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Can the ecological protection red line policy promote food security? -- based on the empirical analysis of land protection in China

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Introduction: China's food security is confronted with multiple pressures such as farmland degradation and ecological constraints. As a crucial factor influencing the ecological environment of food, strictly adhering to the ecological protection red line provides an important institutional guarantee for ensuring grain production capacity. In this context, studying the impact of ecological protection red line policy (ERP) on food security (FS) provides a new research direction for developing countries to safeguard national security and protect national food security.

Methods: This paper selects China as the object of quasi-natural experiment research, takes the panel data of 31 provinces from 2005 to 2023 as the research sample, measures the actual development level of China's food security by using the entropy method, explores the impact of the ecological protection red line policy on food security by using the different-in-differences model, and investigates the heterogeneity between the two by using the quantile model.

Results: This study demonstrates that the level of food security in China shows a fluctuating upward trend, confirming that the ecological protection red line policy has a significant promoting effect on food security and demonstrates obvious heterogeneous effects. In addition, land transfer (LT) and land reclamation (LR) have strengthened the promoting effect of the ecological protection red line policy, verifying the mediating role between the two.

Discussion: This study not only enriches the research on the relationship between ecological protection red line policy and food security from a theoretical perspective, but also empirically proves that the implementation of ecological protection red line policy is an important policy guideline for enhancing the ecological protection capacity of land and the sustainable capacity of food production. This research not only provides significant reference for improving the construction of China's food security risk governance system, but also offers valuable experience for achieving national ecological security and food security.

KEYWORDS

ecological protection red line policy, food security, land use change, sustainable agricultural development, ecological protection, national security

1 Introduction

Protecting food security is an important strategic goal in China. Ensuring food security foundations constitutes an integral component of China's economic advancement and a fundamental imperative for modernizing agriculture. As the lifeblood of grain production, China attaches great importance to strictly adhering to the ecological protection red line (Zhang et al., 2022b). The ecological protection red line refers to the areas with significant ecological functions or high sensitivity in the ecological space (Yue et al., 2024). It is not only an area that must be strictly protected by force, but also an important institutional arrangement to ensure that the ecological functions of these important areas do not decline, their areas do not decrease, and their natures do not change (Zhao et al., 2025). It can be said that the ecological red line, as an innovation in China's ecological and environmental protection system, is of great significance for optimizing the ecological security pattern and ensuring regional ecological security of the country. Protecting the ecological red line of cultivated land is the bottom line and lifeline of national land protection and ecological security (Zhang et al., 2022a). Thanks to China's firm adherence to the red line for arable land, the country's grain production has remained consistently stable at over sixty million kilograms, and the comprehensive grain production capacity has significantly increased. Therefore, doing a good job in the management of ecological conservation red lines is to enhance the supply level of regional ecological products and ecosystem services, reduce the interference of human activities, ensure that cultivated land resources are not threatened by the environment, and ensure that people can "eat enough and eat well" (Chen et al., 2024a). By increasing the quantity and quality of cultivated land, the risks to food production security can be effectively alleviated. Under the premise of ensuring that people's survival and health are not threatened by food supply, food security can be further achieved (Li and Song, 2022). Therefore, exploring how and to what extent the implementation of ERP affects FS is of great significance for the policy implementation effect, land protection and the improvement of the food security governance system.

According to the environmental data jointly released by Yale and Columbia University, China ranks relatively lower in global ecological and environmental performance indicators compared to developed countries. To some extent, this indicates that China's current protection of the ecological environment is far inferior to that of other developed countries (Ma, 2025). Therefore, how to alleviate ecological and environmental risks and problems remains a key project in our country. ERP is an important institutional innovation in China's deepening of the reform of the ecological civilization system and mechanism. It is not only the bottom line and lifeline for maintaining ecological security, ensuring ecological regulation functions, and providing a good living environment, but also a booster for realizing the FS strategy. However, food and energy security, as a global issue, functioning as a critical safeguard for public wellbeing, food safety (FS) simultaneously constitutes a foundational element essential for upholding China's national security strategy (Du et al., 2025). Therefore, how to make good use of environmental policies to prevent and defuse risks in grain production, processing and consumption, and how to make good use of cultivated land resources to increase grain output, are

particularly important in maintaining FS. Fundamentally, the purpose of implementing ERP is to attach importance to the protection of cultivated land resources in the process of local governments pursuing economic growth and ensure that the land is not threatened by the environment (Liu et al., 2025). In reality, as local governments or agricultural business entities often tend to focus more on short-term land development gains and neglect the protection of permanent farmland, the risk of cultivated land loss has not been fundamentally controlled (Zhou et al., 2024). Therefore, safeguarding both arable land resources and crop production requires not only prioritizing the mitigation of farmland ecological pollution and preventing land degradation, but also fostering robust international trade collaboration to ensure the sustained quality of cultivated land and grain output. Against this backdrop, ERP as an important policy constraint for land ecological protection, has played a significant supporting role in ensuring ecological environment security, FS and national security.

From the existing research, ERP, as an important measure and tool for protecting the ecological environment of land in China, playing a pivotal role in mitigating environmental contamination and land resource degradation, ERP-related scholarly investigations are primarily concentrated within three key domains. Firstly, starting from the theory, by taking the aspects of land use, ecosystem services and ecological compensation policies as the research perspectives, the implementation effect of ERP is analyzed in a theoretical and critical way to evaluate the promoting effect of ERP on the ecological environment (Bai et al., 2016; Jiang et al., 2019; Guo et al., 2023). Secondly, based on empirical evidence, existing literature has respectively regarded ERP as policy evaluation and policy investigation, and adopted the DID model and logistic regression model respectively to explore that the implementation of ERP has had a substantive promoting effect on protecting biodiversity, policy satisfaction, land coverage area, and willingness to pay (Choi et al., 2022; Hu et al., 2022). Finally, starting from the impact effect, existing studies have mainly focused on exploring the promoting effect of ERP on ecological service functions, sustainable economic development and green innovation (Liu et al., 2021; Fu et al., 2023; Wang et al., 2024).

FS as an important topic of global concern, has played a significant role in ensuring people's living needs and promoting national economic development. Research on FS also focuses on the following three aspects. First, starting from the development process, existing literature has explored the evolution of the FS concept. The FS concept has undergone an in-depth transformation from the initial survival, to having enough food and clothing, and then to the current hygiene and nutrition, from having food to having good food quality (Chen and Kates, 1994; Maxwell, 1996; Poole et al., 2021). Secondly, from the measurement level, the measurement methods of FS in the existing literature mainly focus on two levels: the area of major food crops and the index system. Among them, the crop areas are mainly rice, wheat, corn and soybeans (Cui and Zhong, 2024). The indicator system covers aspects such as Food supply, Food access, Policy Security, and Economic Security (Zhao et al., 2023; Xu and Lu, 2025). Thirdly, starting from the influencing factors, existing studies have mainly evaluated the impact on FS from the aspects of environmental regulation, sustainable economic development, land use and ecological environment protection, providing important reference significance for protecting the

ecological environment and sustainable food development (Odoms-Young et al., 2024; Xu et al., 2025a).

While prior research offers insightful perspectives on ERP-FS linkages, empirical assessments specifically examining ERP's direct influence on FS remain limited. Constrained by external agricultural environmental and soil quality factors, effective ERP implementation necessitates region specific approaches to sustainably enhance grain production and supply systems (Gao et al., 2020). Moreover, both grain output and ecological outcomes carry equal weight in ERP policy evaluation, serving as fundamental criteria derived from its top-level design and empirical effectiveness. Although the existing research has achieved rich results, there are still the following limitations: On the one hand, although the existing studies have conducted multi-index analyses of FS, they have not focused on the entire grain industry chain and lack systematic analysis. On the other hand, existing studies have only focused on the impact of land on FS and have not investigated the direct assessment effect of ERP on FS. Overall, in this study, ERP has a certain promoting effect on FS. However, as a developing country, it is also necessary to consider how to give full play to the advantages of ERP while protecting land to better promote FS. Hence, assessing ERP's impact on FS is imperative: Does implementation substantively promote FS? Through which mechanisms does ERP affect FS? This paper aims to establish an assessment of the impact mechanism of ERP on FS through scientific policy evaluation methods, provide decision-making guidance for the government to promote land ecological security, and offer reference significance for other developing countries in land quality protection, land ecological protection, and environmental ecological security. The purpose of this study is to utilize land ecological protection policies to ensure grain production, promote the improvement of the land ecological governance system, guarantee China's FS, and achieve the dual benefits of agriculture and land ecological protection.

