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Quantitative Change or Qualitative Change: The Impact of Whole-Region Comprehensive Land Consolidation on Cultivated Land Security—Based on Panel Data from Townships in Zhejiang Province

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Abstract: Land consolidation is a crucial strategy for optimizing land use structure and ensuring cultivated land security and food safety. Since 2019, Zhejiang Province has been piloting and exploring Whole-Region Comprehensive Land Consolidation (WRCLC). However, there remains an insufficient understanding of the feasibility of WRCLC in ensuring cultivated land security and its potential for synergy with other policies. This study utilizes panel data from 707 townships in Zhejiang Province spanning from 2013 to 2022. By categorizing cultivated land security into two dimensions—quantity and quality—this study employs a double machine learning approach to evaluate the impact of WRCLC policies on township cultivated land security. The results indicate that implementing WRCLC significantly enhances both the quantity and quality of cultivated land. A heterogeneity analysis reveals that WRCLC is particularly effective in improving the quality of cultivated land in non-major grain-producing areas and low economic development areas. Furthermore, examining policy synergies indicates that agricultural mechanization and agricultural industry integration policies work well in conjunction with WRCLC, thereby enhancing both the quantity and quality of cultivated land. However, the synergy with rural tourism policies improves cultivated land quality without effectively increasing cultivated land quantity.

Keywords: whole-region comprehensive land consolidation; cultivated land; double/debiased machine learning; policies synergy

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1. Introduction

Cultivated land, as a fundamental resource for food production, directly influences total food output through changes in both quantity and quality [1]. However, due to irrational land use planning and the unchecked expansion of construction land, issues such as the reduction in cultivated land area and declining land quality have become increasingly severe [2]. According to the Third National Land Survey conducted in 2021, the area of cultivated land in China has decreased by 11.3 million hectares since 2009.[1] In the context of a global food supply–demand imbalance, China, as one of the most populous countries in the world, faces a significant responsibility to ensure the security of its cultivated land and food production [3,4].

The severe situation of cultivated land security and its far-reaching impacts have attracted widespread attention from scholars both domestically and internationally, resulting in a substantial body of research. The early literature primarily focused on the security of cultivated land quantity [5–7]. However, relying solely on changes in cultivated land area is insufficient to systematically assess the impact of socioeconomic development on cultivated land security. With the advancement of remote sensing technology, which offers extensive accessibility and detailed spatial information, new perspectives have been provided for evaluating the security of cultivated land quality [8,9]. Cultivated land (in both quantity and quality) is a unique natural resource closely linked to a country's food security, and is critical in promoting regional sustainable development [10,11]. Cultivated land security requires not only sufficient land area but also high-quality and sustainable production capacity to meet future development needs [11,12]. Therefore, this study defines cultivated land security as the ability of a region's cultivated land quantity and quality to meet the long-term demands of socioeconomic development and food production [12–14]. Specifically, the concept of cultivated land security in this paper includes both cultivated land quantity security and cultivated land quality security. The former refers to the adequacy and stability of the land area. The latter focuses on the sustainability of land quality.

Research on land use and cultivated land security has mostly focused on traditional land consolidation models, including cultivated land pattern optimization and farmland protection policies [15,16]. Molnárová et al. (2023) reviewed 93 studies on the impact of land consolidation and found that only 56% of the cases reported positive effects, indicating significant contradictions in the conclusions of such studies [17]. Furthermore, traditional land consolidation mainly uses engineering measures to address inefficient or unused land, focusing on the adjustment of farmland and rural demolition [18]. This approach not only neglects the importance of ecological restoration, but also fails to ensure the sustainable use of rural cultivated land resources. WRCLC, as a key component of China's new phase of land system reform, addresses the entire process, life cycle, and all elements of land use. WRCLC aims to minimize land use conflicts between land projects by formulating detailed land use plans. Additionally, WRCLC requires that the newly created cultivated land area in the project area be at least 5% of the original cultivated land area. Although some scholars have already paid attention to the impact of pilot policies on cultivated land, research methods are limited to theoretical and case analyses [19,20], lacking empirical evaluations of policy effects using large sample data. Additionally, the research scope is still confined to single township samples [21,22], which may lead to biased conclusions. WRCLC, primarily implemented at the township level, is a systematic governance project encompassing the interconnected ecosystems of mountains, waters, forests, fields, lakes, and grasslands. Its land management measures include the concentrated layout of cultivated land and the development of tourism, health care, and facility agriculture within parts of the consolidated area. Land consolidation is closely related to industrial development [23,24]. However, there is limited understanding of how WRCLC affects cultivated land security from the perspective of policy synergy, especially in rural areas with lower levels of food security.

According to the aforementioned analysis, previous research has looked at the connection between cultivated land security and land consolidation. The mitigating effects of comprehensive land consolidation on land degradation have also been studied by some academics. However, three key issues remain unresolved. First, most existing research focuses on theoretical discussions and case studies from rural areas. Few studies use remote sensing technology and big data samples to assess the impact of WRCLC on cultivated land security. Second, past research has not conducted heterogeneous analyses of the effects of WRCLC on cultivated land security under varying natural, economic, and social conditions. Third, in influencing cultivated land security, does WRCLC conflict with or complement other agricultural industrial policies?

To address these knowledge gaps, this study constructs a theoretical framework for the synergy between WRCLC and agricultural industrial policies. Using panel data

from 707 townships in Zhejiang Province, China, we employ a double machine learning approach to assess the impact of WRCLC on cultivated land security. We aim to investigate the following scientific questions: (1) Can WRCLC, which encompasses all processes, cycles, and factors of land use, enhance cultivated land quantity and quality in rural areas? (2) Is there heterogeneity in the effects of WRCLC on cultivated land security across different topographical features, economic development levels, and grain-producing areas? (3) How does WRCLC affect cultivated land security under various agricultural policy synergies? This study presents a fresh viewpoint on the connection between cultivated land security and comprehensive land consolidation. The findings can guide and inform the development of more effective land consolidation modes in other countries and regions.

The structure of this paper is organized as follows: Section 2 presents the research hypothesis based on theoretical analysis. Section 3 describes the technical processes, methods, and data sources used in the study. Section 4 employs a dual machine learning approach to assess the impact of WRCLC on cultivated land security. Section 5 analyzes the heterogeneity of WRCLC's impact on cultivated land security under different scenarios. Section 6 discusses the synergistic effects of agricultural industry policies on cultivated land security. Section 7 presents the discussion of the paper. Finally, based on the research findings, policy recommendations are made, followed by a discussion of the study's limitations and directions for future research.

2. Policy Background and Theoretical Analysis

2.1. Policy Background

Three major phases can be distinguished in China's current land consolidation. The first stage focuses on land development and consolidation, primarily targeting agricultural land to increase cultivated area and improve irrigation facilities. The second stage extends the scope of land consolidation from farming to construction land. It aims to address issues such as fragmented rural farmland, disordered spatial layouts, and inefficient land resource utilization. The third stage is characterized by comprehensive land consolidation, which innovatively incorporates ecological protection and restoration into the consolidation process. This approach seeks to promote projects that consider all elements and phases of land management. Compared to previous efforts, WRCLC encompasses more diverse and specific measures. First, at the planning level, it uses townships as basic units to optimize cultivated land layouts, ensure sufficient cultivated land, and integrate protection with ecological restoration. Second, at the implementation level, WRCLC focuses on consolidating fragmented plots into larger, contiguous areas of cultivated land. This increases utilization efficiency and production potential. Additionally, it enhances irrigation infrastructure and improves soil quality through high-standard farmland construction and low-quality land transformation, thereby elevating the overall quality of cultivated land.

The WRCLC policy created stringent indicators and a negative list to guarantee the efficient application of policies and the sensible distribution of land. Regarding indicators, the policy mandates that the new cultivated land area in consolidation zones must be at least 5% of the existing cultivated land area. For adjustments involving permanent basic farmland, the newly designated area must also be at least 5% of the adjusted area. The negative list enforces strict land use regulations. It prohibits actions that harm the ecological environment, such as deforestation, excavation, filling of lakes, and the conversion of cultivated land into artificial landscapes. In addition, schedules for consolidation projects and construction work must be arranged appropriately to prevent haste and mechanical copying, as well as the emergence of image projects and political performance projects. To promote WRCLC, Zhejiang Province has introduced supportive policies. These include the reclamation of permanent basic farmland, optimization of land layout, reserved construction indicators for project areas, and incentives for new construction plans (see Figure 1).

