charted to analyze the balance and consistency of land consolidation conducted by the county level administration [53].

2.3.2. Redundancy Analysis

In the present study, an index system for redundancy analysis of land consolidation was built (Table 2). The land consolidation level of each evaluation unit was described by three species variables, namely, CS, IA, and NIFA. Considering different factors that influenced the promotion and application of land consolidation [56,78], the environmental variables were chosen from four aspects: nature, society, economy, and policy.

Table 2. Data for redundancy analysis.

Factors	Indicators [56,78]	Units
Natural conditions	Natural quality of grain farmland (NQGF)	/
	Reserved resource potential of newly increased farmland (RLNIF)	ha
	Degree of fragmentation of farmland (DFF)	household·ha^{-1}
	Grain production (GP)	t·ha·a^{-1}
Social conditions	The amount of fertilizer application (IFA)	t·ha·a^{-1}
	Per capita area of farmland (PCAF)	ha·p^{-1}
	Area of the newly increased construction land (ANICL)	ha
	Population density (PD)	p·km^{-2}
	Proportion of rural employees to total population (PRTP)	%
Economic conditions	Land lending revenue (LLR)	10^4 CNY
	The amount of rural production per capita (APPC)	CNY
	The second and third industry production per capita (STIPPC)	CNY
	The proportion of the first industry production in GDP (PFIPGDP)	%
Policy conditions	The proportion of agricultural investment to total investment (PAITI)	%
	The income of financial transferring payment (IFTP)	10^8 CNY
	The amount of science and technology innovation award of land consolidation project (AA)	/

(1) Natural conditions represent the degree of difficulty in carrying out land consolidation projects. The worse the natural conditions, the more difficult it is to carry out land consolidation projects. Therefore, 5 indexes were selected: natural quality of grain farmland (NQGF); reserved resource potential of newly increased farmland (RLNIF); degree of fragmentation of farmland (DFF); grain production (GP); and the amount of fertilizer application (IFA). Among these, NQGF directly reflected the degree of difficulty of project implementation; a low NQGF value meant a difficult path to implement land consolidation. RLNIF reflected the potential of increasing farmland after land consolidation; a large RLNIF indicated it was easy to execute land consolidation projects. DFF restricted the level of agricultural mechanization; a high degree of DFF reflected great demand for land consolidation. GP reflected the output level of cultivated land; a low GP indicated high demand for a land consolidation project that could improve the quality of cultivated land. IFA improved agricultural production (a high IFA indicated a large demand for land consolidation) and could also improve soil structure.

(2) Social conditions directly determine the demand for new farmland and new construction land in the region, and indirectly determine the willingness of rural residents to participate in land consolidation. Therefore, four indicators were selected: per capita area of farmland (PCAF); area of the newly increased construction land (ANICL); population density (PD); and proportion of rural employees to total population (PRTP). From these indicators, less PCAF indicated that cultivated land was under significant pressure and land consolidation was needed to increase it. Greater ANICL inevitably indicated that agricultural land was being occupied and, thus, land consolidation was required to supplement the cultivated land. High PD illustrated a shortage of arable land resources, and that more farmland was then needed to provide agricultural products. A large PRTP indicated that more people were engaged in agriculture, and land consolidation projects were required to boost the economy.

(3) Economic conditions directly determine the capital conditions of land consolidation, and the level of economic development indirectly affects the demand for land consolidation, and particularly

the demand for the replacement of new farmland and new construction land. Thus, four indicators were selected: land lending revenue (LLR); the amount of rural production per capita (APPC); the secondary and tertiary industry production per capita (STIPPC); and the proportion of primary industry production in GDP (PFIPGDP). Among these, higher LLR indicated greater economic strength for land consolidation. A low APPC required high land consolidation, which could increase output and farmers' income. Both low STIPPC and low PFIPGDP indicated that the economy was underdeveloped. Thus, the higher the dependence on agriculture, the more land consolidation is needed.

(4) Policy conditions mainly refer to the support of local government and provincial government for land consolidation policy. Three indicators were selected: the proportion of agricultural investment to total investment (PAITI); the income of financial transfer payments (IFTP); and the amount of science and technology innovation awarded to land consolidation projects (AA). Among these, PAITI reflected the degree of recognition from the Department of Agriculture. A higher PAITI value illustrated higher recognition and, thus, more land consolidation projects might be acquired. IFTP reflected the degree of financial support from the provincial government to local governments, and AA reflected the local government's emphasis on land consolidation projects. Overall, 16 indicators were chosen as environmental variables across the areas of nature, society, economy, and policy.

