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Do Factor Misallocations Affect Food Security? Evidence from China

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Abstract: The reasonable allocation of grain production factors is of vital importance to food security and agricultural development. To assess the impact of agricultural factor misallocation on food security, this paper, based on the panel data from China spanning from 2005 to 2019, conducted a comprehensive evaluation of agricultural factor misallocation and food security coefficients across 31 provinces in China, using a spatial Durbin model to examine the effects of factor misallocations on food security. The findings are as follows: (1) Production factor misallocation has significant negative impacts on food security, among them, capital misallocation and labor misallocation inhibiting food security in the local and neighboring areas, and land misallocation has a significant negative impact on food security in local areas, while its spatial spillover effect is no longer significant. (2) Mechanism analysis shows that capital misallocation and labor misallocation hinder the development of transportation infrastructure and the transfer of rural labor, thereby reducing food security. Land misallocation has accelerated the construction of transportation infrastructure, promoted the migration of rural labor, and helped ensure food security. (3) The regional heterogeneity test reveals that capital misallocation and labor misallocation hinder food security in major grain-producing areas and both sides of the Hu Huanyong Line (Hu Line). Meanwhile, land misallocation hinders food security development in various grain-producing areas, as well as the southeast of the Hu Line. Based on the above conclusions, this paper proposes suggestions to improve the efficiency of land and labor resource allocation, accelerate the construction of transportation infrastructure, and encourage the transfer speed of surplus agricultural labor.

Keywords: food security; factor misallocation; spatial Durbin model; spatial heterogeneity analysis

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1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) released the "State of Food Security and Nutrition in the World 2023" report, highlighting the ongoing severity of the global food security situation [1]. The report indicates that approximately 2.4 billion people worldwide lack sustainable access to food, representing about 29.6% of the global population. Among them, approximately 900 million people face severe food insecurity [2]. This underscores the enduring importance of food security on the global agenda. Nevertheless, agricultural production faces challenges such as market capital misallocation, slow intersector labor transfer, and misallocation of agricultural production factors [3]. These challenges not only increase the burden on farmers but also adversely impact agricultural production. Proper allocation of factors has the potential to increase grain output and alleviate the structural contradiction between grain production and demand [4], thereby stimulating farmers' enthusiasm for grain cultivation. Despite utilizing only 9% of the world's arable land to feed nearly 20% of the population, China has achieved remarkable success in global food production [5]. Therefore, this study focuses on China to explore whether there is factor misallocation in its agricultural production sector and its implications for food security. If a degree of factor misallocation exists, how does it affect food security? Can improving factor misallocation enhance China's food security capacity? If so, what are the mechanisms involved? These questions constitute the research objectives of this study. Given the persistent tight balance between food supply and demand and turbulence in the international food market, investigating factor allocation in China's food production and understanding the ramifications of factor misallocation on food security hold significant strategic importance.

The remaining sections of this paper are structured as follows: the Section 2 presents the literature review; the Section 3 presents the theoretical analysis and research hypotheses; the Section 4 comprises the model setting, variable description, and data sources; the Section 5 describes the empirical results and analysis; the Section 6 presents the discussion; and the Section 7 concludes the study and provides policy implications.

2. Literature Review

The existing literature delineates food security through the lenses of security guarantee [1], big food view [6], and nutrient supply [7]. Nevertheless, in light of the evolving food consumption and utilization structures across society, food security has transcended its conventional focus on mere ration security. It has expanded into a broader context, encompassing even bioenergy security concerns [6,8]. Utilizing the DPSIR model, Lei et al. [9] assessed China's food security across three dimensions: cultivated land quantity, quality, and ecology. He [10] and Sun [11] drawing on the 2009 World Food Security Summit's definition, investigated the quantity, quality, and circulation security of food, considering the four aspects of supply, access, stability, and utilization. Additionally, scholars have examined food security through the lenses of food functional regions [12], administrative divisions in the eastern, middle, and western regions [13], national income levels [14], and industrial chain links [15]. Others have explored the regional heterogeneity of food security by examining the perspective of the Hu line and food production types [16,17], incorporating the spatial differences across various geographical regions.

Factor misallocation is defined as the phenomenon where factor resources flow to inefficient sectors rather than efficient sectors due to exogenous intervention (Hsieh and Klenow, 2009) [18]. Building on this foundation, Daniel (1973) [19] extended the concept to factor misallocation and introduced the measurement method for the factor misallocation coefficient. Previous studies investigated the influence of factors such as factor misallocation in AGTFP [20,21], the degree of regional integration [22], and agricultural production efficiency [23]. They conclude that production factor misallocations not only impede agricultural total factor productivity but also result in agricultural output losses [20,21,24]. Regarding the impact of factor misallocations on food security, certain studies posit that inefficient allocation of agricultural capital may result in the repeated construction of low-level infrastructure [25], exacerbate the problem of structural overcapacity in the food processing industry [26], and present a substantial threat to food security. Efficient allocation of family labor can markedly enhance the coefficient of food security [27]. Furthermore, the optimal allocation of land resources may jeopardize food ecological security while enhancing food quantity security and the economic security coefficient [28,29]. Some scholars, however, contend that optimal allocation of land resources may impede both the quantity and quality security of food.

In summary, existing studies predominantly concentrate on the influence of individual production factors on agricultural production. However, they often neglect to integrate multiple factors into the same research framework and fail to consider the interaction effects among these factors. This oversight may result in an incomplete reflection of the real-world impact of multiple production factors on food security. Simultaneously, the majority of existing literature centers on assessing the quantity and quality of food security, aiding in the comprehension of its variations. However, it overlooks the determinants of multidimensional food security and does not clarify the consequences of factor misallocations on multidimensional food security.