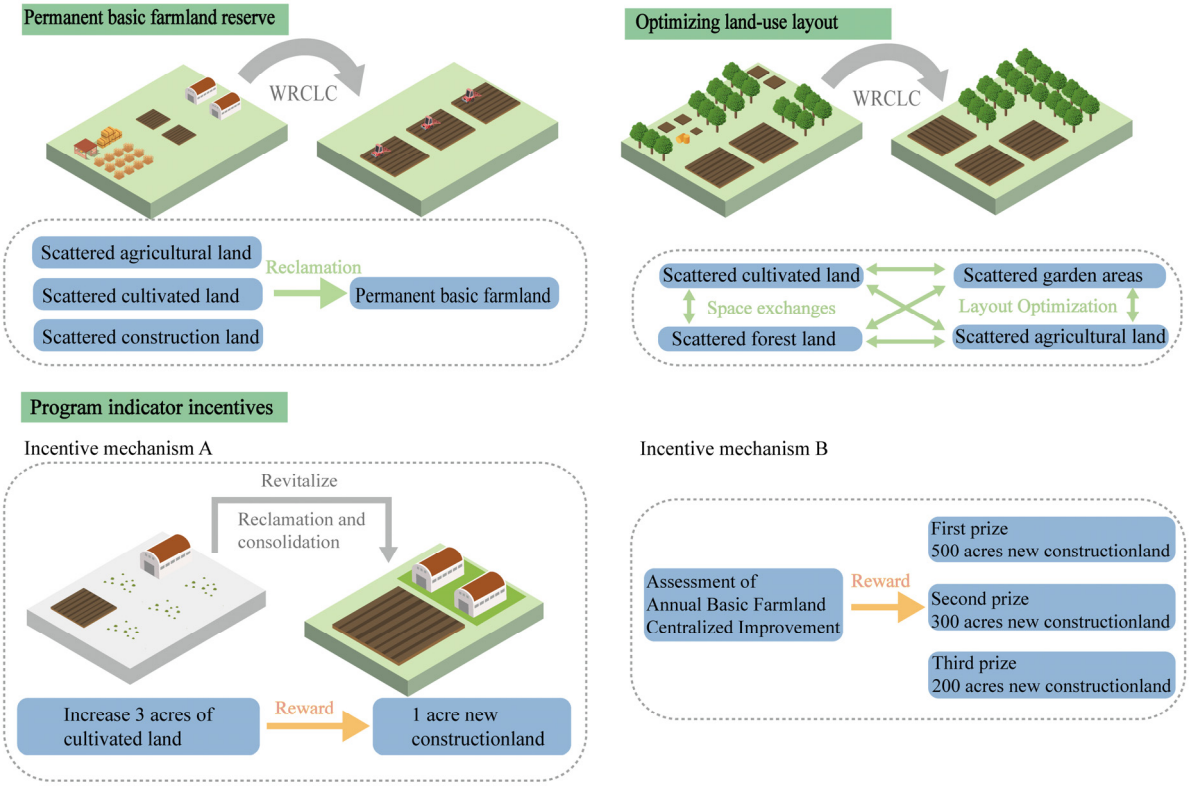


Figure 1. Policy measures for the WRCLC policy.

2.2. Theoretical Analysis

2.2.1. Direct Effect

Traditional land consolidation models mainly focus on land development and utilization, often resulting in issues such as a lack of unified planning, intense competition, and disordered development. As a new policy in land system reform, WRCLC emphasizes the need to address issues such as cultivated land fragmentation, quality degradation, and disordered spatial layout in rural areas. This is achieved through the development of village and townland planning that encompasses the entire space, all elements, and the full life cycle. From the perspective of policy planning, the WRCLC policy primarily promotes the dual improvement of both the quantity and quality of cultivated land through three major measures: agricultural land consolidation, construction land consolidation, and ecological restoration. The first is the specific plan for agricultural land consolidation. WRCLC alleviates issues of abandoned and idle farmland through measures such as merging small fields into larger ones and land transfer, while ensuring a steady increase in the amount of cultivated land through moderate-scale farming [18,25]. At the same time, WRCLC improves the quality of medium- and low-yield lands through high-standard farmland construction, land leveling, and soil improvement [26]. The second is the specific plan for the construction land consolidation. WRCLC aims to balance urban and rural land use to prevent urban expansion from encroaching on cultivated land [27]. Moreover, WRCLC increases cultivated land area and enhances land connectivity by reclaiming inefficiently used construction land and demolishing fragmented rural residential plots [28]. The third is the specific plan for ecological restoration. WRCLC restores land ecosystems through measures such as soil and water conservation, vegetation restoration, and the construction of ecological corridors to prevent soil erosion and protect cultivated land resources [29]. Additionally, WRCLC restores cultivated land functionality and enhances irrigation and drainage capabilities through the ecological reclamation of mining sites and soil pollution remediation [30,31]. In summary, we propose the following hypothesis:

Hypothesis 1. *The WRCLC policy has a positive impact on cultivated land security.*

2.2.2. Policy Synergy Effects

Policy synergy is essentially a systematic approach that ensures the consistency and complementarity of policy objectives. It enhances the convergence of policy content, improves resource utilization efficiency, and strengthens the coordination of policy implementation bodies. The aim is to maximize overall policy benefits. On the agricultural level, the impact of land policy on cultivated land resources is fundamental. However, this impact also depends on synergy with other policies to amplify the effects of individual policies [32].

Firstly, agricultural mechanization, which replaces traditional farming methods with mechanized tools, better meets the needs of large-scale development [33]. However, the promotion of agricultural mechanization faces challenges in the context of an aging agricultural workforce and cultivated land fragmentation [34,35]. From the perspective of policy synergy, on the one hand, the WRCLC policy promotes the consolidation and concentration of cultivated land through land reclamation measures. This approach promotes the adoption of agricultural mechanization, thereby preventing cultivated land abandonment due to labor shortages [36]. On the other hand, according to the theory of economies of scale, agricultural mechanization contributes to reducing production costs and optimizing resource allocation. This will effectively mitigate soil compaction caused by the excessive use of fertilizers and pesticides, thus promoting the sustainable use of cultivated land [37,38]. Secondly, the construction of characteristic agricultural towns aims to promote the integration of agricultural industries and the development of full industry chains. An organic synergy between production, living, and nature is made possible by this approach, which encourages the deep integration of primary, secondary, and tertiary businesses. From the perspective of policy synergy, on the one hand, the WRCLC policy promotes the rational allocation of land resources, meets the needs of rural industrial integration, and facilitates industrial clustering and concentrated pollution control [39]. On the other hand, internal agricultural industry integration, through exploring new agricultural models such as "rice–shrimp co-cultivation" and "rice–fish symbiosis", improves resource use efficiency and enhances land quality [40]. At the same time, the extension of the industry chain enhances the value of agricultural products, promotes the application of green agricultural technologies, and reduces the risk of land degradation [41]. Thirdly, rural tourism, as a new industry expanding the functions of agriculture, relies on natural landscapes such as rice fields and terraced fields to develop ecological tourism and agricultural experiences, thereby promoting cultivated land protection [42]. From the perspective of policy synergy, on the one hand, the WRCLC policy ensures the rational allocation of land for rural tourism, safeguarding both cultivated land security and the sustainable development of the tourism industry [43]. On the other hand, rural tourism provides additional income for farmers and strengthens cultural identity, thus preventing rural population decline and cultivated land abandonment [44,45]. At the same time, the development of rural tourism contributes to the improvement of rural infrastructure, including water, electricity, roads, communications, and the internet, promotes high-standard farmland construction, and enhances land quality [46]. Based on this, the following hypothesis is proposed. The theoretical analytical framework of this paper is shown in Figure 2.

Hypothesis 2. *Policy synergy helps enhance the positive impact of the WRCLC policy on cultivated land security.*

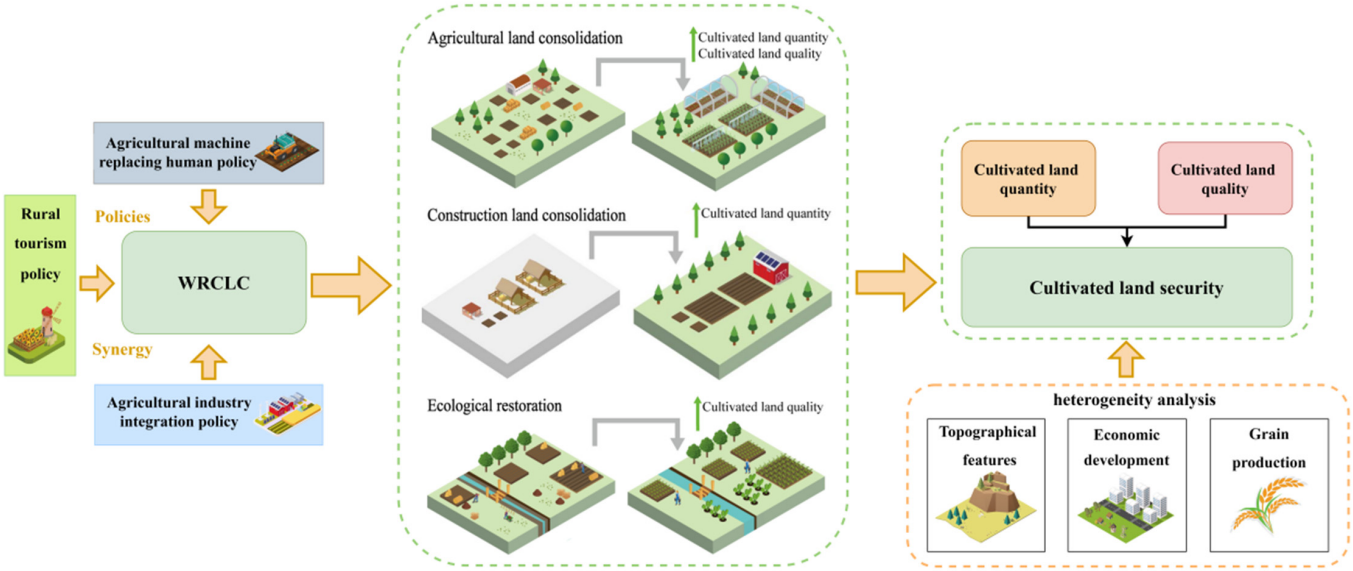


Figure 2. Theoretical analysis framework.

