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Study on the Spatial Effects of Grain Change on Food Security of Feed from the Perspective of Big Food

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Abstract: Using panel data from 30 provinces in China from 2005 to 2020, this paper uses a spatial double difference model to evaluate the policy impact of the "grain-to-feed" policy on feed grain production in pilot areas and adjacent spatial areas. Research has found that the "grain-to-feed" policy has a significant impact on the feed grain production in pilot areas and can significantly increase the feed grain production in pilot areas by about 2.71 million tons. The "grain-to-feed" policy has strengthened the positive connection between pilot areas and adjacent pilot areas, increased feed grain production, and has a significant spatial spillover effect. Robustness analysis shows that whether using different methods to measure spatial adjacency or using different standards to distribute subsidies, the "grain-to-feed" policy can significantly increase feed grain production, narrow the supply and demand gap of feed grain, and ensure feed grain security. Further analysis shows that the "grain-to-feed" policy can not only ensure the security of feed grain for the current and next periods but also promote the increase in farmers' income, which is long-term and sustainable. Compared with non-pilot areas, the "grain-to-feed" policy can mitigate the negative impact of wage–price signals on feed grain production in pilot areas. It is recommended that government departments accelerate the transformation of food security concepts, establish a "Big Food Perspective", gradually promote the pilot of the "grain-to-feed" policy nationwide, increase the subsidy amount of the "grain-to-feed" policy, increase financial support for scientific and technological research and achievement transformation in the field of feed grain, prevent the impact of economic price signal fluctuations on feed grain production, and effectively ensure the security of feed grain in China.

Keywords: big food perspective; "grain-to-feed" policy; the security of feed grain; spatial difference to difference; spatial effect decomposition

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1. Introduction

Food security is a "national priority" [1]. The continuous improvement and diversity of grain production are not only an important measure to ensure China's food security but also an important means to ensure global food security [2]. According to the latest data from the World Bank, China will produce more than 632 million tons of grain in 2021, maintaining first place in the global grain production ranking for ten consecutive years. According to the data of China Statistical Yearbook 2023, China's per capita grain consumption in 2021 exceeded 480 kg, far higher than the Food and Agriculture Organization of the United Nations proposed "400 kg per capita grain consumption" food security warning line. Although China's grain output has been increasing year annually, the supply and demand of feed grain have been in a tight balance for a long time, so it is urgent to ensure the security of feed grain [3].

Effective protection of the security of feed grain plays a key role in achieving high-quality economic and social development, especially in stabilizing prices and ensuring people's livelihoods [4]. The 2022 China and Global Food Policy Report found that the eating habits of Chinese residents are quietly changing, and the trend of balanced and diversified food structure is obvious. The main performance is that the demand for rations continues to decline, and the demand for feed grain is increasing [3]. Therefore, it is urgent to improve the supply of feed grain and ensure its security.

However, China's domestic feed grain supply growth is slow, with long-term dependence on imports to maintain feed grain security [5]. According to the data of the "China Feed Industry Yearbook 2020", the average annual growth rate of China's domestic feed grain output from 2014 to 2019 was 2.96%, and it is noteworthy that the growth rate of domestic feed grain output in 2019 changed from positive to negative growth for the first time. At the same time, statistics from the General Administration of Customs of China show that the import amount of soybeans and corn, China's main feed grain, continued to increase in 2023, with 99.41 million tons of soybeans and 27.13 million tons of corn imported, accounting for 78% of the total grain imports. Therefore, China's food security problems mainly appear in domestic feed grain production, among which soybeans and corn are the key [6]. Therefore, this paper mainly focuses on the study of feed grain yield changes in various provinces in China. First, the feed grain trade among various provinces is easily subject to the macro-control of the central government. Second, the international trade in feed grain is vulnerable to the impact of the international environment, especially the impact of major emergencies such as the COVID-19 pandemic and the Russia–Ukraine war.