In this work, a database of collected data and environmental factors was established using Excel 2017 (Microsoft, San Diego, CA, USA). The quantity statistical testing and the redundancy analysis were conducted using the Canoco 4.5 statistical software package (Cabit Information Technology Co., Shanghai, China). The specific operation steps were as follows:

(1) Excel data sheets of species variables and environment variables were established. The sheets were saved as two DAT files in the WCanoImp interface of Canoco for Windows.

(2) The data selection and method settings based on Canoco for Windows 4.5 software were as follows: ① Click the Species and environment Data Available option in the Available Data interface. ② The species variables are analyzed by detrended correspondence analysis (DCA) to determine whether land reclamation belongs to Linear distribution or Unimodal distribution. Lengths of DCA gradient < 3 indicate suitability for RDA analysis. In this case, click the RDA option under Linear under Type of Analysis. ③ Click both of the above tests under the Global Permutation Test. ④ Select Manual Selection and use Monte Carlo Permutation Tests in the Forward Selection of the Environmental Variables interface.

In other words, significant environment variables were gradually screened by forward selection, and the F- and p-values of each environment factor were calculated by a Monte Carlo displacement test at each step. Thus, the environment variables with Monte Carlo $p < 0.05$ could be screened out. The permutation test statistic is called the pseudo-F value, and the calculation formula is as follows:

$$F = \frac{SS(\hat{Y})/\mathrm{m}}{RSS/(n-m-1)} \tag{7}$$

where n is a number, m is the number of constraint axes (or model freedom), SS ($\hat{Y}$) (explained variance) is the sum of the squares of the fitting value matrix, and RSS (constraint model of residual sum of squares) is SS (Y) (sum of the squares of the response variable matrix Y) minus the SS ($\hat{Y}$).

We compared the pseudo-F value with Fperm. If N times permutations were applied, N sorting models and Fperm values would be obtained, respectively. The positions of Fdata of the observed regression equation were compared to the frequency distribution of the N Fperm values. If the Fdata value was greater than 95% of the Fperm value ($p < 0.05$), then the null hypothesis was rejected. Conversely, if the Fdata value was not greater than 95% of the Fperm value ($p > 0.05$), then the null hypothesis could be accepted.

The calculation of the *p*-value is shown in Equation (8):

$$P = \frac{n_x + 1}{N + 1} \quad (8)$$

where n_x is the number of permutations for which the expected value of the zero distribution of the permutation test statistic is higher than the observed value (Fperm > Fdata), and N is the total number of permutations.

The Average Nearest Neighbor Tool in the Spatial Statistics Tool of ArcGIS 10.2 was applied. Then, the results could be obtained, including Average Observation Distance (r_{obs}), the Expected Observation Distance (r_{exp}), the Nearest Neighbor index (NNI), the Z test value, and the *p*-value.

(3) Finally, the sort diagram was displayed in CanoDraw for Windows.

3. Results and Discussions

3.1. Spatial Pattern Evolution of Land Consolidation Implementation in Jiangsu Province

3.1.1. Spatial Pattern Characteristics of Land Consolidation in the Time Dimension

There were 1064 projects in Jiangsu province from 2001 to 2017, with a CS of 950,122.51 ha. The cumulative IA and NIFA were 25.718 billion and 55,704.77 ha, respectively (Figures 1 and 2). According to Figure 2a, there were only 20 projects in 2001, whereas NP in 2014 reached a maximum of 111 projects. Except for 2002, CS in other years was higher than 15,000 ha. The IA increased from CNY 0.21 billion in 2001 to CNY 3.77 billion in 2014, and then fell to CNY 1.08 billion in 2017. Both CS and AI demonstrated a fluctuating trend, initially increasing and then decreasing from 2001 to 2017. NIFA reached its maximum in 2014, after decreasing dramatically from 2006, a trend which continued in later years. NIFR decreased from 30.37% in 2001 to 0.43% in 2017.