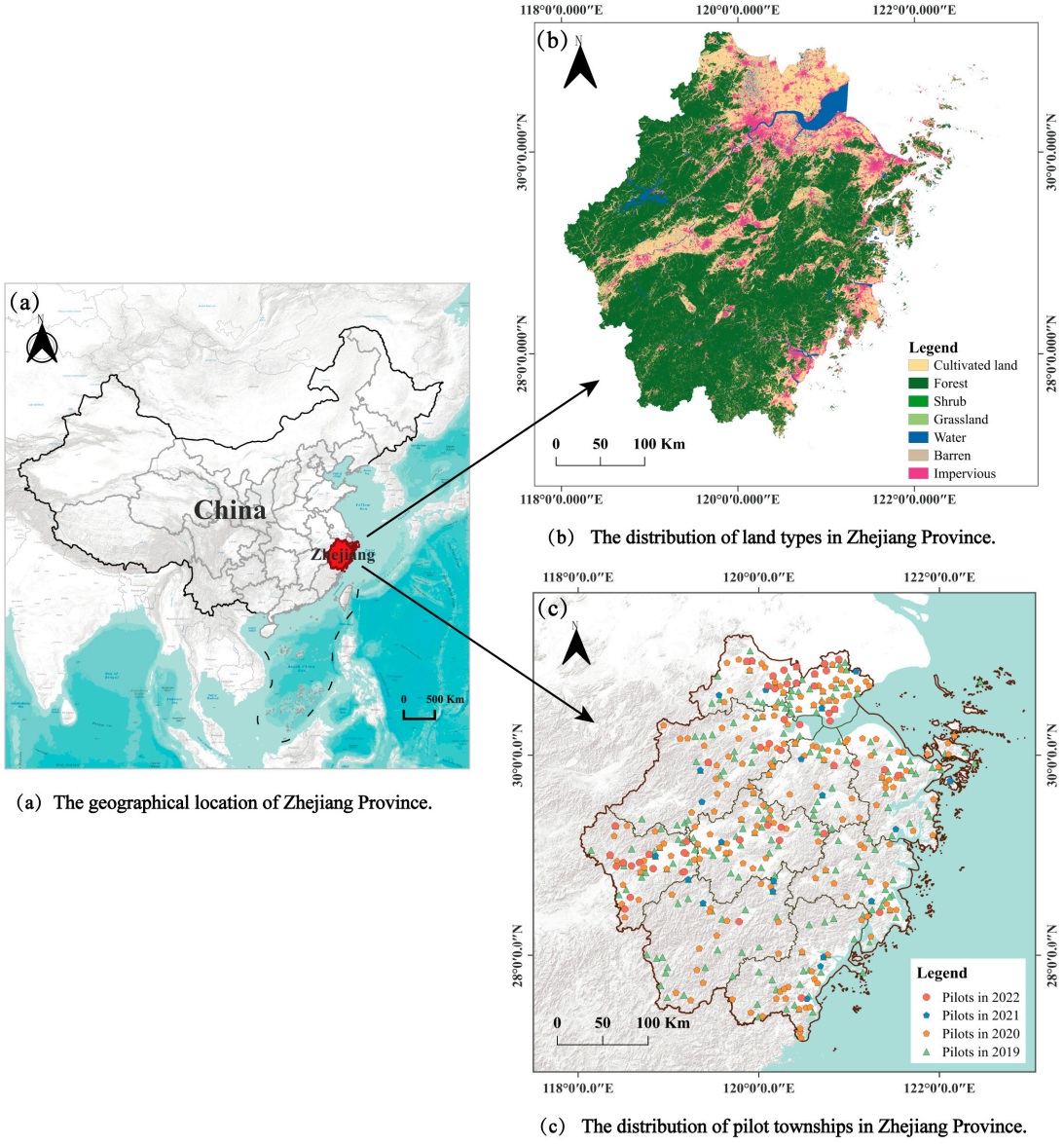
3. Study Design and Data Sources

3.1. Summary of the Research Area

Figure 3 shows the geographical location, distribution of land types, and distribution of pilot townships in Zhejiang Province. Zhejiang Province is situated on the southeast coast of China, in the southern wing of the Yangtze River Delta. Its latitudes range from 27°02′ N to 31°11′ N, while its longitudes range from 118°01′ E to 123°10′ E. The specific geographical location of Zhejiang Province is shown in Figure 3a. The area is distinguished by a humid climate that is influenced by the monsoon, with pleasant temperatures, distinct seasons, lots of sunshine, and copious amounts of rainfall. With a land size of 105,500 square kilometers, Zhejiang has an average annual temperature between 15 °C and 18 °C, 1100 to 2200 h of sunshine, and 1100 to 2000 mm of precipitation. This land area comprises 74.6% mountainous terrain, 5.1% water bodies, and 20.3% flat land, leading to the colloquial saying "seven mountains, one water, and two fields". The distribution of different land types in Zhejiang Province is shown in Figure 3b. This topography underscores the province's significant economic development and the food security challenges posed by land resource scarcity.

In response to issues such as chaotic rural spatial layouts, fragmented farmland distribution, and ecosystem degradation, Zhejiang Province took the lead in 2018 by issuing the "Opinions on Implementing Comprehensive Land Consolidation and Ecological Restoration Projects" from the Zhejiang Provincial People's Government Office. In 2019, WRCLC pilot projects were initiated at the township level, focusing on five main tasks: overall rural land use planning, farmland improvement, remediation of inefficient construction land, ecological and environmental restoration, and the establishment of a democratic management mechanism for rural land. This model has achieved successful outcomes in cities such as Hangzhou, Ningbo, Huzhou, and Jinhua, and it has been promoted nationwide. Subsequently, the Ministry of Commerce issued a notice on launching pilot projects for comprehensive land consolidation, marking the beginning of national pilot initiatives. At present, Zhejiang Province, as a pioneer in implementing comprehensive territorial land consolidation measures, has initiated four groups of pilot projects. Among other things, the Natural Resources Department of Zhejiang Province announced the first and second of CLC pilot projects in Zhejiang Province in 2019 and 2020, a total of 497 pilot projects. In 2021, China's Ministry of Natural Resources released a national list of CLC pilot projects, with a total of 42 pilot projects in Zhejiang Province. Subsequently, in 2022, the Natural Resources Department of Zhejiang Province released a list of 56 township land consolidation pilot projects under the "11350 Project". After excluding pilot projects in urban streets, duplicate

projects, and projects with serious data deficiencies, a total of 258 pilot townships were covered in this study. The specific distribution of the pilot townships is shown in Figure 3c.



(a) The geographical location of Zhejiang Province.

(b) The distribution of land types in Zhejiang Province.

(c) The distribution of pilot townships in Zhejiang Province.

Figure 3. The geographical location of Zhejiang Province, the distribution of land types, and the distribution of pilot townships. (**a**) The geographical location of Zhejiang Province. (**b**) The distribution of land types in Zhejiang Province. (**c**) The distribution of pilot townships in Zhejiang Province.

3.2. Data Sources

The information about pilot townships for CLC in Zhejiang Province was obtained from the official websites of the Department of Natural Resources of Zhejiang Province and the Ministry of Natural Resources of China (https://zrzyt.zj.gov.cn, accessed on 1 March 2023). Township-specific data, including the size of the administrative area and the number of industrial enterprises, were compiled from the "China County Economy Statistical Yearbook (Township Volume)" for the period 2014–2023. County-level control variables were extracted from the "Zhejiang Statistical Yearbook" for the period 2014–2023. Missing values in these statistical yearbooks were imputed using linear interpolation and moving average methods. The National Tibetan Plateau Data Center provided the temperature and precipitation information (https://data.tpdc.ac.cn, accessed on 31 July 2024), with a spatial resolution of 1 km. Township population data were obtained from the LandScan

Global Population Database (https://landscan.ornl.gov, accessed on 1 May 2023), with a spatial resolution of 1 km. Net primary productivity (NPP) and enhanced vegetation index (EVI) data were sourced from NASA EOS/MODIS (https://www.earthdata.nasa.gov/, accessed on 1 January 2024), with a spatial resolution of 500 m. Township cultivated land area data were sourced from the Zenodo data platform (https://zenodo.org/records/8176941, accessed on 1 August 2023), with a spatial resolution of 30 m.

In the data processing process, first, this study constructed a basic township-level panel dataset by collecting township-level data from statistical yearbooks. Subsequently, based on the administrative divisions of the counties where the townships are located, county-level statistical data were matched with township data to enrich the township-level panel dataset. Next, using satellite remote sensing data obtained from public platforms and ArcGIS 10.8.2 software, different resolution raster spatial data were spatially mapped to the vector boundary data of each township in Zhejiang Province. These data were then aggregated within the township boundaries to generate township-level spatial geographic data. Finally, based on township names and year information, the statistical yearbook data were accurately matched and merged with the processed spatial geographic data, resulting in a complete township-level panel dataset for Zhejiang Province.

3.3. Variable Measure

3.3.1. Dependent Variable

This study selects cultivated land security as the dependent variable, which is divided into two dimensions: cultivated land quality and quantity. The quantity of cultivated land is represented by the area of cultivated land in townships (Unit: km^2). For the quality of cultivated land, we reference the research by Zhou Xiaoping et al. (2024) and use the vitality of the cultivated land system as a proxy variable for cultivated land quality [47]. This vitality is constructed based on Net Primary Productivity (NPP) and the Enhanced Vegetation Index (EVI). The rationale for using cultivated land system vitality lies in its representation of the system's metabolic capacity or primary productivity, which is typically reflected by the growth status and biomass of aboveground vegetation. The EVI, which enhances vegetation signals by incorporating the blue band, effectively indicates vegetation coverage and health. Meanwhile, NPP represents the net accumulation of organic matter after subtracting plant respiration from Gross Primary Productivity (GPP), effectively reflecting the production capacity of vegetation communities. Considering the significant variations in crop growth both within a year and between years, this study calculates the annual averages of NPP and EVI, normalizes these values through extreme value normalization, and combines them equally to represent the vitality of the cultivated land system.

3.3.2. Core Independent Variable

This study constructs the key independent variable WRCLC, which indicates the setting of the WRCLC pilots, based on the information released by the Natural Resources Department of Zhejiang Province and the Ministry of Natural Resources of China. Specifically, if a township is designated as a WRCLC pilot during the study period, it will be classified as a treatment group, while the undesignated townships will serve as a control group. For the treatment group townships, WRCLC takes the value of 1 in the founding year of the WRCLC pilot project and in subsequent years, otherwise it is 0. For the control group townships, WRCLC takes the value of 0 for all years.