The study of food security from the perspective of feed grain yield coincides with the concept of the "Big Food Perspective". "Big Food Perspective" is one of the important concepts that ensure food security in the world [7]. The "Big Food Perspective" refers to the formation of a wide range, variety, and nutritious food concepts [8]. In terms of food security, the "Big Food Perspective" refers to ensuring the quantity security, structural security, and nutritional security of food, of which the security of grain planting structure is particularly important [9]. Combined with the current situation of China's high grain output and low feed grain output, the "Big Food Perspective" requires optimizing China's grain planting structure, increasing the output of feed grain, and ensuring the security of feed grain. It is the establishment of the "Big Food Perspective" that has changed the traditional food security concept of the Chinese government "taking rations as the key link" and prompted the Chinese government to pay more attention to ensuring the security of feed grain [10]. Therefore, there is a very close relationship between the "Big Food Perspective" and the research content of this paper. The establishment of the "Big Food Perspective" promoted the in-depth implementation of the "grain-to-feed" policy and improved the output of feed grain, which provided a new perspective and practical support for this paper to study the impact of "grain-to-feed" policy on the output of feed grain.

Under the guidance of the "Big Food Perspective," the Chinese government has issued a series of policies to ensure the security of feed grain, and the "grain-to-feed" policy is one of them. Since 2017, China's ration output has increased annually. Although ration security has been effectively guaranteed, problems such as contradictions in grain planting structure have become increasingly prominent, especially in the planting area, and the yield of corn and soybeans urgently needs to be optimized and adjusted. To this end, under the guidance of the "Big Food Perspective," the Ministry of Agriculture and Rural Affairs of China fully implemented the "grain-to-feed" policy in 17 provinces in 2017. Its policy aim is to optimize the grain planting structure, increase the output of feed grain, and ensure the security of feed grain. In terms of policy content, taking silaged corn as an example, the policy of "grain-to-feed" requires subsidies according to the actual storage capacity of silaged corn, and the subsidy for each ton of silaged corn is about CNY 60. So the implementation of the "grain-to-feed" policy has not only greatly increased the planting area and output of feed grain but also effectively promoted an increase in farmers' income.

However, in the process of implementing the "grain-to-feed" policy, many thorny problems have also been encountered, which is not conducive to the realization of the policy purpose. First, the "grain-to-feed" policy has high requirements for agricultural machinery and equipment, and corn as a feed grain must be harvested with large special machinery and equipment, which increases the planting cost of farmers. Second, the "grain change to feed" policy has higher requirements for agricultural technology, and the production of feed grain corn must rely on scientific production technology, such as the fermentation technology of silage corn, which ordinary farmers find difficult to master. Therefore, whether the "grain-to-feed" policy can achieve the expected policy objectives still needs scientific empirical testing. Furthermore, China's neighboring provinces are closely connected in space, and the impact of the "grain-to-feed" policy on the spatial adjacent areas is also worthy of further exploration. Therefore, can the "grain-to-feed" policy have a significant impact on the output of feed grain in the pilot areas? How big is the policy impact? Can the "grain-to-feed" policy have a significant impact on the output of feed grain in adjacent areas? Do the policy effects differ significantly depending on the types of neighboring areas? Next, this study launches a more detailed and in-depth exploration of the above issues.

Compared with previous studies, this study may provide some marginal contributions in the following aspects. First, it fills the gap in existing research to some extent. Few of the previous studies directly discussed the implementation effect of the "grain-to-feed" policy; in particular, there is a certain research gap in the empirical analysis of the implementation effect of the "grain-to-feed" policy. The research in this paper has filled the gap of empirical analysis of the effect of the "grain-to-feed" policy on feed grain output to a certain extent, which is of great significance. Second, it expands a new research perspective. From the "Big Food Perspective", this paper reveals the direct and indirect effects of the "grain-to-feed" policy on the local and neighboring areas, which provides a new research perspective for the existing research. Third, it enriches the research content. This study not only established a comprehensive theoretical analysis framework of the "grain-to-feed" policy but also used the spatial differential method to accurately estimate the size of the effect of the "grain-to-feed" policy on the feed grain output in local and neighboring areas and even decomposed the spatial effect to accurately capture the difference of the spatial effect. Fourth, it provides new empirical evidence. Compared with the country panel data used in previous studies, this study uses the provincial panel data of the latest year as the research object, which is not only updated in time but also has a finer granularity.