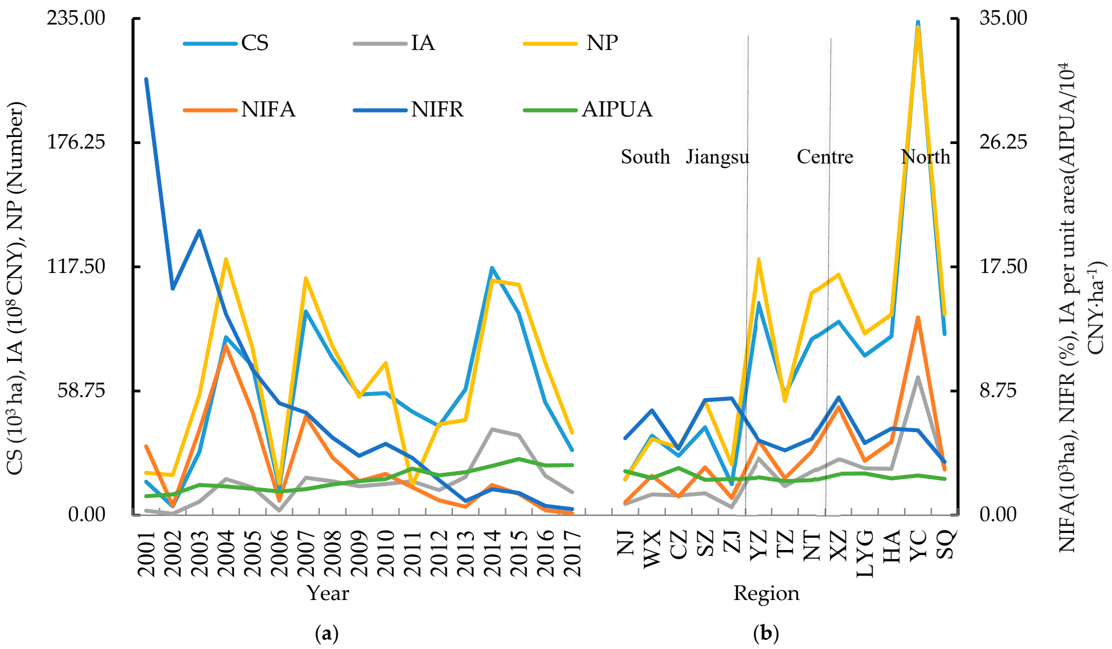


Figure 2. Overview of land consolidation programs in Jiangsu Province from 2001 to 2017. (Note: CS represents the construction scale; IA represents investment amount; NP represents number of projects; NIFA represents the newly increased farmland area; NIFR represents the newly increased farmland rate. Nanjing City (NJ); Wuxi City (WX); Changzhou City (CZ); Suzhou City (SZ); Zhenjiang City (ZJ); the above five cities belong to South Jiangsu. Yangzhou City (YZ); Taizhou City (TZ); Nantong City (NT); the above three cities belong to Central Jiangsu., Xuzhou City (XZ); Lianyungang City (LYG); Huaian City (HA); Yancheng City (YC); Suqian City (SQ); the above five cities belong to North Jiangsu.).

Overall, NP, CS, and IA demonstrated an increasing trend, whereas NIFR fell sharply. Before 2006, the implementation of land consolidation was still at an exploratory stage, and the project arrangement lacked scientific argument. The NP, CS, and IA of annual land consolidation projects changed dramatically in the early stages. In 2006, in particular, NP, CS, and IA all decreased with a large amplitude. The NIFR of land consolidation decreased dramatically after 2007, which was closely related to the policy adjustment. The initial land consolidation target in China was to increase new farmland and to explore unutilized reserve land sources [47]. Before 2007, land consolidation was part of the national investment and was devoted mainly to reserve land source developments [79] with high requirement for NIFR. With the adjustment of land utilization strategy and the farmland protection policy, HBFC has been emphasized since 2008. Land consolidation projects are gradually becoming mainstream, and backup resource development projects and reclamation projects are slowly becoming fewer [76]. To promote rural revitalization, ecological rehabilitation, and a community of shared life with the management of mountains, rivers, forests, land, and lakes as a whole [47] has been emphasized since 2012. NIFR values were all larger than 10% in Jiangsu province between 2001 and 2005. In the later phase, investment was strengthened, whereas the enhancement of farmland quality, as well as comprehensive land consolidation, was paid more attention in Jiangsu Province.