3.3.3. Control Variables

Cultivated land security is influenced not only by climate conditions such as temperature and precipitation [48], but also by socioeconomic factors, including human activities and industrialization [13,49]. Therefore, in the regression analysis, this study incorporates factors such as township-level temperature, precipitation, population density, and the number of industrial enterprises as control variables to mitigate endogeneity issues caused by omitted variables. Specifically, the control variables selected in this study include both

township-level and county-level variables. The township-level variables consist of the following: (1) Population Density (persons/km^2): The number of residents in a township divided by the area of the administrative region. (2) Industrial Development Level: The number of industrial enterprises, represented in logarithmic form. (3) Precipitation (mm): annual average precipitation in townships. (4) Temperature (°C): annual average temperature in townships. At the county level, the variables are as follows: (1) Economic Development Level (10,000 yuan): Per capita regional GDP. (2) Compulsory Education Penetration Rate: The percentage of the population at the end of the year that is enrolled in conventional secondary and primary schools. (3) Government Intervention Level: The ratio of local fiscal revenue to regional GDP. (4) Industrial Structure: The proportion of secondary industry value contributed to tertiary industry value added. (5) Agricultural Development Level: The share of regional GDP that comes from the combined output value of forests, fisheries, agriculture, and animal husbandry. (6) Technological Innovation Level (applications/10,000 persons): The proportion of approved patent applications to the overall population at the end of the year.

3.3.4. Policy Synergy Variables

Based on the theoretical analysis in the previous section, it was found that agricultural mechanization, agricultural–industrial integration, and rural tourism development all have a synergistic effect with the WRCLC policy, which impacts the cultivated land security of townships. Additionally, considering that the WRCLC policy is implemented at the township level, this paper selects three types of pilot policies at the township level as proxy variables. The definitions of these three policy variables are as follows: (1) Agricultural Mechanization (AM) Policy: This paper uses the Zhejiang Province Agricultural Machinery Replacement Pilot Townships as the proxy variable for agricultural mechanization policy. The reason for this is that the policy primarily focuses on promoting agricultural machinery technology and equipment and cultivating agricultural machinery service entities, effectively improving the level of agricultural mechanization in townships. (2) Agricultural Industry Integration (AII) policy: the pilot policy for characteristic agricultural townships in Zhejiang Province serves as a proxy variable for agricultural industry integration policy. This policy promotes the integrated development of agricultural production, agricultural product processing, and agricultural services, leveraging the multifunctionality of agriculture and the region's characteristic agricultural industries. It plays an important role in promoting agricultural industry integration at the township level. (3) Rural Tourism (RT) Policy: The pilot policy for tourism-themed townships in Zhejiang Province is used as a proxy variable for rural tourism policy. This policy relies on the unique natural landscapes and rich cultural resources of townships, promoting the construction of tourism public service facilities, with the aim of forming a comprehensive rural tourism industry system. This is a key policy for supporting rural tourism development in townships. In terms of variable assignment, the paper constructs three dummy variables, AM_{it}, AII_{it}, and RT_{it} for these three types of township pilot policies. Specifically, the dummy variable is assigned a value of 1 for the year a township is designated as a pilot, and for subsequent years, it is 0. For non-pilot townships, the dummy variables always take the value of 0. The descriptive statistics for all variables are shown in Table 1.

Table 1. Descriptive statistics of the variables.

Type	Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	Cultivated land quality	7070	60.257	13.990	1.844	88.929
	Cultivated land quantity	7070	20.639	21.671	0.100	192.578
Core independent variable	WRCLC policy	7070	0.132	0.338	0.000	1.000

Table 1. *Cont.*

Type	Variable	Obs	Mean	Std. Dev.	Min	Max
Control variables	Population density	7070	375.660	513.784	1.312	5001.249
	Industrial development level	7070	4.319	1.918	0.000	9.880
	Precipitation	7070	1334.897	344.824	97.972	2501.282
	Temperature	7070	16.942	1.049	12.815	20.203
	Economic development level	7070	7.586	3.050	1.490	26.737
	Compulsory education penetration rate	7070	0.106	0.021	0.061	0.189
	Government intervention degree	7070	0.085	0.022	0.022	0.171
	Industrial Structure	7070	0.980	0.324	0.149	2.317
	Agricultural development level	7070	0.105	0.060	0.003	0.316
	Technological innovation level	7070	40.599	27.742	2.568	262.046
Policy synergy variable	Agricultural machines policy	7070	0.086	0.280	0.000	1.000
	Agricultural industry integration policy	7070	0.036	0.186	0.000	1.000
	Rural tourism policy	7070	0.034	0.180	0.000	1.000

3.4. Model Specification

The purpose of this study is to evaluate how the WRCLC pilot policy has affected the quantity and quality of agricultural land. Previous research has primarily employed traditional causal inference models; however, some limitations and drawbacks of these models can compromise the accuracy of the conclusions [50,51]. The double/debiased machine learning method proposed by Chernozhukov et al. (2018) effectively addresses the shortcomings of traditional models [52]. On the one hand, the application of machine learning to handle high-dimensional, nonlinear data reduces the risk of model misspecification. On the other hand, double machine learning employs instrumental variables, two-stage residual regression, and subsampling methods to mitigate "regularization bias", thereby ensuring the unbiased estimation of treatment effects [50]. Based on this, the present study adopts the DML approach to evaluate the effects of the WRCLC policy.

The partial linear model for double machine learning is constructed as follows:

$$Y_{it} = \theta_0 D_{it} + g(X_{it}) + U_{it}, E(U_{it}|X_{it}, D_{it}) = 0 \quad (1)$$

$$D_{it} = m(X_{it}) + V_{it}, E(V_{it}|X_{it}) = 0 \quad (2)$$

In Equation (1), i represents the township, t represents the year, Y_{it} denotes cultivated land quantity and quality of townships, D_{it} serves as the policy variable for WRCLC, and θ_0 is the treatment coefficient. X_{it} denotes a set of high-dimensional control variables, $\hat{g}(X_{it})$ are estimated using machine learning algorithms, and U_{it} is the error term. To address the potential bias introduced by regularization in machine learning algorithms, an auxiliary regression, as shown in Equation (2), is constructed.

Furthermore, drawing upon Chernozhukov et al. (2018), a more generalized interaction model is established to estimate the policy effects [52]:

$$Y_{it} = g(D_{it} + X_{it}) + U_{it}, E(U_{it}|X_{it}, D_{it}) = 0 \quad (3)$$

$$D_{it} = m(X_{it}) + V_{it}, E(V_{it}|X_{it}) = 0 \quad (4)$$

The treatment effects obtained from this model are: $\theta_0 = E[g(D_{it} = 1|X_{it}) - g(D_{it} = 0|X_{it})]$. The specific estimation methods for the relevant parameters are consistent with those used in the partial linear model.

To examine the impact of policy synergy on the quantity and quality of cultivated land in rural towns, this study establishes the following model:

$$Y_{it} = \theta_1 D_{it} \times R_{it} + g(X_{it}) + U_{it}, E(U_{it}|D_{it} \times R_{it}, X_{it}) = 0 \quad (5)$$

In Equation (5), $D_{it} \times R_{it}$ denotes the interaction term between the WRCLC policy and other policy variables and θ_1 is the treatment coefficient. The specific functional form of $g(X_{it})$ and its estimates $\hat{g}(X_{it})$ are estimated using machine learning algorithms.

4. Empirical Results and Analysis

4.1. Baseline Regression Results

The influence of the WRCLC policy on the quantity and quality of cultivated land is estimated in this study using a DML approach. Table 2 presents the baseline regression results. The sample split ratio is set at 1:4, and the random forest algorithm is utilized to predict and solve both the main and auxiliary regressions. Models (1) and (2) use partial linear models for estimation. From Model (1), it is evident that the impact coefficient of the WRCLC policy on cultivated land quantity is 1.217, significant at the 1% level. The results from Model (2) indicate that the impact coefficient of the WRCLC policy on cultivated land quantity is 0.678, which is also positively significant at the 1% level. This suggests that implementing WRCLC can effectively increase the area of cultivated land in townships and improve its quality. Models (3) and (4) utilize interactive models for regression analysis, yielding similarly positive and significant results at the 1% level, thus validating Hypothesis 1 and Hypothesis 2.

Table 2. Baseline regression.

Var.	(1) Partial Model Cultivated Land Quantity	(2) Partial Model Cultivated Land Quality	(3) Interactive Model Cultivated Land Quantity	(4) Interactive Model Cultivated Land Quality
WRCLC	1.217 ***	0.678 ***	1.161 ***	4.664 ***
	(0.248)	(0.187)	(0.211)	(0.195)
Controls	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	7070	7070	7070	7070

Note: *** indicates statistical significance at 1% level; values in parentheses represent robust standard error.

4.2. Robustness Checks

4.2.1. Parallel Trends Test

This study evaluates how the WRCLC policy affects cultivated land quantity and quality by adopting a DML approach. A parallel trends test is necessary to satisfy the prerequisites for using the DID research methodology. Figures 4 and 5 display the parallel trends test results, indicating that the coefficients for the policy effects before the implementation of the WRCLC policy are not significant. This supports the parallel trends assumption for the DID research methodology employed in this study, by indicating that there were no appreciable differences between the control and treatment groups prior to the policy's implementation. Furthermore, starting from the second year after the policy's implementation, the regression coefficients show positive significance, indicating that the WRCLC policy effectively enhances cultivated land quantity and quality in rural areas.