The marginal contributions of this paper encompass three main points: Firstly, in contrast to existing studies concentrating solely on labor misallocations and capital misallocation, this paper integrates land factor misallocation into the factor misallocation model, thereby establishing a comprehensive model that accounts for substitution effects. Secondly, employing the entropy-weighted TOPSIS model, this paper evaluates food security across five dimensions: quantity, quality, economy, ecology, and circulation security, and examines the spatial effect of factor misallocation on food security. Thirdly, by examining market resource allocation as the starting point, this paper conducts a deeper analysis of the internal mechanisms involving agricultural transportation infrastructure and rural labor outflow.

3. Theoretical Analysis and Research Hypotheses

3.1. The Impact of Agricultural Factor Misallocations on Food Security

Owing to the presence of information asymmetry and regional institutional disparities, microlevel entities with bounded rationality face challenges in acquiring ample market information. Consequently, they allocate production resources based on their limited understanding, resulting in factor misallocations [18]. Agricultural producers are also confronted with the aforementioned challenges. Firstly, capital misallocation in the agricultural sector results in the repeated construction of infrastructure [30,31], impedes the advancement of agricultural production technology, exacerbates the structural supply contradiction of food, thereby posing a threat to food security [23,32]. Simultaneously, although capital misallocation has increased the level of agricultural mechanization, due to the existence of labor misallocation, some labor force has not been freed and transferred to nonagricultural industries due to the increase in agricultural machinery. Instead, they continue to stay in the agricultural sector [20,33]. This not only reduces the marginal productivity of a unit labor force but also reduces the surplus output of agriculture, which is not conducive to food security, thereby threatening food security [34].

Secondly, the misallocation of the agricultural labor force impedes agricultural production efficiency and impacts the quality of agricultural products [33,35], posing a threat to both the quantity and quality of food security [36]. This arises from the fact that the misallocation of the agricultural labor force retains surplus labor in the agricultural production sector [37]. This results in a reduction in the marginal product per unit of agricultural labor force, an increase in the cost of agricultural production, and a lowering of the enthusiasm of agricultural producers, and consequently, it hinders agricultural production efficiency [23]. Additionally, the misallocation of the agricultural labor force impedes the entry of new professional farmers with high education and strong environmental awareness into the agricultural production sector [37,38]. This perpetuates the use of a large quantity of chemical elements by farmers, resulting in a decline in the agricultural production quality [20,39]. Finally, the misallocation of land resources poses a threat to food security. This results from issues associated with the conversion of cultivated land, including problems such as land fragmentation and insufficient available land for agricultural production [33,40]. These issues are detrimental not only to the moderate-scale operation of agriculture and the adoption of agricultural machinery but also to the promotion of agricultural green production technology [41,42]. Simultaneously, the conversion of cultivated land results in the nonagricultural transfer of the agricultural labor force and the transformation of the agricultural planting structure [27,43], thus undermining food security. Based on these observations, we propose H1:

H1. *Agricultural factor misallocations negatively impact food security.*

3.2. Spatial Spillover Effects of Agricultural Factor Misallocations on Food Security

Agricultural production factors can influence the food security of surrounding areas through spatial agglomeration effect [44], the technology spillover effect [45], and the trickle-down effect [23]. Firstly, grain production exhibits distinctive regional characteristics. In certain nonmajor grain-producing regions, local governments allocate limited land resources to industrial manufacturing and service sectors to stimulate economic growth [46]. This not only occupies local agricultural cultivated land resources [34,40], and enable more capital to flow into nonagricultural industries, exacerbating the shortage of agricultural production funds [40]. This constrains the development of agricultural technology, diminishes agricultural production efficiency [47], and adversely affects food security. Simultaneously, the concentration of industry and service sectors in these areas absorbs the agricultural labor force from the surrounding regions [48,49], leading them to transition to nonagricultural industries. This, in turn, affects the food output in the surrounding areas, subsequently impacting food security.

Secondly, the efficient allocation of production factors has broadened the application of agricultural information technology [50,51]. The trickle-down and diffusion effects resulting from the comprehensive adoption of agricultural information technology facilitate the effective integration of cross-regional capital, labor, technology, and other factors [52,53], thus enhancing food security levels. The successful local implementation of advanced agricultural information technology facilitates its dissemination to surrounding areas through technology transfer and diffusion [54]. This process contributes to enhancing agricultural production efficiency. Simultaneously, the demonstration effect resulting from the local adoption of agricultural information technology to enhance production efficiency is appealing to surrounding areas [55]. This influence can guide farmers in the surrounding regions to adopt similar technologies, thereby enhancing productivity and improving food security. Based on these observations, H2 is proposed:

H2. *Agricultural factor misallocations exhibit spatial spillover effects on food security.*

3.3. The Mechanism Role of Transportation Infrastructure Construction and Rural Labor Outflow between Factor Misallocations and Food Security