In summary, this study's key marginal contributions are manifested through: Firstly, a total of 589 samples from 31 provinces in China from 2005 to 2023 were selected as the analysis objects of this study. The actual development level of FS in China was scientifically and systematically measured by using the entropy method. Taking advantage of the DID model, the actual relationship between ERP and FS was discussed, and five robustness test methods were provided. Prove the rationality of the research. Secondly, this study fully took into account the actual situation of China's grain, explored the development status of FS in different regions and at different quantiles, provided a more accurate basis for formulating ERP in accordance with local conditions, and conducted an assessment using the quantile model. Thirdly, deeply explore the influence mechanism of ERP on FS, and analyze the mediating role of LT and LR in the promoting effect of EW on FS. This research enriches the related studies between ERP and FS. It not only provides ideas for developing countries to achieve sustainable land development and sustainable food development, but also offers significant reference for China's governance system for ensuring food security, ecological security, and improving the national security risk governance system.

The specific structure of this study is arranged as follows: First, in the introduction of this study, the theoretical significance, practical significance and literature review of researching ERP and FS are expounded. Secondly, in the Policy Background and

Theoretical Framework of this study, the policy background of ERP is proposed, and three hypotheses about ERP promoting FS are presented at the theoretical level. Thirdly, the methods and data sources of this research were proposed. Fourth, this study explored the promoting effect and mechanism of ERP on FS through an empirical model. Fifth, it has put forward policy suggestions and future research directions for this study, providing reference significance for the development of developing countries.

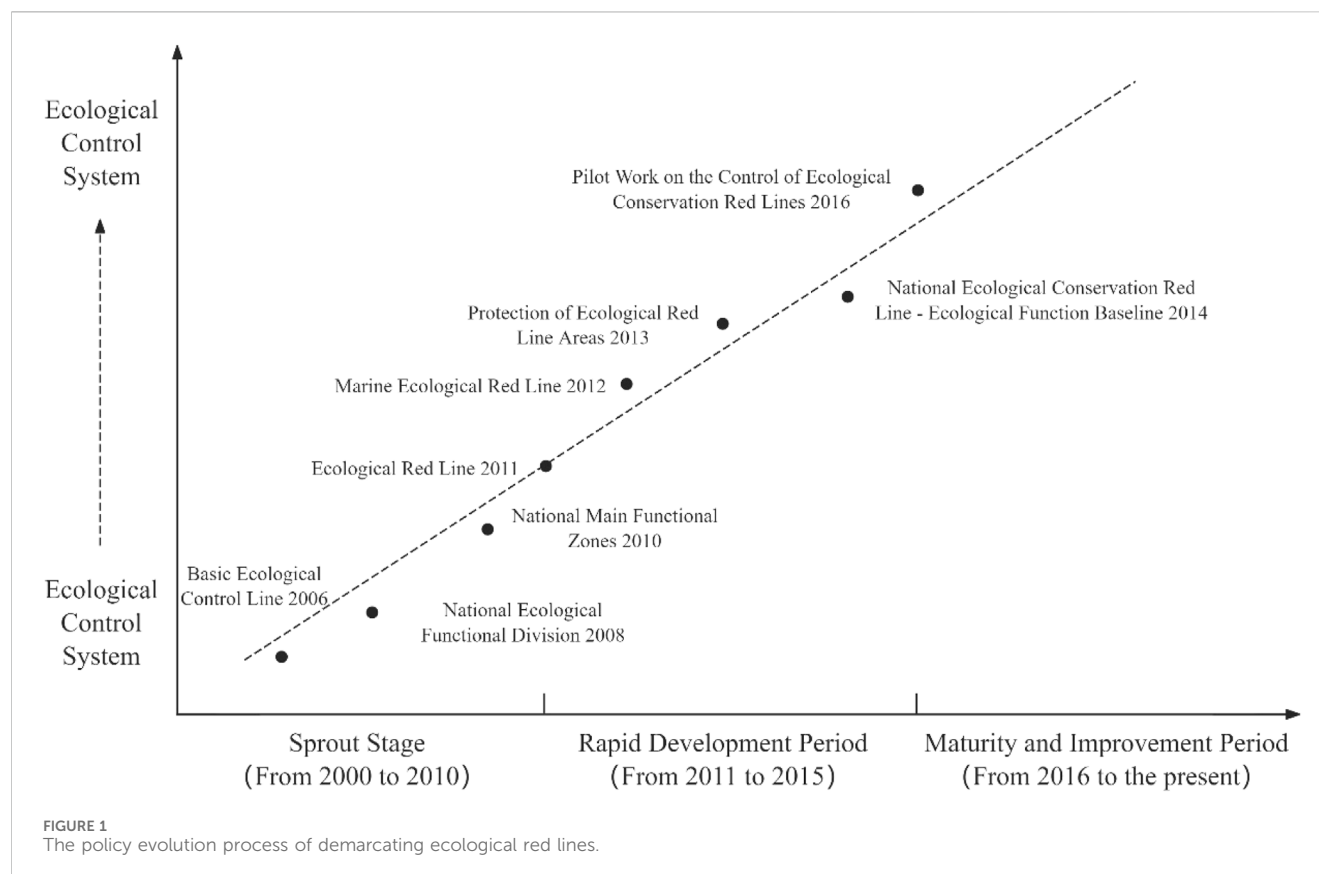
2 Theoretical mechanism

2.1 Policy background

The concept of ERP first emerged in the "Opinions of The State Council on Strengthening Key Environmental Protection Work" in 2011, which stated that "ecological red lines should be demarcated in important ecological function areas, land and Marine ecological environment sensitive areas, fragile areas and other regions (Zhang and Wen, 2008)." In 2014, the Ministry of Environmental Protection of China issued the "Technical Guidelines for the Delineation of Ecological Function Baselines of the National Ecological Conservation Red Line (Trial)" (Shan et al., 2024). This guideline describes the ecological red line as: The ecological conservation red line is a strictly controlled boundary delineated in accordance with the law in key ecological function areas, ecologically sensitive areas and fragile areas, etc. It is not only the bottom line for national and regional ecological security, it also the first programmatic technical guidance document for the delineation of ecological conservation red lines in China. In November 2015, the Ministry of Ecology and Environment officially issued the "Notice on Carrying Out Pilot Work for the Control of Ecological Conservation Red Lines", exploring aspects such as environmental access, performance assessment, ecological compensation and supervision in ecological conservation red line areas (Zeng et al., 2024). This also indicates that the country will officially implement ERP in 2016. The policy evolution process of demarcating ecological red lines is shown in Figure 1 below.