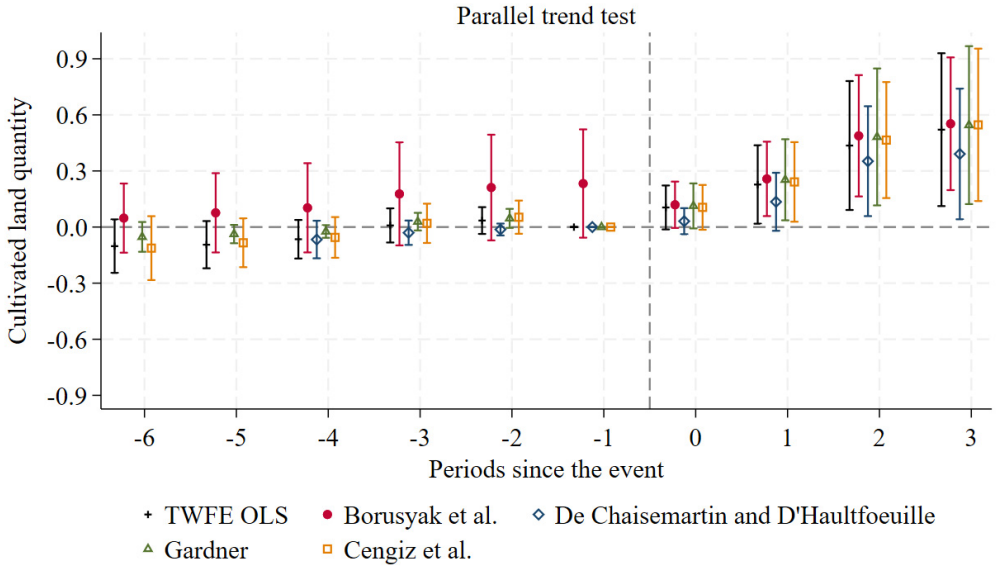


Figure 4. Parallel trends test (cultivated land quantity) [53–56].

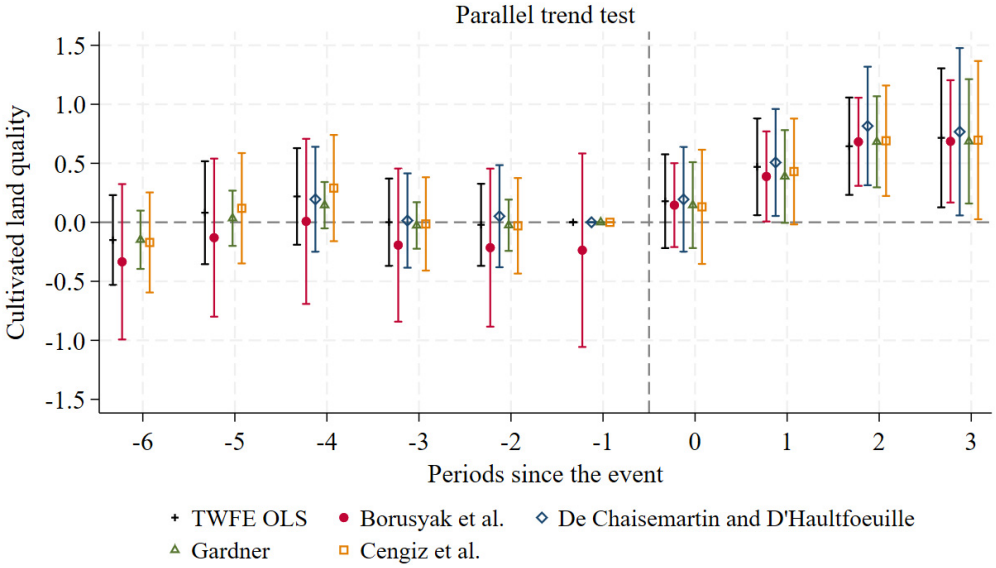


Figure 5. Parallel trends test (cultivated land quality) [53–56].

4.2.2. Adjustment of the Study Period

To mitigate the potential influence of samples spanning an extensive time frame on the research findings, this study confines the analysis to a three-year window before and after policy implementation, ensuring symmetry in the sample time periods. As shown in Table 3, when the study period is adjusted to 2016–2022, the WRCLC policy still demonstrates a significantly positive effect on cultivated land quantity and quality, reinforcing the robustness of the previous conclusions.

Table 3. Robustness checks results (1).

Var.	(1) Adjustment of the Study Period	(2) Adjustment of the Study Period	(3) Winsorization	(4) Winsorization	(5) Exclusion of COVID-19 Impact	(6) Exclusion of COVID-19 Impact	(7) Interactive Fixed Effects	(8) Interactive Fixed Effects
	Cultivated Land Quantity	Cultivated Land Quality	Cultivated Land Quantity	Cultivated Land Quality	Cultivated Land Quantity	Cultivated Land Quality	Cultivated Land Quantity	Cultivated Land Quality
WRCLC	1.121 ***	0.441 **	1.220 ***	0.654 ***	1.547 ***	0.792 ***	0.928 ***	0.566 ***
	(0.270)	(0.176)	(0.247)	(0.185)	(0.315)	(0.244)	(0.210)	(0.175)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COVID-19	No	No	No	No	Yes	Yes	No	No
County–Year	No	No	No	No	No	No	Yes	Yes
Observations	4949	4949	7070	7070	7070	7070	7070	7070

Note: ***, ** indicate statistical significance at 1% and 5% levels, respectively; values in parentheses represent robust standard error.

4.2.3. Winsorization

Considering that outliers in the regression sample may affect the unbiasedness of the regression results, we apply winsorization to all variables (excluding the core explanatory variable) at the 1% levels, replacing values above the upper quantile and below the lower quantile, and conduct regression analysis. After removing outliers, the results in Table 3 show that the regression results are still significantly positive.

4.2.4. Exclusion of COVID-19 Impact

To disentangle the potential influence of the COVID-19 pandemic, a significant event that occurred in 2020, on township cultivated land quantity and quality, this study follows existing research by constructing a dummy variable for COVID-19 (assigning the value of 1 for 2020 and subsequent years, and 0 for other years) and incorporating it into the regression model for control [57]. As shown in Table 3, after controlling for the COVID-19 impact, the regression coefficients remain significantly positive, confirming the robustness of the previous conclusions.

4.2.5. Consideration of County–Year Interactive Fixed Effects

To further validate the robustness, this study employs a method that controls for county–year interactive fixed effects. As shown in Table 3, after controlling for county–year interactive fixed effects, the coefficients remain significantly positive, demonstrating the reliability of the previous findings.

4.2.6. Alternative Estimation Models

This study employs the traditional staggered difference-in-differences (Staggered DID) method, along with two robust Staggered DID estimation techniques, to conduct robustness checks and effectively mitigate estimation bias arising from heterogeneous policy effects at different time points [58,59]. To this end, we use these three model types to re-estimate the average treatment impact of the policy implementation. As shown in Table 4, following the model adjustments, the coefficients for the WRCLC policy remain positively significant, thereby confirming the robustness of our conclusions.

Table 4. Robustness checks results (2).

Var.	(1)	(2)	(3)	(4)	(5)	(6)
	Staggered DID		Robust Estimation of Staggered DID			
			Sun and Abraham		Callaway and Sant'Anna	
	Cultivated Land Quantity	Cultivated Land Quality	Cultivated Land Quantity	Cultivated Land Quality	Cultivated Land Quantity	Cultivated Land Quality
WRCLC	0.318 ***	0.438 ***	0.316 ***	0.444 ***	0.364 **	0.320 *
	(0.116)	(0.149)	(0.066)	(0.119)	(0.166)	(0.191)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7070	7070	7070	7070	7070	7070

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively; values in parentheses represent robust standard error.

4.2.7. Resetting Machine Learning Models

This study re-estimates the models by altering the sample split ratio and machine learning methodologies, in order to lessen the effect of model specification bias on the estimation outcomes. The findings in Tables 5 and 6 show that the conclusion on the WRCLC policy is unaffected by changes to the sample split ratio and machine learning methodologies. This policy promotes simultaneous improvements in cultivated land quantity and quality, thereby confirming the reliability of the original findings.

Table 5. Robustness checks results (3).

Var.	(1) Kfold = 3 Cultivated Land Quantity	(2) Kfold = 8 Cultivated Land Quantity	(3) Lassocv Cultivated Land Quantity	(4) Gradboost Cultivated Land Quantity	(5) Elasticcv Cultivated Land Quantity	(6) Svm Cultivated Land Quantity
WRCLC	1.284 ***	1.131 ***	0.305 ***	2.928 ***	0.321 ***	3.491 ***
	(0.277)	(0.234)	(0.074)	(0.463)	(0.082)	(0.686)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7070	7070	7070	7070	7070	7070

Note: *** indicates statistical significance at 1% level; values in parentheses represent robust standard error. "Kfold = 3" indicates a sample split ratio of 1:2; "Kfold = 8" indicates a sample split ratio of 1:7; "Lassocv", "Gradboost", "Elasticcv", and "Svm" represent different machine learning methodologies.

Table 6. Robustness checks results (4).

Var.	(1) Kfold = 3 Cultivated Land Quality	(2) Kfold = 8 Cultivated Land Quality	(3) Lassocv Cultivated Land Quality	(4) Gradboost Cultivated Land Quality	(5) Elasticcv Cultivated Land Quality	(6) Svm Cultivated Land Quality
WRCLC	0.722 ***	0.587 ***	0.315 ***	1.111 ***	0.350 ***	2.063 ***
	(0.188)	(0.187)	(0.116)	(0.257)	(0.117)	(0.334)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7070	7070	7070	7070	7070	7070

Note: *** indicates statistical significance at 1% level; values in parentheses represent robust standard error. "Kfold = 3" indicates a sample split ratio of 1:2; "Kfold = 8" indicates a sample split ratio of 1:7; "Lassocv", "Gradboost", "Elasticcv", and "Svm" represent different machine learning methodologies.