Agricultural production factor misallocations result in a persistent bias toward capital investment [56]. This leads to the neglect of transportation infrastructure construction, hindering the optimization of the agricultural supply chain [57], and ultimately having a negative impact on food security. Specifically, the misallocation of agricultural capital results in the repeated purchase of agricultural machinery and equipment [23]. This, in turn, diverts investments from transportation infrastructure, including roads, bridges, and logistics centers, and raises the transportation cost of agricultural products and food loss [58]. This reduction in the supply efficiency and elasticity of agricultural products is detrimental to food security. Conversely, the establishment of comprehensive transportation infrastructure promotes the transportation efficiency and management of agricultural products [59]. This shortens the transit time of agricultural products in various links, improving transportation efficiency. Additionally, it enhances the quality and market competitiveness of agricultural products [60], augments farmers' income, and boosts their enthusiasm for grain cultivation [61], thereby exerting a positive impact on food security. Misallocations of agricultural production factors often lead to a relative increase in returns for nonagricultural industries. This will encourage the transfer of agricultural labor to nonagricultural industries, resulting in more elderly and female farmers planting land [62], which will reduce agricultural production efficiency and thus suppress food security However, some scholars argue that the migration of rural surplus labor force accelerates the circulation of market information, foster the rational allocation of agricultural production factors [63]. This migration enhances the level of human capital and stimulates agricultural technology innovation. Moreover, the outflow of rural labor accelerates the diversification of farmers' income structure [64], reducing their overdependence on agricultural production. This shift promotes the transformation from traditional agriculture to green and modern agriculture, thereby enhancing food security. Based on these observations, H3 is proposed:

H3. *Agricultural factor misallocations exert an effect on food security via transportation infrastructure construction and rural labor outflow.*

4. Model Setting, Variable Description, and Data Sources

4.1. Model Setting

The theoretical analysis indicates a spatial spillover effect of factor misallocations on food security. Referring to Chen et al. (2023) [54], this paper employs the Moran index I to analyze the spatial correlation.

$$\mathrm{I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{1}$$

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2 \tag{2}$$

Among these, I represents Moran's index. s^2 denotes the sample variance; x_i represents the factor misallocation coefficient or food security level of region i; and W_{ij} is the spatial weight matrix. The spatial geographical distance matrix is employed to examine the impact of factor misallocation on food security. Firstly, the p-values of Hausman tests are less than 0.1, indicating that the fixed effect is more suitable for analysis. The p-values of LM and LR tests for SDM are less than 0.1 compared with SEM and SAR models, suggesting that the SDM model is suitable for analysis. Lastly, the p-value of the Wald test is less than 0.1, confirming that the SDM model will not degenerate into SAR and SEM models. Simultaneously, the agricultural factors misallocation has significant spatial spillover effects on food security. Among spatial econometric models, only the SDM model contains spatial lag operators of both dependent variables and independent variables, which can test spatial spillover effects in neighboring regions using the partial differential method. Consequently, this paper employs the two-way fixed-effect spatial Durbin model to explore the effect of factor misallocation. The measurement model is constructed as follows:

$$\begin{aligned} GS_{it} = \beta_0 + \alpha_1 \sum_{i=1}^{n} W_{it} GS_{it} + \alpha_2 \tau_{Kit} + \alpha_3 \tau_{Lit} + \alpha_4 \tau_{Nit} + \alpha_5 \sum_{i=1}^{n} W_{it} \tau_{Kit} \\ + \alpha_6 \sum_{i=1}^{n} W_{it} \tau_{Lit} + \alpha_7 \sum_{i=1}^{n} W_{it} \tau_{Nit} + \alpha_8 \mathrm{X}_{it} + \alpha_9 W_{it} \mathrm{X}_{it} + \nu_i + c_t + \mu_{it} \end{aligned} \tag{3}$$

Among these variables, GS represents food security; τ_K, τ_L, and τ_N denote the factor misallocation coefficients of capital, labor, and land, respectively. X_{it} stands for the control variables; i and t represent province and time; α_n ($n = 1, 2...9$) signifies the impact coefficient; W is the spatial weight matrix; W is the spatial lag variable; ν_i represents the individual effect; c_t is the time effect; and μ_{it} is the random disturbance term.

4.2. Selection of Variables

4.2.1. The Explanatory Variable

Referring to Chen and Hu (2011) [65] and Ji et al. (2016) [66], this paper measures the labor factor misallocation index (τ_{Lit}), capital factor misallocation index (τ_{Kit}), and land factor misallocation index (τ_{Nit}), and use τ_{Lit}, τ_{Kit}, and τ_{Nit} to represent the factor misallocation.

$$Y_{it} = AL_{it}^{\beta_{Li}} K_{it}^{\lambda_{Ki}} N_{it}^{\theta_{Mi}}, \beta_{Li} + \lambda_{Ki} + \theta_{Ni} = 1 \tag{4}$$

Take the logarithm of both sides of the production function and incorporate individual and time effects into the regression model. The specific form is as follows:

$$lnY_{i,t} = lnA + \beta_{Li} lnL_{i,t} + \lambda_{Ki} lnK_{i,t} + \theta_{Ni} lnN_{i,t} + \delta_i + \eta_t + \xi_{i,t} \tag{5}$$

where the $lnY_{i,t}$ is gauged by the gross agricultural production of each province and is converted into real GDP with 2004 as the base period. β_{Li}, λ_{Ki}, and θ_{Ni} represent the output elasticities of labor, capital, and land, respectively. The labor input $L_{i,t}$ is determined by the number of employed people in primary industry of each province. The capital input $K_{i,t}$ is determined by the stock of agricultural fixed capital in each province, which is calculated by the perpetual inventory method, and the depreciation rate (9.6%) refers to Zhang et al. (2004) [67] and Zhang et al. (2022) [68]. The land input $N_{i,t}$ is measured by the sown area of grain crops in each province. To further assess the degree of factor misallocation, this paper refer to Bai and Liu (2018) [69], measures the labor misallocation index τ_{Li}, capital misallocation index τ_{Ki}, and land factor misallocation index τ_{Ni} as follows:

$$\gamma_{Li} = \frac{1}{1+\tau_{Li}},\ \gamma_{Ki} = \frac{1}{1+\tau_{Ki}},\ \gamma_{Ni} = \frac{1}{1+\tau_{Ni}} \tag{6}$$

where γ_{Li}, γ_{Ki}, and γ_{Ni} represent the absolute misallocation coefficients of factors, which can measure the relative markups of factors without distortion. The ratio of γ_{Li}, γ_{Ki}, and γ_{Ni} represent the deviation degree between the actual factor usage and the theoretical effective factor allocation, that is, the factor misallocation level of province i. Using labor as an example, the labor contribution of the relative distortion coefficient under competitive equilibrium is expressed as $\beta_L = \sum_{i=1}^{N} S_i\beta_{Li}$, $L_i = \frac{S_i\beta_{Li}}{\beta_L}L$, $\beta_L = \sum_{i=1}^{N} S_i\beta_{Li}$ represents the contribution of labor weighted by output; L_i/L represents the proportion of the labor of province i (L_i) in the national labor (L); $S_i\beta_{Li}/\beta_L$ represents the labor proportion owned by province i when labor is completely free and efficient allocation is realized. The labor relative distortion coefficient can be defined as gamma $\hat{\gamma}_{Li} = \frac{\gamma_{Li}}{\sum_{i=1}^{N}(S_i\beta_{Lj}/\beta_L)\tau_{Li}}$, so as capital relative distortion coefficient $\hat{\gamma}_{Ki}$ and land relative distortion coefficient $\hat{\gamma}_{Ni}$:

$$\hat{\gamma}_{Li} = \frac{L_i/L}{S_i\beta_{Li}/\beta_L},\ \hat{\gamma}_{Ki} = \frac{K_i/K}{S_i\lambda_{Ki}/\lambda_K},\ \hat{\gamma}_{Ni} = \frac{N_i/N}{S_i\theta_{Ni}/\theta_N} \tag{7}$$

where $S_i = p_i \times y_i$ represents the proportion of the output of province i in the whole economic output, among which p_i is the partial derivative of provincial output y_i to the whole economic output Y_i. If the ratio $\hat{\gamma}_{Li} < 1$, it indicates that the labor allocation in province i is insufficient; If the ratio $\hat{\gamma}_{Li} > 1$, it represents the overallocation of labor in province i. The smaller the absolute value of the index is; the higher the labor allocation efficiency is, and the larger the absolute value is, the more serious the degree of misallocation is. Similarly, the degree of capital misallocation between land misallocation can be calculated. Finally, considering the assignment of relative factor misallocation coefficients, we refer to Ji et al. (2017) [70], taking the absolute value of relative factor misallocation coefficients to obtain the final labor factor misallocation index (τ_{Li}), capital factor misallocation index (τ_{Ki}) and land factor misallocation index (τ_{Ni}).

$$\tau_{Li} = \left|\frac{1}{\hat{\gamma}_{Li}} - 1\right|,\ \tau_{Ki} = \left|\frac{1}{\hat{\gamma}_{Ki}} - 1\right|,\ \tau_{Ni} = \left|\frac{1}{\hat{\gamma}_{Ni}} - 1\right| \tag{8}$$

4.2.2. The Explained Variable

Drawing on the experience of Cui (2019) [71] and Lei (2022) [9], this paper constructs the evaluation index for China's food security, encompassing five dimensions: quantity security, quality security, economic security, environmental security, and circulation security (see Table 1). Firstly, quantity security aims to ensure food supply capacity by increasing the quantity of food. It serves as the foundation of food security and remains the primary goal of food production worldwide. Secondly, quality security refers to people's access to nutrient-rich, healthy, and safe food to meet their dietary needs and address concerns about food safety and nutrition. Thirdly, economic security focuses on individuals' economic capacity to access food. Additionally, various agricultural subsidies play a role in ensuring food production and supply, hence constituting part of the indicators of economic security. Fourthly, environmental security focuses on the sustainability of food production methods. Historically, food production has heavily relied on the excessive use of fertilizers and pesticides to boost grain yield per unit area. However, this approach has resulted in ecological damage and posed threats to overall food security. Fifthly, circulation security refers to the capacity to guarantee the safe and efficient movement of food between production and consumption sites, thereby ensuring the stability and reliability of food supply. The entropy method is applied to measure the weight of each index.

Table 1. Construction of food security evaluation index system.

Primary Index	Secondary Index	Index Calculation Method	Nature of Indicators
Quantity security	X1 Volatility of grain output	(total grain output for the year—5-year moving average of grain output)/total grain output for the year	+
	X2 Grain output per unit area	Total grain output/total sown area	+
	X3 Per capita grain output	Total grain output/total population at year-end	+
Quality security	X4 Pesticide use per unit of cultivated land area	Pesticide use per unit of cultivated land area	−
	X5 Amount of fertilizer applied per unit of cultivated land area	Amount of fertilizer applied per unit of cultivated land area	−
	X6 Amount of agricultural film applied per unit of cultivated land area	Amount of agricultural film applied per unit of cultivated land	−
Economic security	X7 Amount of financial support for agriculture	State financial expenditure on agriculture, forestry and water × grain sown area/total sown area	+
	X8 Food prices	Retail food commodity price index	+
	X9 Engel coefficient	Urban Engel coefficient × proportion of urban population + rural Engel coefficient × proportion of rural population	+
Environmental security	X10 Drainage area	Drainage area	+
	X11 Water-saving irrigated area	Effective irrigated area of cultivated land	+
	X12 Proportion of grain affected area	Proportion of grain affected area/total sown area	−
Circulation security	X13 Railway freight mileage	Railway freight mileage	+
	X14 Road density	Road density	+

Source: China Statistical Yearbook over the years. The +(−) sign indicates that the index is positively (negatively) correlated in the entropy weight method.