2.2 Direct impact

From the perspective of land governance, the ecological protection red line demarcated by the Chinese government is essentially to ensure the bottom line of cultivated land resources and cultivated land quality and safety through policy regulation, in order to achieve the dual goals of stable grain production and stable ecosystem. Functioning as a pivotal territorial governance instrument, ERP enforces permanent prime farmland conservation while concurrently boosting cropland ecological resilience and food supply sustainability (Wang, 2022). From an implementation standpoint, the ERP system delivers essential safeguards against cultivated land non-grain utilization and secures grain production spatial capacity through integrated mechanisms for farmland preservation and ecological risk prevention. Firstly, ERP has an "anchoring effect" on the utilization of cultivated land resources (Lu et al., 2025c). The constraints of land ecological protection have prompted the intensive transformation of agricultural production methods, driving the concentration of water and soil resource elements towards the construction of high-standard farmland,



promoting the coordinated improvement of cultivated land quality and grain production capacity, and ensuring the fundamental FS and sustainable grain production capacity. Secondly, when ERP strengthens the ecological control of cultivated land, it may trigger a “competitive and cooperative effect”, prompting the grain production industry to increase production capacity while attaching greater importance to the protection of cultivated land resources. Enterprise synergy accelerates cropland protection technology diffusion while optimizing land resource allocation through collective knowledge exchange. Further enhance the intensive utilization of cultivated land and the comprehensive grain production capacity. Finally, ERP exerts a “radiation effect” on grain enterprises. As the land ecological governance system transmits the policy constraints of farmland protection to grain enterprises, it strengthens the demonstration and promotion of farmland protection technologies by grain enterprises, promotes the learning effect among grain enterprises in various fields, and transforms the traditional extensive utilization model of farmland into a large-scale intensive operation model of farmland. While achieving sustainable development of food, we should also promote the modernization and high-quality development of agriculture.

Therefore, this paper proposes hypothesis H1 that ERP has a promoting effect on FS.

2.3 Indirect impact

In the process of farmland protection in our country, the problems of land fragmentation and decentralized land operation have led to the lack of agricultural scale benefits and resource

allocation, thereby causing the emergence of inefficient utilization of traditional farmland (Zhang et al., 2023). With the implementation of ERP, cropland quality and utilization rates are substantially enhanced, while land transfer and reclamation processes accelerate significantly (Ran et al., 2024). Meanwhile, with the large-scale operation of land and the in-depth integration of contiguous cultivated land, farmers’ enthusiasm for growing grain has been stimulated, the land reclamation rate has increased, the allocation of land factors and the application path of production technology have been reconstructed, and the comprehensive grain production capacity has been promoted (Xue et al., 2024; Shi and Liao, 2025). Firstly, land transfer can promote the reorganization of land elements. Grain business entities can obtain contiguous cultivated land resources through large-scale operations and optimize the spatial layout of grain crops by relying on the reclamation and improvement projects. Land transfer-reclamation collaboration curbs idle and inefficient cropland use, securing foundations for stable grain production. Secondly, land transfer and land reclamation can be combined with grain production factors to integrate the problem of reduced grain production caused by fragmented and extensive land in traditional grain production. By improving the ecological governance system, the risks of grain production and operation can be alleviated. This transformation not only breaks the contradiction between the supply of cultivated land resources and grain production, it has also effectively optimized the adaptation relationship between cultivated land and food crops, significantly improved the land utilization rate, and alleviated the contradiction of food supply. Finally, the improvement of land transfer and land

reclamation has alleviated the FS risk, broken the technical gap between land ecological protection under different conditions, and farmers can learn more about land ecological protection technologies through land transfer, directly improving the efficiency of grain planting and grain output, and indirectly increasing farmers' income from growing grain, making farmers more willing to grow grain. So as to achieve FS through the utilization of land ecological protection.

Therefore, this paper proposes the hypothesis that H2, LT and LR play a mediating role in the evaluation of FS by ERP.

2.4 Heterogeneity influence

As a developing country, China has significant differences in ecological protection levels, land quality and policy implementation among different provinces and cities (Wang et al., 2018; Lu et al., 2025b). In this case, it may lead to different promoting effects of ERP on FS in different regions and at different FS levels. First, in economically backward areas, the guarantee efficiency of ERP for FS is actually more obvious. This phenomenon stems from the coordinated integration of "ecological bottom line constraints" and "precise land protection". Despite the relatively backward economy, there is a high focus on the goal of land ecological protection. By ensuring the large-scale operation of cultivated land and avoiding the loss of cultivated land resources. This will further alleviate the problems of land ecological degradation and food risks. Secondly, in economically developed regions and economically average regions, the economic and technological levels are relatively higher compared to less developed regions, and the agricultural infrastructure construction is relatively complete. However, due to the relatively small area of cultivated land in economically developed regions, the promoting effect of ERP is not obvious. While economically average regions, as major grain-producing areas, focus on grain production and supply. Instead, it led to the ERP having a reverse effect during the implementation process. Thirdly, across varying FS levels, higher-security regions prioritize cropland protection red lines and intensify focus on land ecological integrity. Therefore, the promoting effect of ERP is stronger. Although the ecological protection level in low-level areas is relatively poor, it will generate a "learning effect", and the promoting effect of ERP will be slightly lower than that in high-level areas.

Therefore, this paper proposes hypothesis H3 that ERP has a heterogeneous effect on FS.

3 Methods

3.1 Identification strategy

Based on the above theory, ERP was issued in November 2015 to implement ERP, and the official standardized implementation time point across the country was from 2016 to the present. Moreover, the promotion of ERP has shown typical characteristics of gradual and regional implementation. This indicates that the impact of ERP implementation on FS at different time points will present different evaluation results. Meanwhile, as a quasi-natural experiment, ERP, when using the DID model, not only has the advantage of rich sample heterogeneity but also can effectively assess how the implementation of

ERP actually affects FS. In view of this, this paper will select the DID model to explore the promoting effect of Chinese ERP on FS.

3.2 Measurement model setting

3.2.1 Benchmark regression model

Based on the above analysis, in order to better study the situation of land ecological protection, we take the ecological protection red line policy implemented by China in 2016 as the research object. Meanwhile, due to the certain differences in agricultural and grain development among various regions in our country. Therefore, this study employs the DID model, partitioning the ecological protection red line policy into experimental and control groups. The formula is as follows:

$$FS_{it} = \alpha + \beta ERP_i \times I_t^{post} + \delta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In Model (1), FS_{it} is the explained variable, representing food security, and ERP_i is the core explanatory variable, representing the ecological protection red line policy; I_t^{post} is a dummy variable for the time point of policy implementation; X is the set of control variables. i and t represent the i th province and the t th period respectively. α is the constant term. The estimated parameter β is the net effect. μ_i represents the regional fixed effect, λ_t represents the year fixed effect, and ε_{it} represents the random disturbance term.

3.2.2 Parallel trend test and dynamic effect test models

Furthermore, the validity and rationality of the estimation using the DID model mainly lie in whether the assumption of parallel trends is met. That is, if there is no policy shock to food security, the time trends of the treatment group and the control group of the ecological protection red line should be consistent. Therefore, a series of dummy variables need to be included in the standard regression to further track whether the food security of each province (municipality, autonomous region) has the same changing trend when the ecological protection red line policy has not been implemented, and the following model is constructed:

$$FS_{it} = \alpha + \sum_{t=2005}^{2023} \beta_t (ERP_i \times year_t) + \delta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Parallel trend refers to the situation where the food security levels of the experimental group and the control group show the same trend before the implementation of the policy. That is, if the ecological protection red line policy is moved forward, no significant policy effect will be identified. Therefore, in this paper, the leading and trailing variables of the policy year are set as $year_t$, and the countermeasure effect is selected as β_t . If β_t ($2005 < year \leq 2016$) is not significant or the joint is not significant at this stage, it can indicate that the hypothesis of the parallel trend test is satisfied, and during the β_t ($2016 < year < 2023$) time period, it will represent its dynamic effect.

3.3 Variable selection

3.3.1 Explained variable

Food Security (FS), in terms of both connotation and extension, the core of China's FS is people-oriented, ensuring that people's

TABLE 1 System of indicators of the level of food security.