4.3. Endogeneity and Placebo Test

4.3.1. Endogeneity Test

When evaluating the policy effects of the WRCLC, potential endogeneity issues such as omitted variable bias, reverse causality, and selection bias may arise. First, regarding omitted variables, this study has accounted for factors that may influence cultivated land quantity and quality at the township level, controlling for both time-fixed effects and individual fixed effects to mitigate endogeneity arising from omitted variables. Second, to address reverse causality, this study conducted regressions with lagged control variables, which helped alleviate the endogeneity issues stemming from reverse causality. Third, this study applied Propensity Score Matching (PSM) to address sample self-selection bias. This study estimated propensity scores using township-level characteristics as covariates and employed a one-to-one matching method (k = 1). After excluding samples that violated the common support assumption, this study re-estimated using a double machine learning (DML) approach. The results from Models 3 and 4 in Table 7 indicate that, after addressing the endogeneity issues related to sample self-selection, the WRCLC policy continues to show a positive and significant impact on both the quality and quantity of cultivated land. Finally, this study used instrumental variable methods to further mitigate endogeneity issues. Based on the research of Chernozhukov et al. (2018) [52], this study constructs a partially linear instrumental variable model using DML, as specified below:

$$Y_{it} = \theta_0 D_{it} + g(X_{it}) + U_{it} \tag{6}$$

$$Z_{it} = m(X_{it}) + V_{it} \tag{7}$$

Table 7. Endogeneity test.

Var.	(1) Control Variables Lagged One Period Cultivated Land Quantity	(2) Control Variables Lagged One Period Cultivated Land Quality	(3) PSM-DML Cultivated Land Quantity	(4) PSM-DML Cultivated Land Quality	(5) Instrumental Variable Methods Cultivated Land Quantity	(6) Instrumental Variable Methods Cultivated Land Quality
WRCLC	1.177 ***	0.830 ***	0.478 ***	1.632 ***	1.414 ***	0.507 **
	(0.283)	(0.203)	(0.175)	(0.353)	(0.338)	(0.233)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6363	6363	6673	6673	6363	6363

Note: ***, ** indicate statistical significance at 1% and 5% levels, respectively; values in parentheses represent robust standard error.

In Equations (6) and (7), Z_{it} serves as an instrumental variable for D_{it}. This study used the lagged variable of the comprehensive land rehabilitation pilot policy as an instrumental variable to conduct endogeneity tests, thereby addressing endogeneity issues. The results of the endogeneity tests in Models 5 and 6 of Table 7 indicate that, after mitigating the endogeneity concerns, the WRCLC policy continues to significantly enhance both cultivated land quantity and quality.

4.3.2. Placebo Test

To eliminate potential confounding factors in the relationship between the WRCLC policy and its impact on cultivated land quantity and quality, this study conducted two types of placebo tests. First, using a "pseudo-treatment period" and re-estimating the effects, this study conducted a time placebo test by moving the WRCLC policy's implementation date forward by one to six years. The results shown in Figure 6 indicate that, within a 95% confidence interval, the placebo effects are no longer significant. Second, this study conducted a spatial placebo test by randomly assigning part of the sample to a "pseudo-treatment group" through 500 iterations of random sampling, while the remaining samples served as a "pseudo-control group". According to Figure 6's results, the estimated

treatment effect is an extreme value that is on the right tail of the placebo effect distribution. Therefore, the core conclusion of this study is not a result of random chance, and other unknown confounding factors are insufficient to establish a causal relationship with our primary findings.

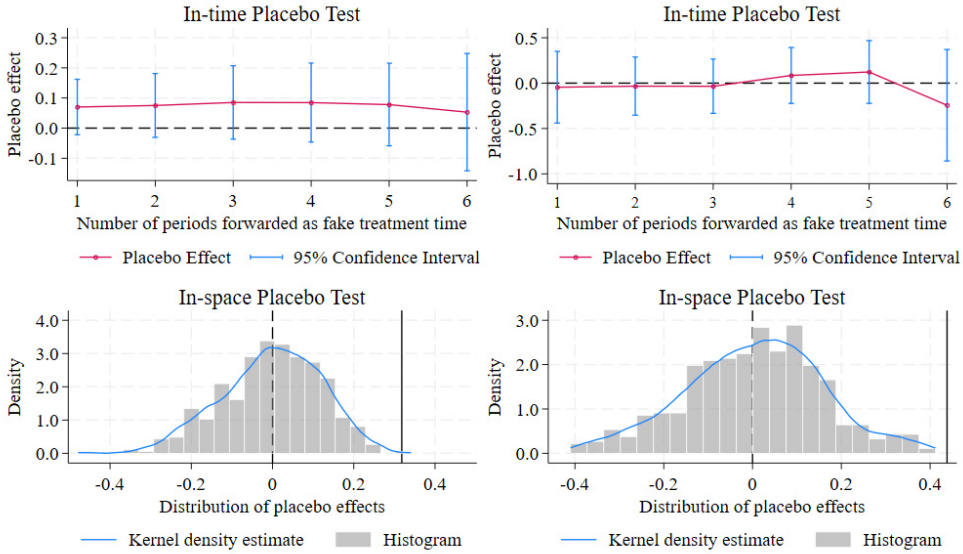


Figure 6. The results of placebo test.

5. Heterogeneity Analysis

5.1. Topographical Heterogeneity

The Zhejiang Provincial County (City) Socio-Economic Statistical Yearbook classifies the county-level cities of Zhejiang Province into three categories based on topography: plain counties, hilly counties, and mountainous counties. Accordingly, this paper further classifies townships in Zhejiang Province into plain and non-plain regions. Specifically, if a township is located in a plain county, it is categorized as the plain region group. If a township is located in a hilly or mountainous county, it is categorized as the non-plain region group. Based on this classification, the paper conducts regressions on the sample by groups to analyze the topographic heterogeneity.

As shown in Figure 7, the impact of the WRCLC policy on cultivated land security exhibits topographical heterogeneity. Regarding cultivated land quantity, the WRCLC policy significantly increases the quantity of cultivated land in towns across all topographical zones. Moreover, the effect of the policy on increasing cultivated land quantity is greater in non-plain areas compared to plain areas.

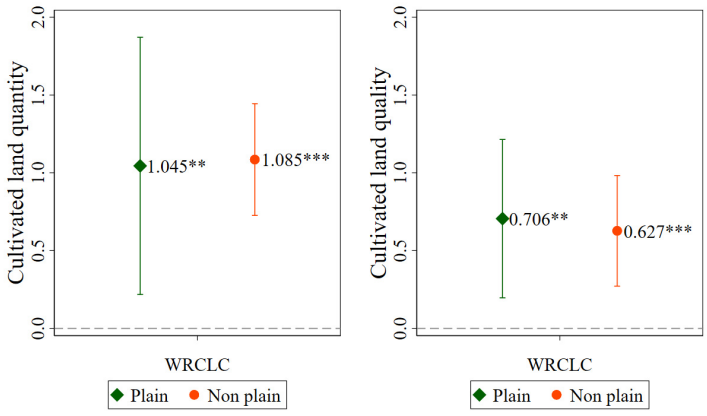


Figure 7. Results of topographic heterogeneity analysis. ***, ** indicate statistical significance at 1% and 5% levels, respectively.

Regarding cultivated land quality, the WRCLC policy appears to enhance cultivated land quality more effectively in plain areas than in non-plain areas. This indicates that the WRCLC policy prioritizes improvements in cultivated land quality in plain regions, while focusing on increasing cultivated land quantity in non-plain regions.

5.2. Economic Development Heterogeneity

In Zhejiang Province, the term "26 mountainous counties" specifically refers to the counties under the jurisdiction of the cities of Quzhou and Lishui, and 26 counties including Chun'an, Yongjia, Pingyang, Cangnan, Wencheng, Taishun, Wuyi, Pan'an, Sanmen, Tiantai, and Xianju. These 26 counties, as an important part of Zhejiang, account for approximately 45% of the provincial land area and about 15% of the permanent population. However, the economic development level in these "26 mountainous counties" is below the provincial average. Based on the above classification, this paper categorizes townships located within the "26 mountainous counties" as the low economic development group, while other townships are classified as the high economic development group. The paper then conducts regressions by groups based on this classification.

As illustrated in Figure 8, the impact of the WRCLC policy on cultivated land security varies across regions with different economic development levels. In terms of cultivated land quantity, the WRCLC policy demonstrates a more pronounced positive effect in areas with lower economic development compared to those with higher economic development levels. Regarding cultivated land quality, the WRCLC policy does not lead to significant improvements in cultivated land quality in areas with higher economic development levels. A possible explanation for this is that, in economically developed regions, the value of land is higher, leading to relatively higher costs for land consolidation investments, which can hinder the effective implementation of WRCLC projects.

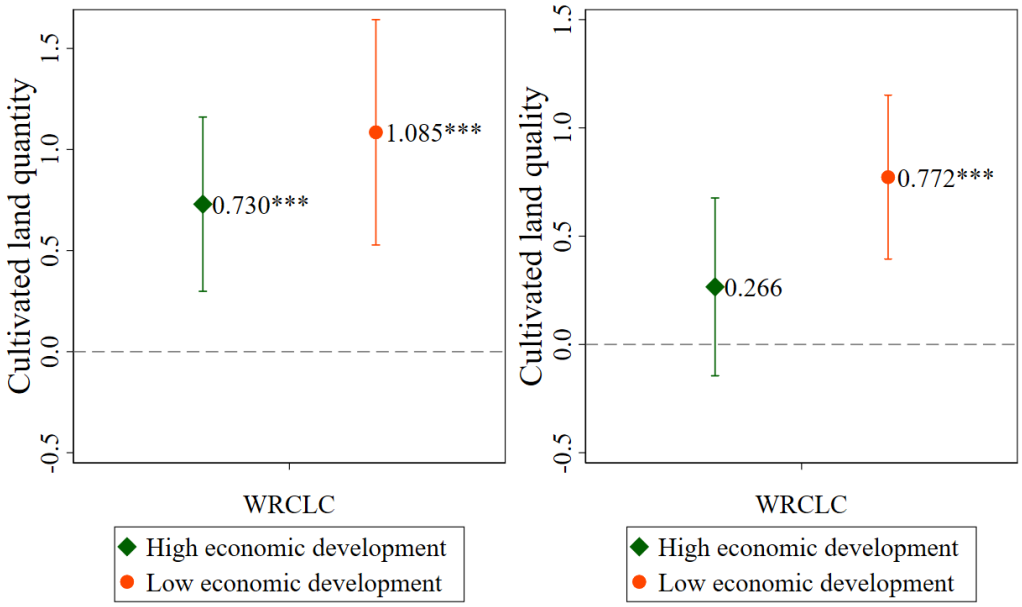


Figure 8. Results of economic development heterogeneity analysis. *** indicates statistical significance at 1% level.