4.2.3. The Moderating Variables

Agricultural transportation infrastructure (Infra), represented by the total mileage of highways and railways, as indicated by Wang et al. (2023) [72] and Tong et al. (2013) [59]. For rural labor outflow (labor), this paper refers to Deng et al. (2018) [64]. It adopts 2004 as the base period and considers 2005–2019 as the reporting period for rural migrant workers. The ratio between the reporting period and the base period represents the scale of rural labor outflow.

4.2.4. The Control Variables

Drawing from the existing literature [73,74], this paper selects the following control variables: Agricultural mechanization level (mac): represented by the logarithm of the total power of agricultural machinery. Rural infrastructure construction (wat): represented by the logarithm of the number of rural reservoirs. The degree of openness (open): expressed by the ratio of import and export volume to regional GDP. Financial support to agriculture (finan): expressed by the ratio of agricultural fiscal expenditure to agricultural sector.

Industrialization level (ind): expressed by the ratio of the secondary and tertiary output value to the total output value. The descriptive statistics characteristics of variables are shown in Table 2.

Table 2. Descriptive statistical characteristics of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
Food security	465	0.281	0.139	0.084	0.748
τ_K	465	0.594	0.744	0.002	6.434
τ_L	465	3.691	2.618	1.088	13.499
τ_N	465	3.305	3.917	0.888	33.548
Infra	465	13.469	7.537	0.810	33.710
Labortr	465	0.699	0.561	0.015	2.412
Mac	465	7.585	1.085	4.542	9.499
Wat	465	7.124	1.762	1.386	9.553
Open	465	0.298	0.339	0.012	1.494
Ind	465	0.898	0.057	0.672	0.997
Finan	465	0.138	0.245	0.000	1.811

4.3. Source of Data

Considering the issuance of China's No. 1 central document in 2004, which clearly emphasizes the promotion of the grain industry, this paper selects the panel data from 2005 onwards for research. The data for X4 pesticide use per unit of cultivated land area and X5 fertilizer application per unit of cultivated land area in the food security index are updated only until 2021. Meanwhile, the data for the X1 grain production volatility index in 2020 and 2021 are missing due to the use of the exponential weighted moving average method. Although this paper employs data from 2005 to 2021 to measure food security, the final dataset only includes data up to 2019. Therefore, this paper ultimately uses panel data from 31 inland provinces spanning from 2005 to 2019 for research. Data on food security was sourced from the China Statistical Yearbook, China Grain Yearbook, China Environmental Statistical Yearbook, and China Grain and Material Reserves Yearbook. The data for capital misallocation, labor misallocation, and land misallocation were obtained from the China Statistical Yearbook, China Rural Yearbook, and China Fixed Asset Investment Statistical Yearbook. Data on Agricultural transportation infrastructure, rural labor outflow, and control variables were derived from the China Statistical Yearbook, National Rural Economic Statistics, China Rural Management Statistical Annual Report, and China Rural Policy and Reform Statistical Annual Report. Missing values were supplemented using the linear interpolation method.

5. Empirical Results and Analysis

5.1. Impact of Factor Misallocations on Food Security

This paper uses Stata 17.0 to compute the global Moran index of food security, and the results are presented in Table 3. It is observed that the global Moran index of food security is significantly positive at the 1% level between 2005 and 2019, signifying a substantial positive spatial correlation of food security. Therefore, this paper employs the two-way fixed-effect spatial Durbin model to analyze the impact of factor misallocations on food security (refer to Table 4).

It can be observed from column (1) of Table 4 that the direct impact coefficients of capital factor misallocation, labor factor misallocation, and land factor misallocation on food security are −4.293, −10.600, and −4.044, respectively, and are significant at the 5%, 1% and 1% significance levels, indicating factor misallocation have negative impacts on food security in the region, Hypothesis 1 is verified. This is because the lower misallocation of capital factors leads to higher efficiency in capital allocation, resulting in higher agricultural mechanization and infrastructure. This, in turn, fosters increased grain productivity and contributes to ensuring food security. Simultaneously, lower labor misallocation can facilitate the rational allocation of agricultural labor, encouraging high-quality labor transfer to the agricultural sector, which will accelerate the development of green agriculture, improve production efficiency, and comprehensively enhance food security. The lower the land misallocation, the higher the utilization rate and productivity of agricultural land, which contributes to reducing land resource wastage. Additionally, it facilitates the transformation of agricultural production methods towards scaling and intensification, thereby comprehensively improving food security factors. The impact of the spatial lag term of capital and labor misallocations on food security are negative, and significant at the 10% and 1% levels, respectively, indicating that capital and labor misallocation inhibit food security in surrounding areas. The lower capital misallocation in the local region can improve agricultural technology and promote industry upgrades, spreading technology progress to surrounding areas through technology demonstration and industrial linkage effects. This enhances the agricultural production efficiency of the surrounding areas and improves their food security. Hypothesis 2 is verified.

Table 3. Global Moran's I index of food security.