3.1.2. Spatial Pattern Characteristics of Land Consolidation in the Spatial Dimension

From prefecture-level city analysis (Figure 2b), NP, CS, IA, and NIFA of Yancheng City were intensive. The IA per unit area of Changzhou City was the highest (33,200 CNY·ha^{-1}). The NP and NIFA values of Nanjing City were the smallest, whereas its IA per unit area was only smaller than that of Changzhou City. The pattern formation was closely related to farmland resource characteristics and natural conditions. From the perspective of the district, not only the project number but also the investment amount and the newly increased farmland amount all showed a decreasing trend in the order of North Jiangsu > Central Jiangsu > South Jiangsu. In addition to the IA per unit area, NIFR values also showed a decreasing trend, in the order of South Jiangsu (27,700 CNY·ha^{-1}, 6.9%) > North Jiangsu (27,700 CNY·ha^{-1}, 5.92%) > Central Jiangsu (25,300 CNY·ha^{-1}, 5.14%). This result was ascribed to land consolidation projects in South Jiangsu during the early period (2001–2006), adopted mainly as demonstration projects, which required higher NIFR and IA. After a 17-year implementation period, only 20.8% of the farmland in Jiangsu Province was consolidated. Even though this ratio is higher than other provinces in China [70], it is far below the level of agriculturally developed countries.

3.2. Spatiotemporal Pattern Differentiation of Land Consolidation in Jiangsu Province

3.2.1. Spatial Pattern Evolution of Land Consolidation

According to Equations (2) and (3), the average observed distance of land consolidation projects in Jiangsu province was calculated as 5644.94 m using the Average Nearest Neighbor of Spatial Statistics Tool in ArcGIS 10.2, compared with the expected observed distance of 6169.43 m. The nearest neighbor index NNI was 0.914985 < 1 with a significant p-value (Table 3). This illustrates that the land consolidation projects were distributed in aggregation from 2001–2017, whereas the possibility of this result occurring randomly was less than 1%.

Table 3. The nearest neighbor index analysis result.

Indicator	Average Observed Distance	Expected Observed Distance	NNI	Z	*P*
Value	5644.94 m	6169.43 m	0.9150	−5.3051	0.00

From Figure 3, it is observed that the spatial distribution of land consolidation in Jiangsu province was unbalanced. There was significant differentiation among different units. The resulting kernel density did not depend only on CS of land consolidation, but also on the NIFA of land consolidation. These were mainly distributed in the districts of Central Jiangsu and North Jiangsu. The kernel density of CS was mainly distributed in Dafeng, Funing, Jianhu, and Sheyang of Yancheng City in North Jiangsu. In some districts, such as Siyang and Muyang of Suqian City in North Jiangsu, Hongze and Jinghu of Huaian City in North Jiangsu, Xinyi of Xuzhou City, and Ganyu and Donghai of Lianyungang City in North Jiangsu, aggregation resulted not only due to the CS of land consolidation, but also the NIFA of land consolidation. This demonstrated a consistent distribution, although all were at higher levels. The kernel density of NIFA was mainly distributed in Tongshan, Feng county, and Pei county of Xuzhou City in North Jiangsu, Hongze, Jinghu, and Baoying of Huaian City in North Jiangsu, Ganyu of Lianyungang City in North Jiangsu, every county of Yancheng City in North Jiangsu, and Yizhen and Jiangdu of Yangzhou City in Central Jiangsu. However, the kernel density of the investment amount was mainly distributed in Northeast Zhenjiang City in South Jiangsu.

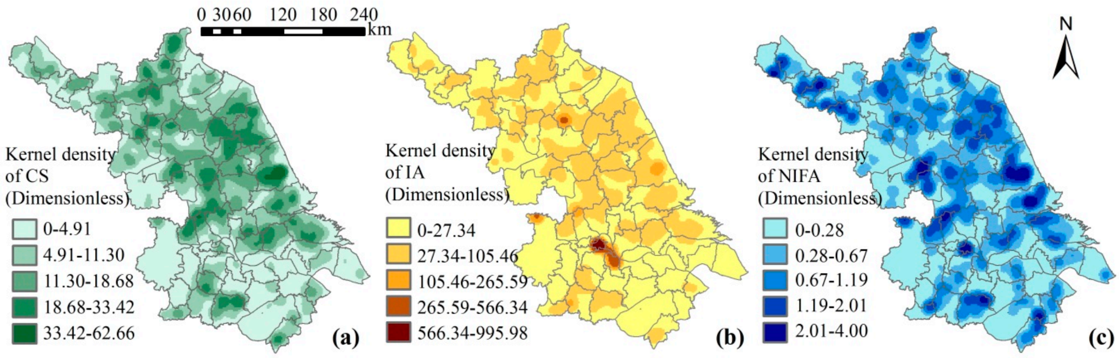


Figure 3. The kernel density of CS (**a**), IA (**b**), and NIFA (**c**) based on each project in Jiangsu Province from 2001 to 2017.