5.3. Heterogeneity of Grain-Producing Functional Zones

According to the "Major Grain-Producing Counties" list of Zhejiang Province, this paper groups all counties into major and non-major grain-producing categories. Building on this classification, the paper identifies whether a township belongs to a major grain-producing area based on its location within a county-level city, and then performs regressions by groups accordingly.

As shown in Figure 9, the impact of the WRCLC policy on cultivated land security varies across different grain-producing functional zones. In terms of cultivated land quantity, implementing the WRCLC policy in major grain-producing regions results in a more significant increase in cultivated land quantity compared to non-grain-producing regions. Regarding cultivated land quality, the WRCLC policy significantly improves cultivated land quality in non-grain-producing regions, while its effects on cultivated land quality in major grain-producing regions are not as pronounced. This may be due to the generally higher quality of cultivated land and more developed agricultural infrastructure in major grain-producing areas, making the improvements from land rehabilitation less noticeable.

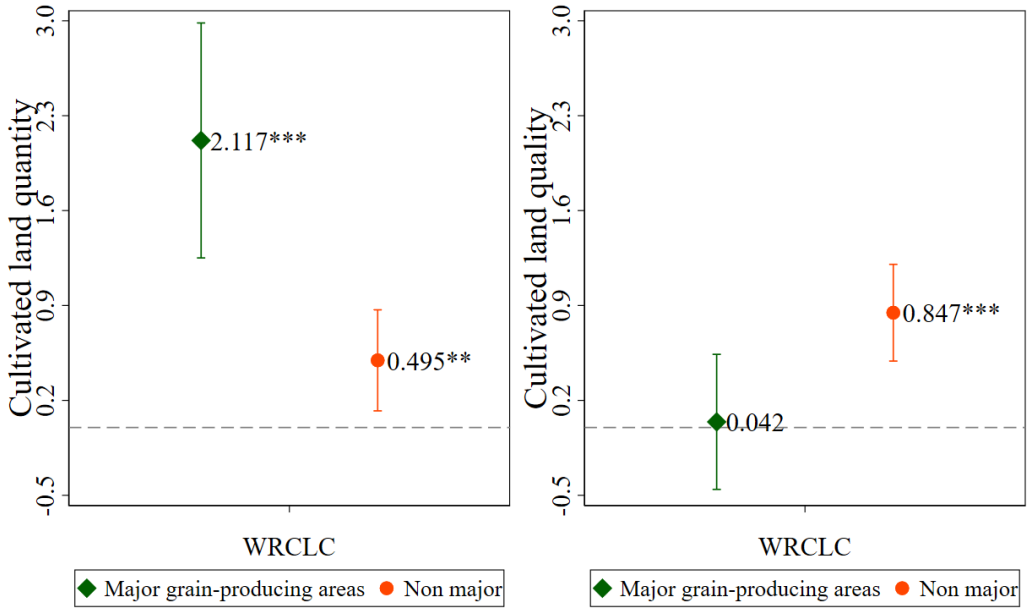


Figure 9. Results of grain-producing functional zones heterogeneity analysis. ***, ** indicate statistical significance at 1% and 5% levels, respectively.

From the standpoint of guaranteeing food security, the WRCLC policy can significantly enhance cultivated land quantity in major grain-producing regions, effectively contributing to an overall increase in regional grain production and thus ensuring regional food security. Additionally, the WRCLC policy can simultaneously improve the cultivated land quantity and quality in non-grain-producing regions, further enhancing local self-sufficiency in food production and realizing the goal of "zero hunger".

6. The Impact of Policy Synergy on Cultivated Land Security

6.1. The Impact of Policy Synergy on Cultivated Land Quantity

This study examines the effects of policy synergy on cultivated land quantity and quality in rural areas by constructing interaction terms. The results presented in Figure 10 indicate that the coefficient for the impact on cultivated land quantity increases from 1.217 to 2.570 and 2.717, respectively, when the WRCLC policy is coordinated with the AM policy and AII policy, achieving statistical significance at the 1% level. This suggests that the measures for WRCLC and the development of agricultural mechanization can form a complementary relationship, thereby promoting an increase in cultivated land quantity in rural areas. Additionally, the coordinated advancement of agricultural industry integration and WRCLC can effectively enhance the quantity of cultivated land, contributing to food security. It is noteworthy that when the WRCLC policy is coordinated with RT policies, the coefficient for the impact on cultivated land quantity decreases to 0.493 and is no longer statistically significant. This may be attributed to the fact that the development of rural tourism significantly stimulates the construction of homestays and tourism facilities, which can encroach on cultivated land resources [60]. Furthermore, the focus on creating

aesthetically pleasing landscapes in rural tourism may lead to issues that indirectly alter the nature of cultivated land.

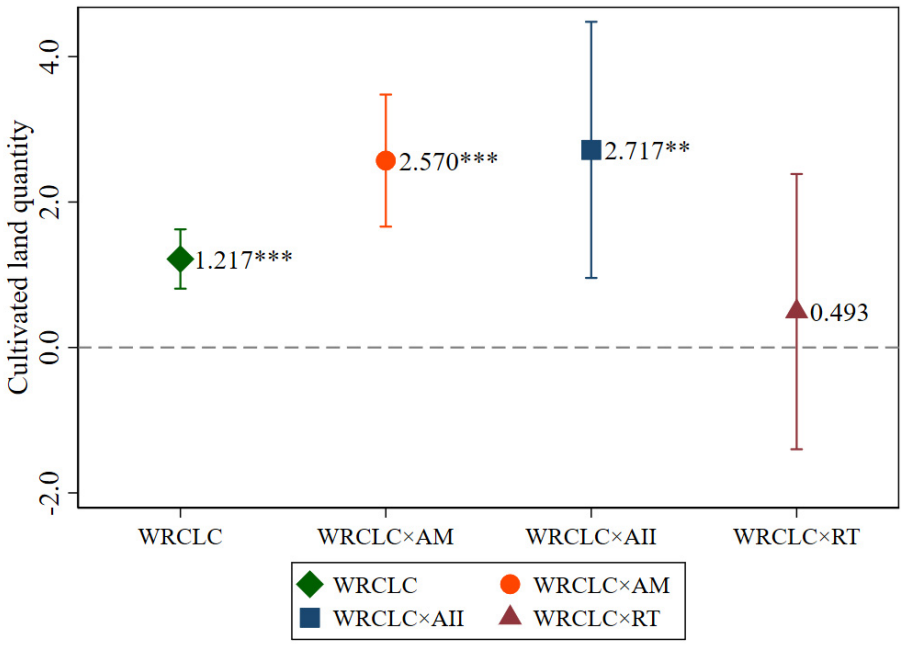


Figure 10. Results of the impact of policy synergy on the quantity of cultivated land. ***, ** indicate statistical significance at 1% and 5% levels, respectively.

6.2. The Impact of Policy Synergy on Cultivated Land Quality

The results shown in Figure 11 indicate that the enhancement of cultivated land quality is positively significant when the WRCLC policy is coordinated with the three types of policies. The impact coefficients increase from 0.678 to 1.485, 1.382, and 1.329, respectively. These findings validate that the coordination of agricultural mechanization, agricultural industry integration, and rural tourism development policies with the WRCLC policy effectively promotes the improvement of cultivated land quality in rural areas.

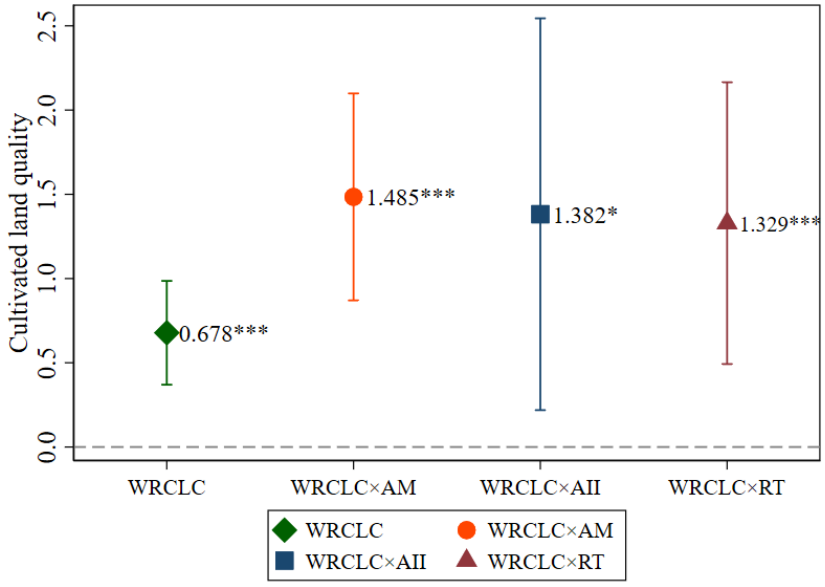


Figure 11. Results of the impact of policy synergy on the quality of cultivated land. ***, * indicate statistical significance at 1% and 10% levels, respectively.