Year	Moran's I	*p* Value	Year	Moran's I	*p* Value
2005	0.232	0.001	2013	0.221	0.001
2006	0.241	0.001	2014	0.208	0.003
2007	0.219	0.002	2015	0.208	0.003
2008	0.216	0.002	2016	0.219	0.002
2009	0.228	0.002	2017	0.222	0.002
2010	0.212	0.003	2018	0.198	0.004
2011	0.219	0.002	2019	0.199	0.004
2012	0.219	0.002			

Table 4. Results of agricultural factor misallocations on food security.

Variables	Food Security (1)	Variables	Food Security (2)
τ_K	−4.293 **	$W \times \tau_K$	−12.172 *
	(2.116)		(6.998)
τ_L	−10.600 ***	$W \times \tau_L$	−17.167 ***
	(1.464)		(3.994)
τ_N	−4.044 ***	$W \times \tau_N$	−1.533
	(0.846)		(2.415)
mac	50.528 ***	rho	0.459 ***
	(6.902)		(0.071)
wat	19.461 ***	sigma2_e	0.287 ***
	(6.934)		(19.206)
open	−30.302 ***	N	465
	(11.548)	R^2	0.437
ind	−202.693 ***	Control Variables	YES
	(58.900)		
finan	−23.970 ***	Fixed Effect	YES
	(5.993)		

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1% in the two-tailed test, respectively.

The direct impact of the level of agricultural mechanization and the number of rural reservoirs on food security is significantly positive, indicating that the increase in the level of agricultural mechanization and the number of rural reservoirs is beneficial for improving regional food security (see Table 4). This is because as the level of agricultural mechanization increases and the number of rural reservoirs rises, the efficiency of grain production will also increase accordingly. The direct effects of opening-up, industrialization, and financial support to agriculture on food security are significantly negative, suggesting that opening-up, industrialization, and financial support to agriculture will inhibit regional food security. This is because the higher the level of opening to the outside world, the more the region is associated with the international food market, making it more vulnerable to fluctuations in the international food market, which is not conducive to the food security of the region. Additionally, a higher level of industrialization results in a greater proportion of the secondary and tertiary industries, occupying agricultural resources to some extent, and is not conducive to local grain production. Furthermore, a higher level of financial support for agriculture entails more government subsidies to maintain the price of agricultural products.

5.2. Analysis of the Moderating Effect of Heterogeneous Transportation Infrastructure Construction and Rural Labor Outflow

The collinearity test shows that the maximum VIF value is 3.04, which does not exceed the commonly accepted threshold of 10, this suggests the absence of multicollinearity in the model. Consequently, following the methodology proposed by Jiang (2022) [75], this paper employs the two-step mediating effect model to investigate the mediating effect of agricultural transportation infrastructure and rural labor outflow. Table 5 presents the results of agricultural factor misallocations. It can be seen that the direct influence coefficients of capital misallocation, labor misallocation, and land misallocation on transportation infrastructure construction and labor outflow are −0.651, −0.480, 0.236 and −50.292, −14.816, 15.733. The negative coefficients associated with capital misallocation and labor misallocation indicate that these factors hinder the construction of agricultural transportation infrastructure and rural labor outflow. On one hand, this hinders the market-oriented operation of agricultural production factors and the innovation of agricultural production technology, ultimately reducing the level of rural transport infrastructure construction. On the other hand, misallocations of capital and labor lead to low productivity in agricultural production, posing a dual challenge for rural areas: insufficient employment opportunities to attract professionals and limitations on the ability of the existing rural labor force to improve their skills and increase their incomes due to inefficient production methods. Consequently, this situation impedes the outflow of rural labor. The influences of land misallocation on transport infrastructure and labor outflow are positive, suggesting that land misallocation promotes the construction of transport infrastructure and rural labor outflow. This is because the misallocation of land elements has led to some agricultural land being used for road and bridge construction. Furthermore, land misallocation (such as highly fragmented land and insufficient agricultural land availability) makes it difficult to transition to scale agricultural and modernized agriculture, which will limit the production benefits and agricultural income. This is conducive to the transfer of farmers to nonagricultural industries and accelerates the rural labor outflow, Hypothesis 3 is verified.

Table 5. Moderating effect of heterogeneous transportation infrastructure construction and rural labor outflow.

Variables	Infra	Labortr
τ_K	−0.651 ***	−50.292 ***
	(0.176)	(8.746)
τ_L	−0.480 ***	−14.816 ***
	(0.108)	(5.337)
τ_N	0.236 ***	15.733 ***
	(0.055)	(2.701)
W × τ_K	−1.458 ***	97.832 ***
	(0.561)	(27.714)
W × τ_L	−0.545 **	−21.789 *
	(0.266)	(13.050)
W × τ_N	0.140	14.051 **
	(0.135)	(6.767)
rho	0.336 ***	0.520 ***
	(0.078)	(0.069)
sigma2_e	2.088 ***	507.569 ***
	(0.141)	(34.034)
N	465	465
R^2	0.116	0.220
Control Variables	YES	YES
Fixed Effect	YES	YES

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1% in the two-tailed test, respectively.

It is noteworthy that the spatial lag term of capital misallocation in rural labor outflow is positive, indicating that capital misallocation hinders local rural labor outflow but promotes rural labor outflow in neighboring areas (see Table 5). This occurs because when capital misallocation results in lagging economic development and insufficient employment opportunities in local rural areas, the rural labor force often encounters employment difficulties and low income. Consequently, the local rural labor market becomes relatively weak, with limited employment opportunities, leading individuals to prefer staying in the area to explore alternative livelihoods rather than migrating. Conversely, when capital misallocation fosters relatively robust economic development and abundant employment opportunities in surrounding areas, rural labor is drawn to these regions in search of better job prospects and living conditions. The active labor market in neighboring areas provides more employment options and higher income levels, making rural workers more inclined to migrate to these locations.