Target level	Level 1 indicators	Secondary indicators	Tertiary indicators (units)	Weights	Quality
FS	Food supply security	Volatility of total food production	(Total food production in the current year - average of total food production in the last 5 years)/total food production in the current year (%)	0.002	-
		Land mobility	Cultivated land per capita (mu/person)	0.057	+
		Grain reserves	Total grain production (tons)	0.068	+
		Resilience of crops to disasters	Area affected by crops/area sown with crops (%)	0.004	-
		Food supply stability	Grain purchases (tons)	0.136	+
		Food Circulation	Grain sales (tons)	0.123	+
	Food production security	Stability of food production	Grain sown area (millions of hectares)	0.063	+
		Level of financial support for agriculture	Grain sown area/total sown area (%)	0.019	+
		Agricultural innovativeness	Total power of cropland machinery (10,000 kW)	0.067	+
		Level of human capital	Qualified food workers (persons)	0.135	+
		Agricultural productivity	Gross agricultural output/primary sector employment (yuan/person)	0.049	+
		Infrastructure development	Number of agricultural water conservancy facilities constructed (units)	0.097	+
	Food access security	Rural Engel coefficient	Rural food consumption expenditure/total consumption expenditure (%)	0.009	-
		Food price volatility	(Current year food price index - previous year food price index)/current year food price index (%)	0.001	-
		Food share	Total food production/resident population (tons/person)	0.053	+
		Road density	Length of transport routes (rail, road, waterway)/urban area (km/sq km)	0.070	+
	Sustainable food security	Pesticide application rate	Pesticide application per unit of food sown area/crop sown area (%)	0.006	-
		Fertilizer application rate	Fertilizer application per unit of food sown area/crop sown area (%)	0.004	-
		Agricultural film use	Agricultural film uses per unit of food sown area/crop sown area (%)	0.004	-
		Quality assurance	Effective irrigated area/crop sown area (%)	0.034	+

diverse preferences for food are met at any time level. Furthermore, given China's huge population size, FS is confronted with multiple threats both at home and abroad. Therefore, in this paper, FS is expressed as a general term for comprehensive food security formed by the input of various endowment factors. The specific indicator system is shown in Table 1.

- (1) Regarding the measurement system, drawing on the existing research basis (Lee et al., 2024; Xu et al., 2025c), it is proposed to select corresponding indicators from four dimensions: food supply security, food production security, food acquisition security, and sustainable food security. Compared with the existing research (He et al., 2025), it can start from the entire food industry chain. Present and measure the possible security risks in the grain industry scientifically and reasonably.
- (2) Regarding the measurement method, to avoid possible analytical biases, the entropy value method is selected for measurement. The advantages of the entropy method over

principal component analysis and factor analysis lie in its ability to comprehensively consider the degree of variation of indices in various indicators, providing more precise weight empowerment, having a simpler calculation process, making the comprehensive evaluation results more scientific, fair and reasonable compared to other weighting methods, and having the advantages of being unaffected by the preferences of evaluators compared to subjective weighting methods

3.3.2 Core explanatory variables

The ecological protection red line policy (ERP), in this paper, the interaction term of the dummy variable at the policy time point is selected as the core explanatory variable of this paper (Wang and Yang, 2025). In addition, since China began to steadily promote ERP in 2016, it has continuously emphasized the quality of the land environment and ensured the efficient utilization of land resources (Wang and Yang, 2025). As a result, the land within the scale red line in our country has shown a certain growth trend. Therefore, in order to scientifically and reasonably explore the situation of land

protection in China, we choose ERP as the research object for protecting the ecological environment of land, and take the implementation node of the ecological protection red line time as the starting point of the research, with 2016 as the base year, to characterize ERP. Among them, I_t^{post} is a dummy variable at the time point of policy implementation. And when $t < 2016$, $I_t^{post} = 0$, while when t is greater than or equal to 2016, $I_t^{post} = 1$.

3.3.3 Control variables

Considering that there are many factors affecting FS, this paper refers to the existing research (Lu et al., 2025a; Xu et al., 2025b) and will set the following control variables: Urbanization rate (URB), which is represented by the proportion of urban population to the permanent resident population in each province in this paper. Government fiscal intervention (FE) is measured by the proportion of provincial government fiscal expenditure to the GDP of each province. The degree of agricultural technology (ATD) is measured by the total power of *per capita* agricultural machinery; Industrial structure (IS), the proportion of the added value of the primary industry in each province to the GDP of that province is selected to represent the industrial structure. The degree of economic development (LNGDP) was measured by selecting the total *per capita* GDP of each province. To further ensure the comparability of the estimation results and reduce the interference of variable dimensions, the total *per capita* GDP was logarithmic processed.

3.3.4 Mediating variables

- (1) Land transfer (LT), as a key path for the marketization of land and the structure of scale operation to release the allocation of factors, can not only enhance the efficiency of integrating fragmented land and matching grain business entities, but also provide fundamental assistance for improving grain production. Referring to the existing research (Fei et al., 2021), the ratio of the transferred area of household contracted cultivated land to the total area of household contracted managed cultivated land was selected to represent land transfer.
- (2) Land reclamation (LR), the large-scale and contiguous reclamation and the integration of restoration technologies, as the core paths to improve land quality, can not only optimize the synergy among cultivated land elements, but also enhance the synergy between land and grain production. Referring to the existing research (Dong et al., 2025), the ratio of the sown area of crops to the total area of cultivated land was selected to represent the land reclamation index.

3.4 Data sources and descriptive statistics

This paper investigates ERP and FS within the Chinese context. To reflect the availability and operability of relevant indicators, the original data related to FS comes from the “China Grain and Strategic Reserves Yearbook” and the development work reports of each province, and the data of control variables are from the “China Statistical Yearbook” and the “China Rural Statistical Yearbook”. Considering that the data of each indicator may be missing in different years, in order to obtain as complete the data

resources as possible and reflect the latest situation of ERP and Chinese FS, this study set the sample time range from 2005 to 2023, and selected 31 provinces as the sample regions. Nevertheless, data gaps persist for several provinces. This study employs linear interpolation and exponential smoothing to impute these missing values. The statistical analysis results of the symbols and representativeness of each variable are shown in Table 2 as follows.

3.5 Spatio-temporal evolution trend

To better present the spatio-temporal variation trend of FS in China, based on the existing data samples of this study, we have drawn a spatio-temporal evolution trend graph. Figure 2 specifically depicts the variation trend of FS in China from 2005 to 2023. It can be clearly seen that FS shows a fluctuating upward trend. This indicates that from 2005 to 2023, under the joint influence of policy support, technological innovation and the concept of sustainable agriculture, China not only effectively responded to multiple risks and challenges, consolidated the foundation of food security, but also laid a solid foundation for ensuring long-term food supply security. Furthermore, with the strengthening of the strategic position of national food security, the popularization and application of precision agriculture technologies and disaster prevention and mitigation measures, as well as the continuous release of policy dividends such as high-standard farmland construction and producer subsidies, agricultural production entities are investing more in ensuring stable output and improving quality and safety. Meanwhile, with the continuous increase in investment in agricultural science and technology, the wide application of precision agriculture technology and efficient resource utilization models, as well as the implementation of ecological compensation policies and farmland protection systems, agricultural producers have gradually shifted to more intensive and sustainable production methods, ultimately driving FS to show an overall upward development trend despite fluctuations during this period.