Overall, CS agglomeration of land construction does not match the spatial distribution of the farmland resource, and IA agglomeration of land construction is inconsistent with RLNIF. On the one hand, 19.4% of the land consolidation projects were mainly distributed in 7.24% of the farmland resource zone, while 28.36% of the farmland resource zone was only arranged for 7.82% of the land consolidation projects. On the other hand, 52.87% of IA was invested in 10.41% of the reserve land resources zone, whereas only 15.01% of IA was invested in 62.17% of the reserve land resource zone. These unmatched and inconsistent zones were mainly distributed in the Ning-Zhen-Yang hilly region of southwest Jiangsu and the northern plain area of Tai Lake. According to Yang et al. [52], the balanced development of land consolidation of different areas could be promoted to some extent by ensuring the investment strength of the high input district, as well as the IA of the low-input district. This unmatched and inconsistent phenomenon reflected the low efficiency of land consolidation implementation. Some non-efficient factors, such as the rent-seeking behavior of local governments, greatly interfered with the site selection of projects. The results were attributed to the management mechanism of land consolidation projects in China. Because the funds come from unpaid financial payments, local governments have rent-seeking behavior when applying for capital investment for land consolidation. The investment behavior of land consolidation in China is completely different from that seen with market-oriented incentives in Europe [43–45] and other countries [44]. In the future, IA should be matched with the project type according to the characteristics of the different evaluation units. Differentiated policy should be formulated to increase the implementation efficiency and multifunctionality of land consolidation.

3.2.2. Unbalanced Development of Land Consolidation in the Time Dimension

The gravity centers of CS, IA, and NIFA of land consolidation in Jiangsu province from 2001 to 2017 all fluctuated and changed in the directions of latitude and longitude (Figure 4). The patterns demonstrated a characteristic of "northwest–west–southeast–northwest" and a total moving trend in the direction of northwest. The change of the gravity center represented regional differentiation. In the initial phase of land consolidation, CS and IA of land consolidation of South Jiangsu and Eastern Coast regions were higher than those of the West and North. The gravity center position of NIFA moved towards the north dramatically compared with those of CS and IA. This illustrated that the NIFA of North Jiangsu was far higher than that of South Jiangsu.

The gravity centers of IA and CS of land consolidation in Jiangsu province were synchronized; of the 17 yearly gravity centers, 16 were sited at the Li-Xia River plain in North Jiangsu. The local terrain is plain with three coordinated elements of light, heat, and precipitation in summer, which is conducive to agricultural production. Due to high-quality cultivated land and fertile soil, the Li-Xia River plain has become the main grain production area in Jiangsu Province. In contrast, the Ning-Zhen-Yang hilly region of southwest Jiangsu has been characterized by weak inputs of land consolidation due to poor natural conditions. The investment preference also reflected that land consolidation policy was tilted towards the main grain producing areas in Jiangsu Province. Although spatial distribution of land consolidation was influenced greatly by natural conditions and policies, spatial site selection and investment trends of the projects were clear and stable over time, which is consistent with the conclusions of Xiong [51], Hu [79], and Yang [52]. In fact, China's land consolidation planning is often blind. Although there are policy preferences, planning often cannot determine site selection of the project. Ultimately, funds were not invested where they were most needed [1]. This is completely different from market-oriented investment preferences in Europe and America, where concerns focus more on efficiency of input and output.