2. Literature Review

2.1. International Cutting-Edge Research

Food security is a top priority for all countries in the world. The existing international research on food security mainly focuses on four aspects: food loss reduction, agricultural big data construction, climate change response, and legal protection.

2.1.1. Food Loss Reduction

Food loss reduction is one of the important ways to ensure food security. Promoting food loss reduction and ensuring food security has reached a consensus around the world. Food loss reduction mainly includes two aspects: one is to reduce food waste, and the other is to reduce the loss of food production and post-production. Among them, food waste mainly occurs in developed countries and primarily occurs in the household consumption link. In Germany, 12 million tons of food go to waste every year, more than half of which is wasted by households [11]. The UK wastes enough food each year to fill 3600 Olympic-size swimming pools, 70% of which is wasted by households [12].

In order to reduce food waste in household consumption link, developed countries have introduced a series of targeted policy measures according to their national conditions. First, they will strengthen legal and institutional safeguards. Italy introduced the Anti-Food Waste Law in 2016, introducing the concept of reducing food waste into national legislation for the first time [13]. Japan, on the other hand, introduced the Food Reuse Law, which supports the recycling of wasted food into feed and fertilizer. Second, they will strengthen basic research and promote technological innovation. Through its self-developed automatic food sorting system, the United States can accurately distinguish low-quality food from high-quality food in the food recycling process and reduce food waste [14]. Third, they will provide financial support. The New Zealand government provides a large amount of money every year to turn wasted food into other products, such as making beer from uneaten bread [15]. Fourth, they will promote the circulation of surplus food. Japan has launched "food bank" activities to provide surplus and unused food at the consumption link to people in need [16]. The fifth is to carry out publicity and education to raise awareness of food saving. South Korea has launched a nationwide campaign to reduce food waste [17].

Different from food waste in household consumption linked in developed countries such as Europe and the United States, food loss in developing countries such as Asia, Africa, and Latin America is concentrated in production and post-production. About half of Fiji's food losses come from production [18]. In Brazil, on average, 14 percent of food is lost each year before it reaches the market [19]. To address food loss in the production and post-production sectors, different developing countries have adopted measures suitable for their national conditions in light of local conditions. First, they will promote infrastructure development. The Senegalese government is investing USD 400 million in food storage and logistics infrastructure [20]. Second, they will strengthen scientific and technological support. Vietnam is vigorously supporting high-tech agriculture, speeding up agricultural mechanization and processing of agricultural products [21]. Third, they will increase policy support. Brazil has implemented a number of public food security policies, from food production to consumption, which are critical to reducing food losses [22]. The fourth is to raise our awareness of the economy. Turkey has implemented a food loss awareness program, which has resulted in a 20% increase in producers' awareness of conservation and a 40% reduction in food losses during production and post-production [23].

2.1.2. Agricultural Big Data Construction

At present, scientific and technological innovation has become a new driving force to promote the development of the food industry. New production factors represented by big data have produced good results in international practice, effectively ensuring food security. From simple sensor information collection to large-scale crop identification and disaster warning, the innovative application of big data in the field of food security is increasingly large. Remote sensing early warning technology implemented in Cambodia, Vietnam, Thailand, and Indonesia has not only effectively increased the area and willingness of farmers to grow food but also increased the annual income of each farmer by an average of 255 euros [24]. India and Germany have used big data platforms to provide farmers with food farming decisions, significantly improving food production efficiency. An agricultural big data insurance policy implemented in Kenya shows that the application of big data technology can significantly reduce the losses caused by uncertainty in food production, resulting in a 20% increase in farmers' willingness to grow food and a 16% increase in income [25].