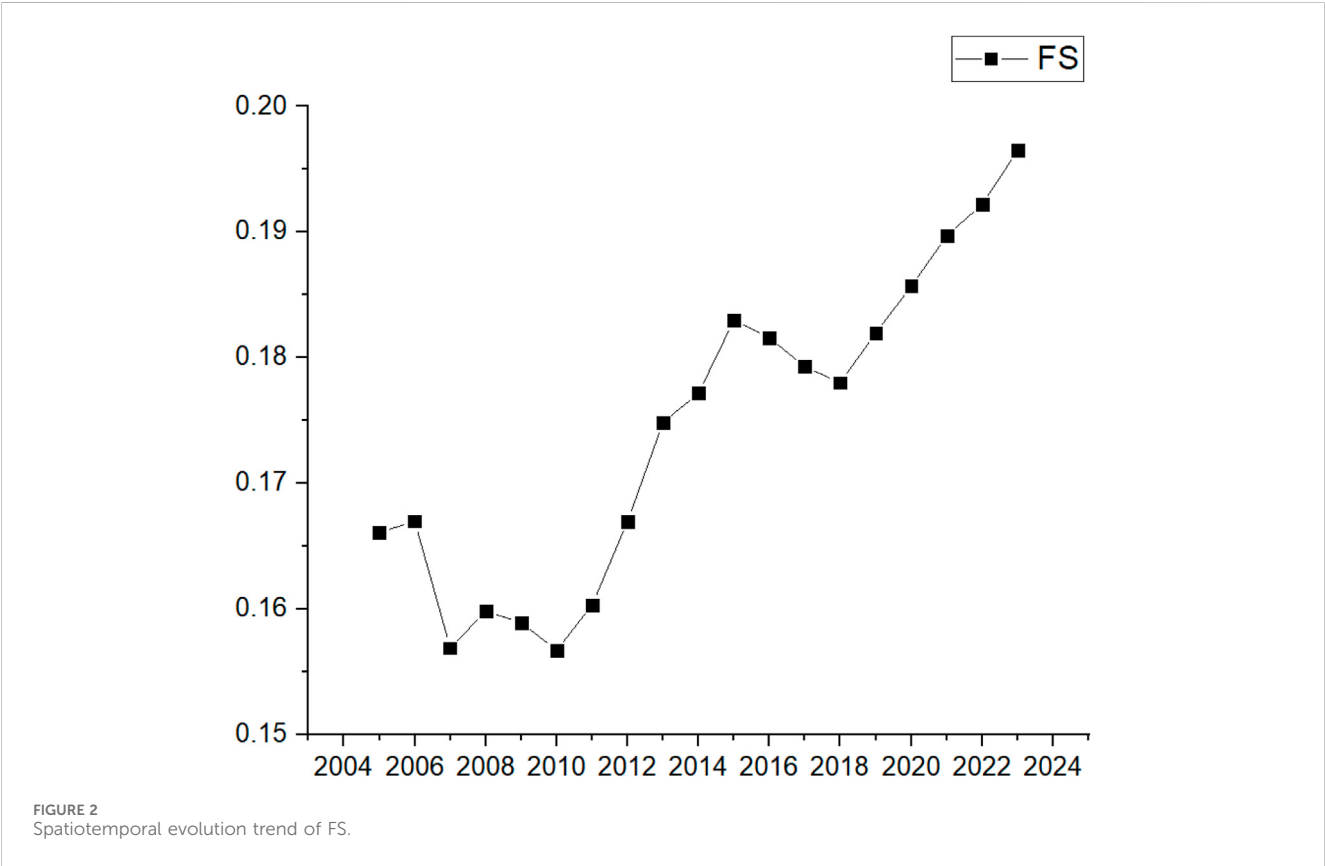
4 Result

4.1 Benchmark regression results

To verify the direct effect of ERP on FS, this study conducted an empirical evaluation using Formula 1, and the results are shown in Table 3. Among them, column (1) shows the direct regression results of ERP and food security under fixed effects, column (2) shows the regression results under the addition of control variables and fixed effects, and column (3) shows the regression results using Bootstrap sampling for 1,000 times. From the regression results in column (1) of the above table, it can be found that the policy dummy variable is positively significant at the 1% level without adding control variables, indicating that the implementation of ERP has significantly improved the level of FS. After adding five control variables such as urbanization rate, government financial support, industrial structure, agricultural technology and high-quality economic development on the basis of column (1), the estimated coefficients of the policy dummy variables in columns (2) and (3)

TABLE 2 Descriptive statistics of variables.

Variable description	Code	N	Average	Standard deviation	Min	Max
Food security	FS	589	0.174	0.077	0.049	0.517
Ecological protection red line policy	ERP	589	0.421	0.494	0	1
Urbanization	URB	589	0.559	0.146	0.207	0.895
Government financial support	FE	589	0.266	0.191	0.091	1.353
Industrial structure	IS	589	0.105	0.0565	0.0020	0.327
Agricultural technology	AT	589	0.299	0.192	0.064	1.196
Economic development	GDP	589	10.570	0.685	8.559	12.207
Land transfer	LT	589	0.251	0.188	0.001	0.958
Land reclamation	LR	589	1.277	0.417	0.494	2.395



did not change much, and the significance was slightly lower. This indicates that the implementation effect of ERP is not only in line with the original intention of national policy-making, it also indicates that ERP plays an important role in ensuring the national FS, and Hypothesis H1 has been verified. Furthermore, by controlling variables, it can be found that government financial support and agricultural technology have significantly enhanced the level of food security. This proves that the government’s support for agriculture can drive the development of the grain industry and simultaneously promote the improvement of the level of FS. Meanwhile, the improvement of agricultural technology levels

promotes the production efficiency of the grain industry and can also drive the protection of land resources. This also implies that: First of all, ERP cannot do without the financial support of the government, including promoting rural economic development, popularizing rural finance, and increasing farmers’ income, *etc.* It can effectively improve the utilization efficiency, production efficiency and transfer efficiency of farmland, help improve the planting efficiency and product quality of grain, and further reduce the risks of grain production and supply. Secondly, ERP has promoted the development and application of advanced agricultural technologies, including smart agriculture,

TABLE 3 Direct effect.

Variable	(1)	(2)	(3)
ERP	0.193*** (0.019)	0.195*** (0.069)	0.195** (0.082)
URB		−0.099 (0.173)	−0.099 (0.193)
FE		0.249*** (0.079)	0.249*** (0.091)
IS		−0.264 (0.230)	−0.264 (0.451)
AT		0.095** (0.046)	0.095* (0.052)
LNGDP		0.009 (0.050)	0.009 (0.053)
Year	Control	Control	Control
Region	Control	Control	Control
Cons	−1.903*** (0.013)	−2.007*** (0.461)	−2.620*** (0.538)
R ²	0.494	0.513	0.974
N	589	589	589

Note: The values in parentheses are robust standard errors; *, **, and *** respectively indicate significance at the levels of 10%, 5%, and 1%. The following tables are the same.

TABLE 4 Time Placebo test.

Variable	(1)	(2)	(3)	(4)
	Policy node = 2006	Policy node = 2007	Policy node = 2008	Policy node = 2009
ERP	0.195 (0.156)	0.195 (0.156)	0.195 (0.156)	0.195 (0.156)
Control variables	Control	Control	Control	Control
Year	Control	Control	Control	Control
Region	Control	Control	Control	Control
Cons	−2.007* (1.007)	−2.007* (1.007)	−2.007* (1.007)	−2.007* (1.007)
R ²	0.513	0.5130	0.513	0.513
N	589	589	589	589

water-saving irrigation, and pest and disease early warning systems, enhancing the security resilience of the grain industry and thereby preventing food security risks from the source of grain planting. Finally, the implementation of ERP fundamentally promotes the transformation of grain production. The ecological protection and improvement of land mean the diversification of planting, enhancing the stability and diversity of the grain production system and ensuring the supply and sustainability of grain. This means that the fact of ERP plays an important foundational role in the development of modern agriculture. It not only helps to achieve the strategic goal of China’s FS, but also contributes to improving the national security governance system and protecting the ecological environment of the land.

Summarizing the above empirical assessment results, this study took various provinces in China as the research objects and, in combination with the actual situation in China, found that ERP can indeed effectively promote the improvement of FS levels in China. This result is highly consistent with the reality that China is a major agricultural country and attaches great importance to the protection of cultivated land. Similarly, as the world’s largest developing country, China’s abundant arable land resources are an

important foundation for ensuring the stability of grain production. The proposal and implementation of ERP can guarantee the quantity and quality of arable land to the greatest extent, ensuring that China can prevent and defuse potential grain crises. This not only provides important experience for improving China’s food security risk early warning system and food security risk governance system, but also serves as a benchmark for other developing countries around the world.