5.3. Robustness Tests

In order to verify the robustness of the empirical results, this paper conducts the following robustness test. First, in actual agricultural production, regions with larger grain production scales may also pay more attention to factor allocation efficiency, resulting in endogeneity problems. Referring to Zhang and Zhang (2022) [76], this paper chooses the total urban land supply as the instrumental variable of factor misallocation and uses the 2SLS method for regression (Column (1) of Table 6). Second, in order to avoid the errors caused by variable selection, referring to Cui (2019) [71] and Lei (2022) [77], this paper uses the coefficient of variation method to measure food security and uses it as a proxy variable to conduct a robustness test. Third, in order to avoid the impact of extreme data values on the research results, this paper refers to Lei (2023) [9] and winnows the misallocation coefficients of capital, labor, and land. Finally, in order to avoid the possibility of the SDM model degrading into SAR and SEM models in the LR test, this paper refers to Li (2023) [78] and uses the spatial autocorrelation model (SAR) and spatial error model (SEM) to conduct robustness tests. It can be seen that among the results of the five robustness tests, the significance and direction of the core explanatory variables are highly consistent with the benchmark regression results, indicating that the research conclusions have good robustness.

Table 6. Robustness tests of agricultural factor misallocations on food security.

Variable	Endogenous Check (1)	Food Security (2)	Factor Misallocation (3)	SAR (4)	SEM (5)
τ_K	−20.427 ***	−3.836 *	−4.528 *	−4.743 **	−4.327 *
	(6.933)	(2.004)	(2.429)	(2.405)	(2.225)
τ_L	−0.499 **	−8.478 ***	−11.352 ***	−7.652 ***	−6.383 ***
	(0.253)	(1.386)	(1.451)	(1.541)	(1.414)
τ_N	−6.411 **	−1.626 *	−1.981 *	−3.891 ***	−2.645 ***
	(2.731)	(0.955)	(1.150)	(0.910)	(0.970)
_cons	206.937				
	(133.973)				
rho		0.453 ***	0.463 ***	0.435 ***	
		(0.071)	(0.071)	(0.072)	
lambda					0.566 ***
					(0.068)
sigma2_e		254.670 ***	280.391 ***	0.362 ***	341.276 ***
		(17.299)	(19.069)	(24.188)	(23.504)
Control Variable	YES	YES	YES	YES	YES
W × Control Variable	YES	YES	YES	YES	YES
N	465	465	465	465	465
R^2	0.945	0.224	0.284	0.350	0.313
AndersonLM	169.916 ***				
C-D WaldF	422.685 ***				
Hansen	0.865				

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1% in the two-tailed test, respectively.

5.4. Reginal Heterogeneity Test

The impact of factor misallocation on food security will also be affected by the endowment of production resources and population density. Resource endowment (such as soil fertility, natural environment, and agricultural economic structure) provides specific planting methods and technologies for different regions, which leads to differences in food production efficiency and dependence on imported food among regions, thus affecting the effect of factor misallocation on food security. Furthermore, in areas with higher population density, agricultural production is faced with more intense competition for land, resource pressure, and internal consumption demand, which leads to reduced production efficiency, and increases the dependence on local food, making a greater threat to food security.

Therefore, this paper refers to Chen et al. (2023) [54] and Zhao (2022) [79], dividing the samples according to the grain functional zones and Hu line, and the results are shown in Table 7. The misallocation of capital, labor, and land has a significantly negative impact on food security in major producing areas, consistent with the previous regression results. However, the impact of agricultural production factors on food security in nonmajor producing areas is not significant. Moreover, in non-grain-producing areas, the economic structure is more diversified, and agriculture is not the primary industry. Firstly, although the inclination of capital towards off-farm industries may result in under-investment in local agriculture, regions with developed off-farm industries generally exhibit higher market allocation efficiency and infrastructure levels. Consequently, nonmajor food-producing areas can procure food products from other regions through market channels, compensating for the deficiency in local food production. This market mechanism effectively mitigates the impact of misallocation of agricultural production factors on food security. Secondly, labor forces in nongrain main-producing areas have greater employment opportunities and income sources. In the event of misallocation of agricultural production factors leading to decreased agricultural efficiency, the labor force in these regions is more likely to secure employment in other industries, thus alleviating the potential adverse effects of misallocation. The diversified economic structure of nonfood main-producing areas enhances their adaptability and resilience to risks compared with major producing areas, resulting in a relatively minor impact on food security.

Table 7. Regional heterogeneity test of agricultural factor misallocations on food security.