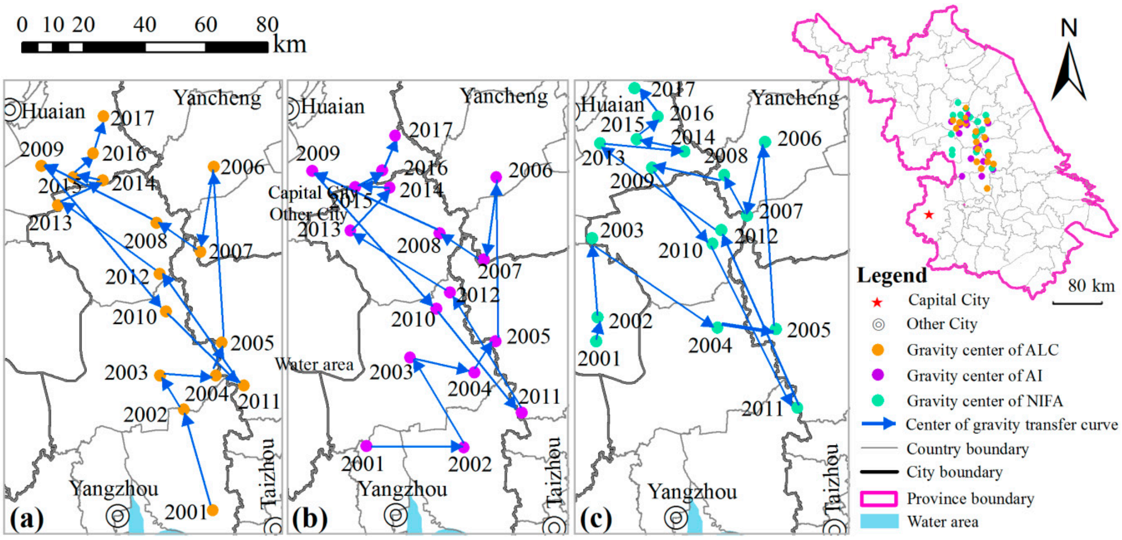


Figure 4. Center of gravity transfer map of CS (**a**), IA (**b**), and NIFA (**c**) of land consolidation in Jiangsu Province from 2001 to 2017.

3.3. Analysis of the Dominant Factors Influencing Project Implementation

All sequencing axes in the Monte Carlo permutation test reached the significant level (p = 0.002 < 0.05), illustrating the ideal sequencing effect. The first axis explained 52.6% of the species change information and 99.4% of the species–environment relationship information (Table 4). The significance of the effect of the environmental factors in different stages on land consolidation was analyzed by forward selection and the Monte Carlo test [2]. A sharp angle between the arrow of the species and the arrow of the environmental variable indicated a positive correlation; if the angle was blunt, a negative correlation was indicated. A right angle means that no correlation is indicated between the two [1,2]. The overall results showed that NQGF (F = 27.32, p = 0.002) and PFIPGDP were at a 1% confidence level (Figure 5a), whereas NQGF, PFIPGDP, RLNIF, GP, and IFTP in different stages demonstrated different confidence levels, thus illustrating the variability of key factors in different stages for promoting land consolidation implementation.

The implementation pattern of land consolidation was influenced by multiple factors in China [78,80]. Natural conditions, economic conditions, and policy conditions were the main influencing factors in Jiangsu Province, while social conditions were relatively weaker. From Figure 5b,d, the two variables of RLNIF (F = 12.95, p = 0.004) and PD (F = 4.67, p = 0.04) were key factors in the promotion of land consolidation implementation from 2001 to 2005. The two variables of APPC (F = 30.94, p = 0.002) and DFF (F = 4.17, p = 0.032) were key factors in the promotion of land consolidation implementation from 2006 to 2011. The three variables of PFIPGDP (F = 36.39, p = 0.002), NQGF (F = 6.68, p = 0.008), and IFTP (F = 3.16, p = 0.106) were key factors in the promotion of land consolidation implementation from 2012 to 2017.

Table 4. Redundancy analysis result of land consolidation in Jiangsu Province from 2001 to 2017.

Axis	1	2	3	4	Total Variance
Eigenvalues	0.526	0.273	0.154	0.047	1.000
Species–environment correlations	0.730	0.525	0.591	0.000	
Cumulative percentage variance of species data (%)	52.6	53.0	53.0	99.1	
Cumulative percentage variance of species–environment relationship (%)	99.4	100.0	100.0	100.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.530