4.2 Parallel trend test

To ensure the validity and authenticity of the ERP assessment of FS, further tests should be conducted on the experimental group and the control group to ensure that they have the same trend before the policy implementation. Therefore, in order to further avoid the possible deviation of the estimation results caused by interfering factors, this paper will use Formula 2 to conduct parallel trend tests six years before the policy implementation and eight years after the policy implementation. The specific results are shown in Figure 3 below. According to the policy effect estimation trajectory diagram,

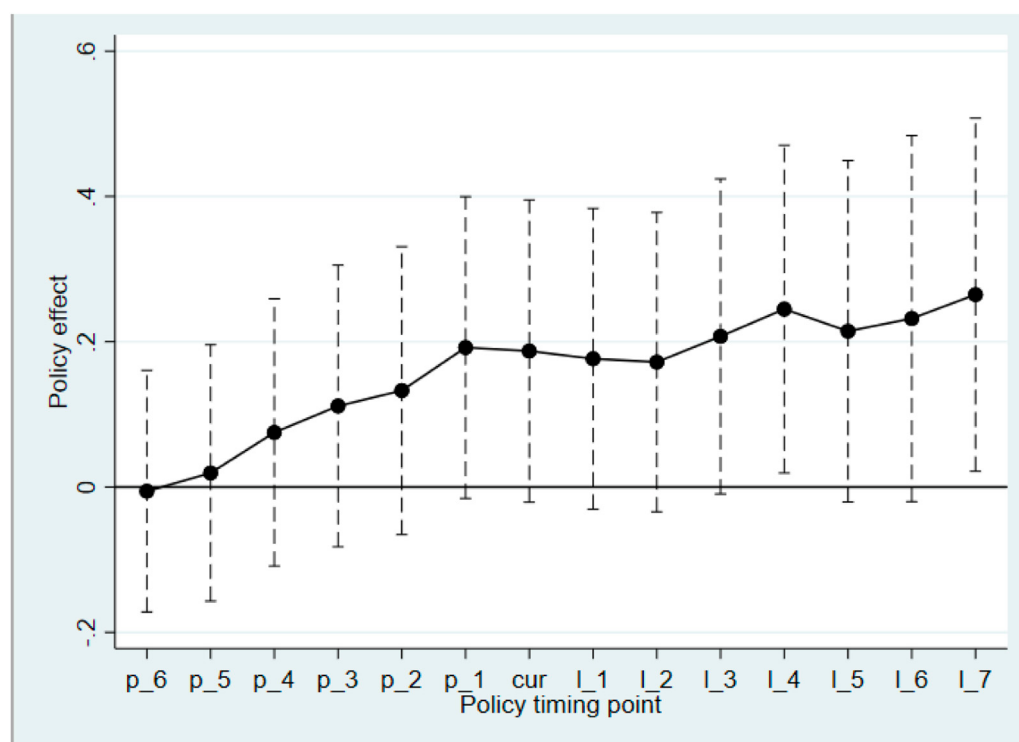


FIGURE 3
Parallel trend test.

it can be intuitively seen that the estimation results are not significant during the pre-implementation period of the policy. Moreover, as time goes by, after reaching the policy implementation point, the ERP estimation parameters begin to be significant, and the policy effect gradually increases over time, indicating that the policy effect of ERP before implementation is not significant. There is no difference in the actual situation of FS between the experimental group and the control group. This is due to the lag of agricultural production and the fact that land quality is affected by the environment, resulting in poor cultivated land resources and quality. However, after the implementation of ERP, it has promoted the protection of land quality and the increase of the scale of the land red line, effectively enhancing food security. Therefore, to meet the hypothetical requirements of the parallel trend test, it is reasonable and reliable to use the DID model to explore the policy effect of ERP on FS.

4.3 Robustness test

4.3.1 Time placebo test

Although the characteristic variables of a large number of provinces have been controlled in the quasi-natural experiments in this paper, there is still a possibility that some unobserved provincial characteristic factors may affect the evaluation results of ERP. The time placebo test can solve the fundamental problem of confounding effects in the time dimension in policy evaluation by constructing a counterfactual framework. Its advantage lies in the ability to eliminate the interference of time trends, identify expected

effects and test the sensitivity of model Settings. It is the gold standard for verifying the robustness of causal inference conclusions (Margo, 1999). This paper randomly selects 2006, 2007, 2008 and 2009 before the policy implementation as the policy time points for placebo tests. The results are shown in columns (1) and (2) of Table 4. From the policy node from 2006 to 2009, the ERP coefficients were all negative and not significant, which can indicate that ERP did not have a policy effect before 2016. The robustness of the benchmark regression findings has been partially validated.

4.3.2 Lag method and tail narrowing method

Given that agricultural production and agricultural economic benefits inherently have a lag, in order to further enhance the reliability and robustness of this study. Firstly, this paper selects to conduct a re-regression of the lag period of the explained variable FS. Taking the lag period of the explained variable as the evaluation object can not only effectively alleviate the endogeneity problem and solve the reverse causality problem, it is proved that the evaluation result of ERP for FS is not caused by the contingency of model setting (Bellemare et al., 2017). The specific results are shown in Column (1) of Table 5. It can be seen that ERP remains positive and is significant at the 5% level. This further proves that ERP can effectively promote the improvement of FS level both in the current period and in the future, thereby verifying the robustness of the benchmark regression results. Secondly, in this paper, the control variable is lagged by one period for regression again. The core value of the control variable lagging by one period lies in using the time sequence to cut off the reverse causal path from FS to the control

TABLE 5 Tests by the lag method and the tail narrowing method.

Variable	(1)	(2)	(3)	(4)
ERP	0.147** (0.069)	0.270*** (0.067)	0.218*** (0.067)	0.294*** (0.080)
Control variables	Control	Control	Control	Control
Year	Control	Control	Control	Control
Region	Control	Control	Control	Control
Cons	−2.130*** (0.488)	−1.601*** (0.458)	−1.771*** (0.445)	−1.306*** (0.499)
R ²	0.482	0.538	0.510	0.515
N	558	558	579	513

variable, thereby alleviating the possible endogeneity problem of the control variable. The sensitivity of the benchmark results to the endogeneity problem of the control variables can be evaluated (Wilkins, 2018). It can be seen from column (2) of Table 5 that the coefficient of ERP for FS remains positive and is significant at the 1% level, once again proving the robustness of the benchmark regression. Thirdly, this paper chooses to process FS by the tailing method, mainly to evaluate the sensitivity of the benchmark empirical results to extreme values and outliers (Wang et al., 2023). It can be seen from column (3) of Table 5 that ERP is still significantly positive at the 1% level, proving that the promoting effect of ERP on FS remains valid after eliminating or weakening the influence of extreme values, once again demonstrating the robustness of the results and not being affected by a few extreme observations. Fourthly, to eliminate the interference of administrative privileges and the inclination of central financial resources, this paper selects to re-evaluate the promoting effect of ERP by excluding the samples of the four municipalities directly under the Central Government in China (Zhao and Xi, 2022). The results can be seen from column (4) of Table 5 that the promoting effect of ERP on FS is still significant below 1%, once again proving the robustness of this paper.

4.4 Heterogeneity test

To clarify the impact of ERP on FS at a higher level, this study conducted re-regression among different geography and different quantiles respectively to explore the heterogeneous effects of ERP on FS. This not only enriches the understanding of the effect of ERP, but also provides a more refined perspective for developing countries on land protection and food protection.