Variables	**Major Grain-Producing Areas (1)**	**Nonmajor Grain-Producing Areas (2)**	**Southeast of the Hu Line (3)**	**Northwest of the Hu Line (4)**
τ_K	−26.207 ***	2.087	−2.830 *	−44.017 **
	(7.181)	(1.628)	(1.621)	(18.429)
τ_L	−57.144 ***	1.833	−13.899 ***	−21.455 *
	(13.405)	(1.190)	(1.181)	(12.422)
τ_N	−1.730 **	−1.165 ***	−1.095 **	8.002
	(0.876)	(0.381)	(0.539)	(5.133)
W × τ_K	−25.981 ***	−52.788	−53.612 ***	−5.672
	(6.013)	(47.313)	(58.799)	(9.117)
W × τ_L	−25.080 ***	−6.935	16.967 ***	−36.939 ***
	(3.409)	(6.854)	(51.421)	(9.279)
W × τ_N	−8.394 ***	−21.697	64.751 **	−1.189
	(1.515)	(16.054)	(27.496)	(1.549)
rho	−0.508 ***	−0.145	0.426 ***	0.048
	(0.121)	(0.089)	(0.081)	(0.143)
sigma2_e	0.119 ***	0.876 ***	0.153 ***	0.237 ***
	(12.110)	(9.037)	(12.805)	(26.394)
Control Variable	YES	YES	YES	YES
W × Control Variable	YES	YES	YES	YES
N	195	270	300	165
R^2	0.340	0.283	0.284	0.160

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1% in the two-tailed test, respectively.

It can be observed from columns (3) and (4) of Table 7 that the misallocation of agricultural capital and labor resources on the southeast and northwest sides of the Hu line has a significantly negative impact on food security, with regression coefficients of −2.830, −13.899 and −44.017, −21.455, respectively. Additionally, the impact of land resource misallocation is only significantly negative on the southeast side of the Hu Line. Notably, the negative impact of capital misallocation and labor misallocation on the northwest side of the Hu Line is greater than that of the southeast side. Possible reasons for this phenomenon include: Firstly, in regions with higher population densities, there is usually greater access to skilled labor and knowledge resources, which can drive agricultural advancements. However, misallocation of labor, where skilled individuals are not adequately employed in the agricultural sector or are incentivized to migrate to other industries, can impede innovation and productivity growth in agriculture, thereby negatively affecting food security. Secondly, the southeastern regions tend to have better access to markets, infrastructure, and transportation networks compared with the northwestern regions, which is crucial for reducing postharvest losses and ensuring the timely delivery of agricultural products to consumers. Misallocation of capital in infrastructure investment may lead to inefficiencies, hindering market access and exacerbating food security challenges.

6. Discussion

Reasonable allocation of production factors is crucial to improve food security. The existing literature mainly focuses on the economic impact of a single factor. Huang and Du (2023) [80] believe that the price distortion effect caused by the misallocation of land hinders economic development. Meanwhile, Azariadis and Kaas (2016) [81] found that capital factor misallocation has a significant negative impact on total factor productivity. Few studies incorporate multiple elements into the research framework. Li et al. (2023) [78] incorporated capital, labor, and energy factors into the dynamic general equilibrium model and explored the misallocation of production factors on production efficiency. One of the contributions of this paper is incorporating capital, labor, and land factors into the analysis framework, taking into account the substitution effect between different factors, so as to more accurately reflect the effect of multiple factors in reality. This approach is similar to Hsieh and Klenow (2009) [18], Chen and Hu (2011) [65]. In addition, the existing literature only considers quantity safety and quality safety when calculating food security and uses principal component analysis to measure food security, which ignores the impact of the ecological environment, logistics networks, and other factors. Based on the five dimensions of quantity, quality, economy, ecology, and circulation security, this paper uses objective entropy to measure food security, which can avoid the problem of reducing the rating dimension under the principal component analysis method, so as to improve the existing research.

There are some limitations in the study. First, we currently use provincial-level data to analyze the impact of factor misallocation on food security, the nexus of factor misallocation and food security will be more accurate when city-level data are available in the future. Secondly, although we used the model of Hsieh and Klenow (2009) [18] to calculate factor misallocation and consider the substitution effect between different production factors, this model could not demonstrate the optimal factor allocation. Therefore, in future research, we will try to use the multifactor competitive equilibrium model to analyze the gap between the real factor misallocation level and the optimal allocation level.

7. Conclusions and Suggestions

As a pivotal element in enhancing grain output and quality, maintaining an optimal balance among production factors is crucial for ensuring food security. This study quantifies the factor misallocation and the food security coefficient across 31 provinces in China spanning the years 2005 to 2019 and uses the spatial Durbin model to analyze the impact of factor misallocation on food security. The results suggest that (1) factor misallocation (capital, labor, and land) significantly impairs food security, with regression coefficients of −4.293, −10.600, and −4.044, respectively. Specifically, capital misallocation and labor misallocation not only markedly undermine local food security but also affect the food security level of neighboring areas. (2) Mechanism tests reveal that capital misallocation and labor misallocation hamper the construction of transportation infrastructure and the outflow of rural labor. Conversely, land misallocation can facilitate the construction of agricultural transportation infrastructure and the outflow of rural labor, enhancing the smooth flow of factors and thereby improving food security. (3) The impact of factors misallocation on food security is based on differences in food functions and heterogeneity on both sides of the Hu line.

Firstly, the government can establish a smart agricultural information system to release market information promptly, enabling agricultural producers to adjust the allocation of production factors and reduce the degree of factor misallocation. Secondly, the government can augment investments in transportation infrastructure, including agricultural irrigation and rural roads, to enhance food production, circulation, and ecological security. The government can also enhance technical training for the rural labor force, enabling them to fully utilize agricultural machinery and adapt to the transition to the tertiary industry, thereby mitigating the shortage of professional labor and surplus labor force. Considering that the factors misallocation between the main grain-producing areas and the southeast side of the Hu Line significantly suppresses food security, the government can increase land transfer in these areas, improve the quality and skill level of rural labor, and improve factor utilization efficiency through large-scale and intensive management.

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