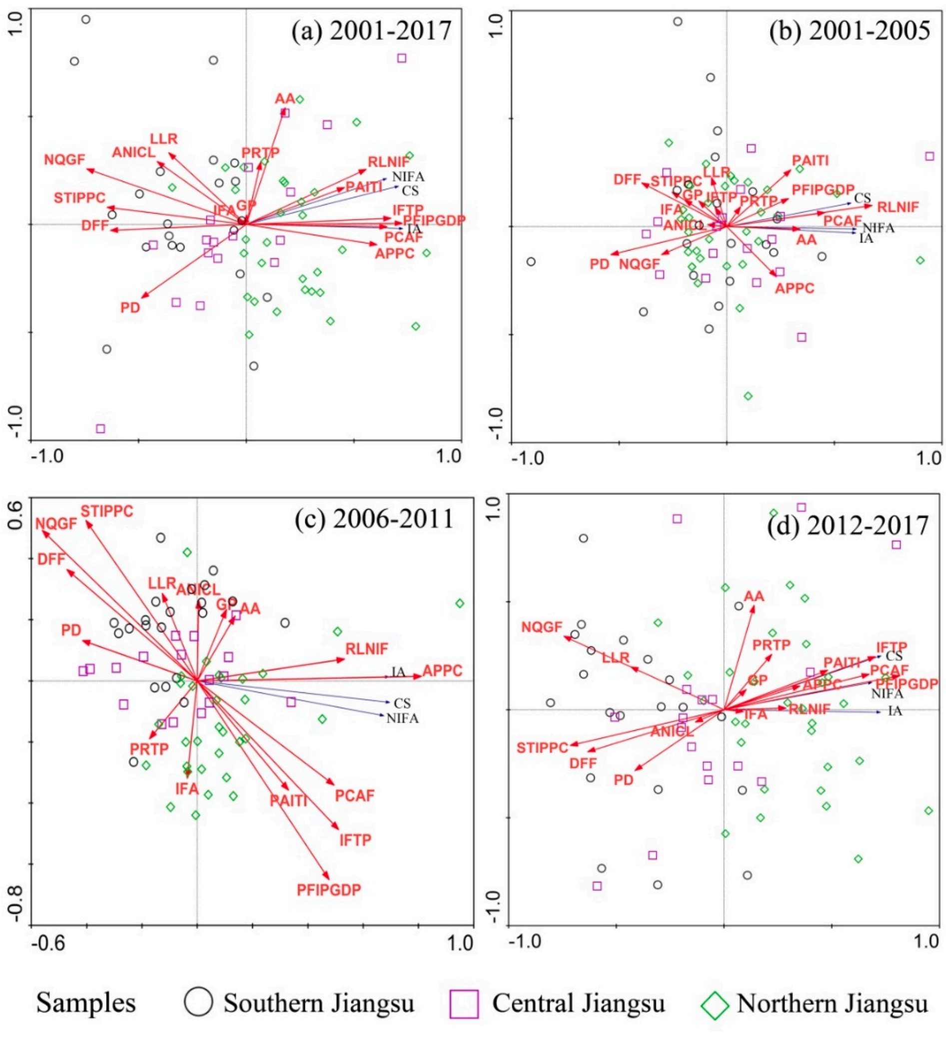


Figure 5. Redundancy analysis result of land consolidation in Jiangsu Province from 2001 to 2017.

Overall, land consolidation of Jiangsu province was mainly influenced by natural conditions and social conditions during the period 2001–2005, whereas it was mainly influenced by economic conditions and policy conditions during the period 2012–2017. (1) In natural conditions, there was a positive correlation between NIFA and RLNIF. This finding verified the conclusion of Wei [50], namely, the relatively strong correlation between NIFA and the farmland resource characteristic. Guan et al. [7] and Yang et al. [53] showed that the greater the value of RLNIF, the larger the CS and the greater the NIFA. RLNIF dramatically influenced the implementation pattern of land consolidation in the early stage (2001–2005). This result was due to more selected sites of land consolidation projects and larger requirements for NIFR. Thus, land consolidation was usually conducted in zones with an abundant reserved land resource. This is very different from other countries. Most land consolidation projects in Europe aimed to reduce land fragmentation, reduce production costs, improve agricultural competitiveness, and attract young people to stay in the countryside [16,19,42]. Most land consolidation projects in South Asia aimed to improve farmland infrastructure in order to increase grain production capacity [21,30]. China's original intention to promote land consolidation aimed to increase NIFA by offsetting arable land occupied by urban or industrial development [1–3]. (2) In economic conditions, the higher the value of PFIPGDP, the less developed the local economy. In other words, the higher the reliance on agriculture, the more urgent the need for land consolidation implementation. The interest in implementing land consolidation of North Jiangsu was far higher than that of South Jiangsu due to the latter's relatively less developed economy. (3) In policy conditions, IFTP demonstrated the support degree of provincial government towards local government. Policy factors, such as IFTP, promoted site selection of land consolidation projects towards the main grain production district [79]. In addition, the district with a less-developed economy and larger RLNIF was selected to undertake the task of farmland requisition–compensation balance within the scope of Jiangsu Province. These districts were located in the Li-Xia River plain and coastal districts of North Jiangsu, which showed high CS and IA. In the future, different types of land consolidation projects in different districts should be considered together to practically increase NIFR in Jiangsu Province. Differentiated land consolidation policies should be formulated to optimize the investment efficiency. The existing coal mine subsidence, waste industrial land, and rural residential land in Jiangsu province should be reclaimed. The input of ecological consolidation should be enlarged to promote rural transformation and update effective implementation.