4.4.1 Geographical regional heterogeneity

Although land ecological protection is an important foundation for ensuring food production and supply, as China is a major grain importer and exporter and a developing country, there are obvious differences in land protection, food production resources and economic development among different geographical regions. Therefore, the mechanism of ERP's effect on FS may show significant geographical heterogeneity. For this purpose, this study chose to divide the samples from the Chinese region into three regions: the eastern, central, and western regions, and then conducted regression respectively. The results in columns

(1)–(3) of Table 6 show that ERP in the eastern region has a promoting effect on FS, but not significantly. The reason is that in the developed eastern regions, the ecological red line areas usually overlap with high-quality cultivated land resources, resulting in the pressure of “non-grainization” of cultivated land resources after they are included in ecological protection areas. Meanwhile, although ERP emphasizes the protection of the quantity of cultivated land, it pays insufficient attention to the improvement of quality and the synergy of ecological functions. Although it shows a promoting effect in the eastern region, it is not significant. It is worth noting that ERP in the central region shows a significant inhibitory effect on FS. This is mainly because the ecological red lines in the central region are mostly demarcated in ecologically sensitive areas such as rivers, lakes, wetlands, and the periphery of forests, which restricts the utilization of high-quality land and cultivated land resources. This reflects that some local governments in this region, in order to meet ecological targets, have included gentle slopes and forest edges that could have been cultivated in the red lines. Furthermore, the functional positioning of the central region as a major grain-producing area and the ecological compensation standard being much lower than the income from growing grain make it face more constraints in the process of balancing the protection of high-quality cultivated land resources and FS. However, in the western region, ERP shows a significant promoting effect on FS, and the influence coefficient is significantly positive at the 1% level. This is mainly due to the fact that the region has promoted the terraced development of cultivated land resources under the impetus of ERP, which has to some extent alleviated the problem of cultivated land erosion. Moreover, the western region has combined the protective forest project with the construction of ecological red lines for cultivated land to further prevent natural disasters and effectively ensure grain production. In addition, with the implementation of ERP, the ecological pollution of grain has been alleviated, farmers' enthusiasm for growing grain has been stimulated, and FS has been further guaranteed.

4.4.2 Quantile heterogeneity

This study captured the structural differences of the FS conditional distribution by selecting the quantiles of different conditional distributions, revealed the heterogeneous influence of ERP on FS, especially focusing on extreme values, thereby capturing the potential nonlinear relationships among variables (Lodder and Hieftje, 1988). For this purpose, this study selected

TABLE 6 Geographical regional heterogeneity.

Variable	(1)	(2)	(3)
	Eastern region	Central region	Western region
ERP	0.100 (0.131)	−0.875*** (0.313)	0.843** (0.164)
Control variables	Control	Control	Control
Year	Control	Control	Control
Region	Control	Control	Control
Cons	−2.822*** (0.963)	−4.437*** (1.463)	−0.787 (0.679)
R ²	0.626	0.526	0.510
N	589	589	589

TABLE 7 Quantile heterogeneity.

Variable	(1) P10	(2) P30	(3) P50	(4) P70
ERP	0.052* (0.031)	0.065** (0.025)	0.049** (0.023)	0.069** (0.030)
Control variables	Control	Control	Control	Control
Year	Control	Control	Control	Control
Region	Control	Control	Control	Control
Cons	−4.123*** (0.408)	−3.514*** (0.574)	−4.015*** (0.698)	−4.423*** (0.552)
R ²	0.879	0.859	0.849	0.839
N	589	589	589	589

four quantiles of 10%, 30%, 50%, and 70% to explore the dynamic characteristics of the effect of ERP on FS under different levels of land protection. The results in Table 7 show that there is a significant distribution heterogeneity in the impact of ERP on FS: At the 70% quantile, it can be seen that the promoting effect of ERP is the most prominent, and its coefficient is significantly positive at the 5% level. As the quantile decreases, the promoting effect gradually weakens. The promoting effect rebounds at the 30% quantile and is significantly positive at the 10% level at the lowest 10% quantile, proving Hypothesis H3.

This nonlinear variation result can indicate that the protection effect of ERP on cultivated land resources is closely related to the FS level between regions. In areas with a higher FS level, the agricultural ecological foundation is better and the quality of cultivated land resources is higher. ERP is more likely to optimize the grain production mode through the technology spillover effect. For example, the combination of green agricultural technology and land consolidation can rapidly improve land quality and enhance land output capacity. This also indicates that the promoting effect of ERP on FS mainly lies in the following aspects: On the one hand, it is necessary to give full play to the advantages of land protection in areas with a higher FS level. On the other hand, different regions should implement different differentiation strategies. For example, in lower-level regions, environmental supervision and technical support should be strengthened even more to maximize the promoting effect of ERP.

TABLE 8 Indirect effect.

Variable	(1) LT	(2) LR
ERP	0.671*** (0.058)	0.399*** (0.112)
Control variables	Control	Control
Year	Control	Control
Region	Control	Control
Cons	0.872** (0.384)	4.764*** (0.745)
R ²	0.804	0.479
N	589	589

4.5 Mediation effect analysis

4.5.1 Land transfer

The results in column (1) of Table 8 show that LT has a significant mediating effect in the influence of ERP on FS. By strengthening the rigid constraints of agricultural land space, ERP not only directly ensures the stability of the total amount of cultivated land resources, but also reshapes the long-term guarantee mechanism for enhancing grain production capacity through the synergistic effect of LT's policy regulation and market mechanisms. Firstly, ERP has restructured the balance between the protection of cultivated land and the development and construction of rural land by solidifying permanent basic farmland, promoting the

transformation of the traditional land use situation where only expansion is emphasized but quality is not to green ecological land. In addition, standardizing the access regulations and use control of land transfer can promote the concentration of fragmented farmland into new types of agricultural business entities, systematically break through the capacity bottleneck of small-scale operations, deeply integrate the red line guarantee of farmland with the input of modern agricultural factors, enhance the sustainable capacity of land, and consolidate the foundation of FS.

Secondly, ERP has strengthened the scale agglomeration effect of farmland quality protection and improved the collaborative mechanism for enhancing grain production capacity. At present, the standardized operation of land transfer promotes the formation of large-scale grain operation entities, thereby affecting the application demand of modern agricultural production technology and effectively increasing agricultural science and technology investment and the upgrading of professional services. Meanwhile, with the support of the intelligent supervision system for cultivated land, through dynamic monitoring and precise regulation of data such as cultivated land quality and crop growth, sustainable land development is achieved, further ensuring stable and increased grain production.

Finally, ERP has deepened the reform of farmland protection and governance, and established a regulatory framework that combines land rights protection with responsibility constraints. ERP has further accelerated the process of standardizing land transfer, forming a collaborative system for cultivated land management and protection led by provincial governments in China and implemented by new types of grain business entities. In addition, the demonstration subjects of large-scale land transfer should be included in the certification system for cultivated land protection. Through standardized transfer contracts, the quality constraints of cultivated land should be integrated into the entire process of grain production. Local governments should dynamically implement differentiated protection and compensation policies based on the health indicators of cultivated land, further strengthening the foundation of FS resilience.

4.5.2 Land reclamation

The results in column (2) of Table 8 show that LR has a significant mediating effect on the impact of ERP on FS, and it is also significant at the 1% statistical level. Through the consolidation of fragmented land and the development of reserve resources, ERP not only directly strengthens the total guarantee of cultivated land resources, but also promotes the sustainable improvement of grain production capacity by relying on the synergy effect of integrated reclamation technologies and internal policy drive. Firstly, ERP has restructured the pattern of territorial space development and protection, broken the predicament of low efficiency and waste in traditional cultivated land utilization, and promoted the transformation of the cultivated land resource system towards a green and ecological direction. Meanwhile, the development of land reserve resources and the regeneration of wasteland have enhanced the intensity of engineering reclamation, further improved the technical division of labor in bioremediation, optimized the path of land consolidation, and promoted the sustainable operation of grain production from marginal farmland development to high-quality farmland, reducing the risks of overdraft and ecological disturbance caused by farmland utilization.

Secondly, ERP has strengthened the synergy and diffusion effect of cultivated land restoration technologies and enhanced the large-scale economic attributes of cultivated land resources. Through the ERP-driven demand for reclamation, the systematic application of soil reconstruction and ecological land technologies has been achieved, promoting the transformation of the main skills of land consolidation towards engineering remediation and biological governance. In addition, the policy constraints of ERP integrate sustainable farming techniques throughout the entire reclamation process, enabling the new cultivated land to simultaneously achieve farmland restoration and ecological risk prevention and control at the stage of capacity formation, and further reducing the environmental threats in the process of grain production and operation.