7. Discussion

The research findings indicate that WRCLC can enhance cultivated land security. Existing studies on land use and cultivated land security have mainly focused on traditional land consolidation models, but the conclusions are inconsistent [17]. Traditional land consolidation typically uses engineering measures to improve inefficient or unused land, primarily on a project-by-project basis, focusing on land adjustment and rural reconstruction, without considering ecological restoration projects [18,61]. Additionally, in some regions, traditional land consolidation is seen as a tool to provide land use quotas, overlooking the protection of cultivated land and agricultural ecosystems, which makes it difficult to ensure the security of rural cultivated land [62]. WRCLC emphasizes the holistic scope of consolidation, the comprehensive nature of the consolidation targets, and the systematic implementation of consolidation measures, providing an important guarantee for achieving cultivated land security [19]. In terms of scope, WRCLC takes townships as the basic unit for implementation, promoting planning, design, and consolidation at the regional level. Regarding the consolidation targets, WRCLC focuses on all elements of the landscape—mountains, water, forests, fields, lakes, and grasslands—within the region, coordinating the optimization of land resource allocation. In terms of measures, WRCLC systematically implements three key actions: agricultural land consolidation, construction land consolidation, and ecological restoration. Therefore, WRCLC not only contributes to increasing the quantity of cultivated land but also addresses improvements in land quality, and the sustainable use of cultivated land [19,20]. Although some scholars have already recognized the significant impact of WRCLC on cultivated land security, existing studies primarily use theoretical analysis or case study methods to qualitatively explore the relationship between the two [63,64]. Furthermore, due to limitations in data availability, existing research often focuses on single pilot township samples [21,22], which may raise doubts about the reliability of the conclusions. To address the limitations of previous studies, this research innovatively combines spatial data analysis methods with econometric causal inference techniques. Using ArcGIS 10.8.2 software, satellite remote sensing images are processed into data with numerical characteristics, forming township-level panel data with a time series. This approach effectively resolves the issue of limited research samples and improves the accuracy of the findings.

In terms of model selection, current research predominantly relies on traditional difference-in-differences (DID) models [26,65], which may lead to biased policy evaluation results. In contrast, this study uses township-level panel data and treats the WRCLC policy as a quasi-natural experiment, employing the double machine learning (DML) method for causal inference. This approach aims to examine the impact of WRCLC on cultivated land security from a more micro and precise perspective. DML offers significant advantages in variable selection and model estimation [52]. On the one hand, since the cultivated land security is influenced by various natural, economic, and social factors, this study includes ten covariates such as population density, temperature, and precipitation, while controlling for township-fixed and year-fixed effects. This helps to avoid estimation bias caused by omitted variables, improving the accuracy of policy effect evaluation. The DML approach, by employing machine learning and regularization algorithms, automatically selects the most predictive and relevant subset of control variables from the pre-selected high-dimensional set. This not only effectively resolves the issue of redundant control variables in traditional models, but also alleviates estimation bias caused by insufficient key control variables [66]. On the other hand, thanks to its advantages in handling nonlinear data, DML can effectively mitigate model specification errors [50,66], thus providing more robust estimates.

Existing research has primarily focused on the analysis of individual land adjustment policies, with less attention given to the exploration of policy synergy effects. However, from the perspective of regional development needs, single policies often fail to achieve their expected outcomes. Only through the synergy effect of multiple policies can regional policy goals be more effectively realized [67–69]. Meanwhile, scholars have identified that

agricultural mechanization, agricultural industrial integration, and rural tourism development all have significant impacts on land security [37,38,70–73]. Therefore, based on existing research, this study selects three pilot policies implemented at the township level in Zhejiang Province: the AM policy, the AII policy, and the RT policy. By constructing interactive terms, this study further examines the impact of policy synergy on cultivated land security within the framework of WRCLC. The results show that during the implementation of WRCLC, the synergy with the AM policy and the AII policy both significantly improved the quantity and quality of cultivated land in townships. Notably, however, the synergy between the WRCLC policy and the RT policy does not show a significant effect on the improvement of cultivated land quantity, which contrasts with the findings of previous studies [74]. Field surveys reveal that tourism-oriented rural development models, emphasizing projects such as "study tours" and "sightseeing", have led to a rapid increase in land demand for infrastructure development. When there is insufficient land for rural construction, it often results in the cultivated land encroachment. Furthermore, tourism development has caused local farmers to shift from traditional agricultural activities to tourism-related industries (such as operating homestays and providing catering services), leading to cultivated land abandonment. Therefore, during the development of the tourism industry, the government should firmly establish awareness of cultivated land protection, strictly review land for tourism construction, and ensure the protection of cultivated land quantity and the stability of its quality. Additionally, in the process of implementing comprehensive land consolidation, the government should carefully plan tourism land and construction projects, optimize the layout of the tourism industry, improve land use efficiency, and promote a high-efficiency balance between tourism development and farmland protection [75]. The government should also establish a well-functioning land transfer system, encourage part-time farmers to lease out their cultivated land and enhance the scale of cultivated land management.

8. Conclusions and Implications

8.1. Research Conclusions

Based on panel data from 707 townships in Zhejiang Province from 2013 to 2022, this study employs the DML approach to estimate the impact of WRCLC on cultivated land. Meanwhile, the heterogeneous impact of WRCLC on cultivated land security is examined under different geographic characteristics, economic development levels, and grain functional zone scenarios. Additionally, this study incorporates the AM policy, the AII policy, and the RT policy into the WRCLC policy analytical framework, to explore the effects of policy synergy on cultivated land security in townships. The main findings are as follows:

(1) After the implementation of WRCLC, pilot townships saw significant improvements in both the quantity and quality of cultivated land, further ensuring cultivated land security. This conclusion remains valid after a series of robustness, endogeneity, and placebo tests. Therefore, Hypothesis 1 is confirmed.

(2) Heterogeneity analysis shows that the policy effects of WRCLC are minimally affected by geographic features, with significant improvements in cultivated land quantity and quality occurring in townships, regardless of terrain conditions. However, there is some heterogeneity in the policy effects across different economic development levels and grain-producing functional zones. Specifically, WRCLC is more effective in improving cultivated land quality in non-grain-producing areas and regions with lower economic development levels.

(3) From the perspective of policy synergy, when the AM policy is synergized with the WRCLC policy, as well as when the AII policy is synergized with the WRCLC policy, cultivated land quantity and quality in townships experience significant improvements. However, the synergy between the RT policy and the WRCLC policy only leads to enhancements in cultivated land quality, without effectively increasing the quantity of cultivated land.

8.2. Policy Implications

Based on the above discussions, the research policy implications are as follows:

(1) Zhejiang Province's WRCLC promotes improvements in the cultivated land security of townships, offering new perspectives for innovating land rehabilitation models and addressing food security issues. The Zhejiang Province should continue to explore and optimize new models of WRCLC at the township level, while further promoting the establishment of pilot programs across the country. In the process of policy implementation, it is essential to base actions on the protection of basic farmland and ecological red lines. Measures such as the consolidation of agricultural land and construction land, along with ecological protection and restoration efforts, should be employed to enhance the role of land consolidation in ensuring cultivated land security.

(2) Through a heterogeneity analysis, it has been found that the impact of WRCLC in Zhejiang Province on cultivated land security varies based on geographical characteristics, regional economic development levels, and grain-producing functional zones. In the subsequent policy implementation, particular attention should be paid to improving cultivated land quality in economically developed areas and major grain-producing regions, avoiding an imbalanced focus solely on quantity at the expense of quality.

(3) WRCLC, as a systematic project encompassing all elements and processes, can play a synergistic role with relevant agricultural industry policies during its implementation, promoting cultivated land security. First, it is essential to promote the synergy between the AM policy and the WRCLC policy, advancing the concentrated, contiguous rehabilitation of cultivated land and large-scale operations. This will improve the input structure of production factors through agricultural mechanization, ensuring the sustainable use of cultivated land. Second, the government should utilize the policy synergy between the AII policy and the WRCLC policy. To improve the effectiveness of the use of cultivated land resources, the government ought to support the internal integration of the agricultural sector. Additionally, the government should promote the extension of the agricultural value chain to facilitate the adoption of green agricultural technologies that improve cultivated land quality. Finally, during the synergic advancement of the RT policy and the WRCLC policy, the government should place a high emphasis on cultivated land protection, strengthening the management of both the quantity and quality of cultivated land. The government should establish a negative list based on field investigations, and strictly review the approval process for tourism construction land to ensure that cultivated land resources are not excessively occupied. Simultaneously, during the implementation of WRCLC, the government should reasonably plan tourism land and related construction projects, optimize the spatial layout of the tourism industry, enhance land use efficiency, and achieve a win–win situation for tourism development and cultivated land protection. Furthermore, the government should establish and improve the land transfer system, encourage part-time farmers to participate in land transfers, and promote large-scale farming operations, thereby improving the efficiency and sustainability of land use.

8.3. Research Limitations and Prospects

This study, based on WRCLC, expands the research on the relationship between land consolidation and cultivated land security. It employs a DML approach to scientifically evaluate the policy effects of WRCLC. From a policy synergy perspective, it explores the impact of the synergy between the WRCLC policy and other agricultural industry policies on cultivated land security. While this study has made certain contributions, several limitations remain, warranting further investigation. Firstly, the mechanisms through which WRCLC influences cultivated land security are complex and multifaceted, involving factors such as production, livelihood, and ecology. Future research should delve deeper into the interactions between these factors to obtain a more comprehensive understanding and develop a more systematic theoretical framework. Secondly, this study's sample is limited to Zhejiang Province, thus, the generalizability of the results is constrained by regional limitations and the lack of sample diversity. Subsequent research should consider

expanding the sample to include data from townships across the country, in order to better explore the effects of WRCLC on cultivated land security, thereby providing more comprehensive and representative empirical analysis. Lastly, the influence of multiple factor combinations on a single outcome is systematic and complex, making it difficult to conduct a detailed analysis using the interactive terms approach. Future research could consider adopting qualitative comparative analysis (QCA) to uncover the specific configuration pathways through which different factor combinations affect cultivated land security. Additionally, based on causal asymmetry, the QCA method could be used to identify the core conditions that lead to low levels of cultivated land security, thus providing theoretical insights for optimizing the WRCLC policy.

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Note

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