4. Conclusions

Land consolidation is a key measure for the sustainable utilization of farmland with strategic importance for farmland fragmentation reduction and rural revitalization. From the spatial patterns of land consolidation implementation in Jiangsu Province, the results showed the following:

(1) The CS and IA of land consolidation showed an increasing trend in Jiangsu Province, China, whereas NIFR demonstrated a decreasing trend. In addition, the CS, IA, and NIFA of land consolidation projects demonstrated a decreasing trend in the order of North Jiangsu > Central Jiangsu > South Jiangsu.

(2) The spatial pattern of land consolidation implementation in Jiangsu Province was in an aggregation distribution (NNI = 0.914985 < 1 with a significant p), whereas the spatial distribution was unbalanced and the regional differentiation was significant. The kernel density of CS was in a decreasing trend in the order of Central Jiangsu > North Jiangsu > South Jiangsu. The kernel density of NIFA was in a decreasing trend in the order of North Jiangsu > Central Jiangsu > South Jiangsu. The kernel density of IA was in a decreasing trend in the order of South Jiangsu > Central Jiangsu > North Jiangsu. The agglomeration of IA of land consolidation was highly consistent with NIFA in the county level districts of coastal North Jiangsu.

(3) Overall, the gravity centers of CS, IA, and NIFA of land consolidation in Jiangsu Province moved with a trend from south to north. However, the change during the 2007–2012 period was irregular. Finally, the gravity centers of CS, IA, and NIFA of land consolidation were sited at the Li-Xia

River plain of North Jiangsu, demonstrating the preference of site selection of land consolidation projects for the main grain production district in Jiangsu Province.

(4) NQGF, PFIPGDP, RLNIF, GP, and IFTP were key factors influencing the promotion of land consolidation implementation. In the early stage, the influence of natural conditions was dominant. In the later stage, the influence of economic and policy conditions became gradually more significant.

The impact factors show different confidence levels at different stages, which highlights uncertain efficiency of land consolidation implementation. However, matching IA with cultivated land agglomeration zones and consistent site selection of projects with reserved land resources are the basic guidelines for land consolidation implementation all over the world. Policy adjustments may lead to lower efficiency of land consolidation implementation. The results of the present research help elucidate the implementation effect of the engineering of land consolidation and provide evidence for the optimization of the spatial configuration of land consolidation, the synergetic development of districts, and the adjustment and improvement of policies. In the future, maintaining policy stability, combating rent-seeking behavior of local governments, and guiding public participation may be effective ways to improve the efficiency of land consolidation implementation. This study will help China and other developing countries achieve sustainable land consolidation.

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List of Terms: Newly increased farmland rate (NIFR) represents the ratio of newly increased farmland area to construction scale of land consolidation project. It is the only indicator of whether a place is worthy of investment at an early stage of land consolidation planning in China. Degree of farmland fragmentation (DFF) refers to the number of households per unit area; the larger the value, the greater are the restrictions in the use of agricultural machinery. Proportion of the first industry production in GDP (PFIPGDP) represents the ratio of primary industry output value to GDP in each evaluation unit. The farmland requisition-compensation balance system requires that any unit occupying farmland must supplement the same area of farmland or pay the cost of reclaiming the same area of farmland for food security in China. High-standard farmland construction project (HBFC) refers to carrying out land consolidation within the scope of basic farmland for improving land productivity. Comprehensive land consolidation (SLC) includes soil pollution remediation projects, mine reclamation projects, and whole village restructuring projects, accompanied by land consolidation. Construction scale (CS) refers to the size of the land consolidation area that excludes undisturbed parts such as villages, rivers, and lakes. Community of shared life with the management of mountains, rivers, forests, land, and lakes as a whole is President Xi Jinping's green development concept, which allows various environmental elements to coexist in harmony to provide better ecological services for human beings. Reserved resource potential of farmland refers to the amount of land resources that can be developed as arable land, such as barren grassland, tidal flats, and unused land.

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