Finally, the collaborative evolution of ERP and reclamation projects has achieved a model of intelligent land governance. The main body of land consolidation has systematically upgraded the land use model by applying digital restoration algorithms to the land. During this process, not only has the precise prevention and control of environmental and ecological risks of cultivated land been formed, but also the protection of land resources has been achieved by building a monitoring and early warning platform for cultivated land quality and non-point source pollution. In addition, the department of food and natural environment resources has deeply resolved the structural contradiction of land ecological degradation by strengthening the intelligent supervision of farmland protection regulations, laying a technical foundation for the construction of a land protection and FS governance system, and providing significant assistance for ensuring food production and supply.

4.6 Discussion

This study explored the role and influence of ERP on FS. The conclusion proved that the implementation and enforcement of ERP in China would effectively promote FS, verified hypothesis H1 of this paper, and was consistent with the conclusions of existing research results (Lü et al., 2013). This proves that cultivated land resources, as the lifeblood of grain production, are an important cornerstone for consolidating national security. To better safeguard national food security, it is necessary to protect the ecological red line of land and ensure the quantity and quality of cultivated land. LT and LR have demonstrated a significant promoting effect in the facilitation of FS by ERP, which proves that the development of LT and LR can promote the implementation of ERP and have a clear leading role in maintaining China's food security and improving the food security risk early warning system. Hypothesis H2 of this paper was verified and maintained consistency with the conclusions of existing research results (Chen et al., 2024b; Xu et al., 2025a). It can be said that China and other developing countries should attach importance to the development of LT and LR, give full play to their advantageous role in protecting the national FS, and further promote the construction of the national food security governance system. Furthermore, this study confirmed that ERP has significant differences on FS in different regions of China, especially in the western regions where the promoting effect of ERP is particularly obvious, while this is not the case in other regions. The hypothesis H3 of this paper was verified, which is the same as the previous research results (Xu et al., 2018). In fact, due to the unbalanced

development among different regions in China, especially the significant differences in policy implementation caused by the varying economic levels of different regions, there is obvious heterogeneity in the implementation effect of ERP. For other developing countries around the world, they can draw on their own situations and those of different development regions in China.

5 Conclusions and policy recommendations

5.1 Conclusion

In this study, we constructed a measurement system of ERP and FS, explained the promoting effect of ERP on FS from a theoretical perspective, and explored the mechanism by which ERP affects FS. Furthermore, the panel data of 31 provinces in China from 2005 to 2023 were selected as the empirical evidence for this paper. Three models, namely, the DID model, the quantile model and the mediation model, were respectively utilized to investigate the influence effect, influence mechanism and heterogeneity between ERP and FS from a multi-dimensional perspective. The main findings are as follows:

Firstly, the results of the regression through the benchmark DID model indicate that the direct impact of ERP on FS shows a significant promoting effect, and no significant change was found in this result after adding various control variables. Furthermore, we verified the equilibrium trend test and found through the time placebo test, variable lag test and tailing test that the promoting effect of ERP on FS did not change significantly. This conclusion emphasizes that the state should strengthen the implementation and application of ERP to promote FS.

Secondly, the heterogeneity regression results show that ERP has a significant promoting effect on FS in the western region of China, but it shows no significant effect in the eastern region, and it shows an inhibitory effect in the eastern region. Furthermore, studies show that in areas with a higher FS, the promoting effect of ERP is more prominent. This result indicates that in regions with a higher FS, the advantage of ERP in promoting FS is more obvious. It further explains that in regions with a higher FS, the implementation of ERP should be prioritized to more effectively achieve the strategic core goal of the country to protect FS.

Thirdly, the results of the mediating effect indicate that LT and LR have significant mediating effects in the assessment of the impact of ERP on FS. Among them, the increase in the index of land transfer and land reclamation is conducive to providing assistance for land factors and technological factors in food production, supply and sustainability, and offers important support for improving FS. This conclusion provides a specific direction for the Chinese government's financial input in land and grain, and also offers practical experience for developing countries.

5.2 Policy recommendations

Firstly, strictly adhere to the ecological protection red line and build a guarantee system for the resilience of cultivated land. The core constraint of red line control is the core guarantee for releasing the governance efficiency of land space and consolidating the foundation of

food security. The natural resources department should coordinate the spatial pattern of farmland protection and ecological restoration, optimize the coordinated layout of permanent basic farmland and land ecology, and accelerate the formation of a three-dimensional guarantee system consisting of grain production capacity reserve bases, intelligent land monitoring networks, and farmland quality cultivation mechanisms. Concurrently, state and local authorities should coordinate cultivated land development by: establishing standardized health certification systems, implementing land grading protocols, refining protection compensation mechanisms, and boosting grain production efficiency. Concurrently prioritize targeted fiscal investments in land improvement and grain production, advance cultivated land restoration technologies, and synchronously enhance ecological conservation capacity with agricultural productivity.

Secondly, deepen the coordination of red line control and restoration technologies, and strengthen the quality of cultivated land and grain production. The innovation of land ecological governance systems and the integration of land ecological restoration technologies are the core driving forces for enhancing the sustainable productivity of cultivated land. It is suggested that the government and environmental protection departments accelerate the research and development of smart ecological land technologies and promote the integration of soil reconstruction and bioremediation technologies. Further improve the land allocation mechanism, enhance the efficiency of grain production, and provide institutional guarantees for enhancing the resilience of the cultivated land system. In addition, by deeply integrating land ecological control with the empowerment of farmland restoration technologies, we can promote breakthroughs in the ecological red line policy between enhancing grain production capacity and maintaining the resilience of grain production, accelerate the extension of the farmland restoration industrial chain, and fully implement the strategic response of promoting production capacity through restoration and ensuring food security through control.

Thirdly, we will strengthen the support system for ecological red line control and improve the long-term mechanism for farmland protection and quality enhancement. Strictly adhering to the ecological protection red line serves as a fundamental institutional constraint for ensuring food security. On the one hand, the government should accelerate the improvement of the collaborative supervision mechanism for ecological red lines, be self-sufficient in the national food security strategy and the national security strategy, deepen the development strategy for agricultural, ecological and natural resource security, ensure that permanent basic farmland and high-standard farmland are not encroachment upon or damaged, and enhance the resilience of food production. On the other hand, efforts should be accelerated to establish a compensation mechanism for ecological protection of cultivated land within the red line area, improve the mechanism for balanced ecological protection of cultivated land, set up core systems for incentives to improve the quality of cultivated land and for the prevention and control of pollution risks in grain production, and improve the early warning system for food security risks. We will fully implement the shared responsibility of the Party and government for food security, enhance the government's capacity to safeguard food security, establish a comprehensive assessment responsibility mechanism that links the ecological value of cultivated land with the effectiveness of food security guarantees, and take local governments and the Ministry of Agriculture as the main responsible parties to curb

the reduction of the ecological red line area of cultivated land and ensure national food security.

5.3 Research deficiencies and prospects

Future research can be conducted through: First, a deeper exploration of the data dimensions of ERP and FS. Although this study uses provincial panel data to demonstrate the macro impact of ERP on ERP, the transmission mechanism at the micro level still requires more in-depth research. For instance, by using data from city panels, county panels, and the enterprise level, and in combination with the specific implementation of policies, it can deeply demonstrate the role path of ERP in land protection and FS. The second is to strengthen the research on the dynamic coupling between the ERP implementation environment and land factors and FS. Further demonstrate the long-term mechanism and spatio-temporal heterogeneity characteristics of ERP for FS, providing more precise theoretical support for improving the land protection and FS governance system.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MX: Project administration, Software, Methodology, Data curation, Investigation, Writing – original draft, Visualization, Resources, Conceptualization, Validation, Funding acquisition, Writing – review and editing, Supervision, Formal Analysis.

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