2.1.3. Addressing Climate Change

The food sector is globally recognized as the most sensitive to climate change, and it has reached a broad consensus around the world to strengthen response to the impact of climate change in the food sector. Since the Food and Agriculture Organization of the United Nations formally put forward the concept of climate-smart agriculture in 2010, foreign scholars have extensively discussed the theory and practice of climate-smart agriculture. As a leader in climate-smart agriculture, the United States is modernizing its digital irrigation infrastructure to cope with drought and ensure food security by developing new varieties of corn and soybeans that are more resistant to heat [26]. Canada has effectively responded to the impact of global climate change by using straw returning, fallow, crop rotation, and the establishment of green buffer zones in farmland [27]. France uses remote sensing and network monitoring technology to strengthen the intelligent management of food production by accurately monitoring climate change [28]. By spraying self-developed plant growth promoters such as carrageenan on rice, the Philippines has effectively improved the typhoon resistance of rice, increasing the average yield per mu by about 20% and effectively ensuring food security [29]. Australia is strengthening its resilience to climate change by developing a climate change-based drought index and infrared heat signal system to monitor the growth of food crops [30].

2.1.4. Legal Protection

Legal protection is an important means for countries to ensure food security. Through the implementation of the new Agricultural Promotion Act, the United States has strengthened policy incentives in the field of food production and circulation, reduced the institutional cost of high-quality food supply, improved the global competitiveness of food production, and ensured food security [31]. Through the Common Agricultural Policy (CAP), the EU has unified the management of agriculture in its member states and ensured food security by directly subsidizing food production, enhancing the resilience of the food system, and emphasizing biodiversity [32]. In order to strengthen the legal guarantee of its food security, Japan has formed a legal guarantee system for food security based on the Basic Law on Food, Agriculture, and Rural Areas and supplemented by special legislation [33]. Among them, the Basic Law on Food, Agriculture, and Rural Areas provides overall planning and comprehensive guarantee for legal guarantee of Japan's national food security, and special legislation such as the Law on Stabilizing the Supply, Demand, and Price of Major Grains provides provisions and coordination on specific areas and specific issues. The establishment of this legal guarantee system not only realizes the absolute security of domestic rice supply but also helps to make full use of foreign resources and effectively protect domestic food security.

2.2. Comparison of Domestic and Foreign Studies

In addition to the above four aspects of research, China and foreign scholars also pay more attention to the study of grain structure transformation. Foreign studies on the transformation of grain structure mainly focus on the structural security of grain quantity, variety, and region. Among them, Fukase and Martin et al. (2020) believe that with the improvement of per capita consumption level, the structural problem of the difference between food consumption demand and food production and supply quantity in Mexico becomes prominent [34]. Kimura et al. (2008) found obvious variety differences in Japan's grain structure, in which rice is the least dependent on imports, and crops such as soybean and corn are underproduced and vulnerable to changes in the international price mechanism [35]. Saleh (2012) found that in recent years, the grain structure of Egypt has obvious regional differences, and the difference in grain production between the eastern and western regions is gradually expanding [36].

The research on grain structure transformation in China started late, and there are not many studies and discussions on grain structure transformation in the existing literature, which mainly focus on the discussion of ideas and plans for grain structure transformation [37]. Brandt et al. (2008) believe that the key point of China's grain structure transformation is to adjust the proportion of grain crop planting structure, especially to increase the area and yield of feed crops such as corn silage, alfalfa, and oats. Few studies have discussed the impact of policies related to the grain structure transformation, especially the impact of the "grain-to-feed" policy on feed food security from the perspective of empirical analysis. This gives this paper the opportunity to fill the existing research gap to some extent.

In summary, the existing research has the following shortcomings. First, the existing studies lack sufficient attention to the security of feed grain. The existing research mainly focuses on ensuring ration security, and there are few discussions on ensuring the security of feed grain. Second, the discussion on ensuring the security of feed grain has not gone far enough. Although some countries have begun to pay attention to the impact of feed grain on the transformation of grain structure, the existing studies are more focused on qualitative analysis and lack scientific quantitative research. Third, the existing studies have ignored the spatial impact of policies to ensure the security of feed grain. The existing studies mainly focus on the impact of feed policy on the local area, ignoring the potential impact of feed policy on neighboring areas. The above deficiencies urgently need to be supplemented and improved by relevant research.

3. Theoretical Analysis

3.1. Research Hypothesis

The "grain-to-feed" policy aims to increase the production of feed grain by enhancing farmers' production enthusiasm and leveraging economies of scale. On the one hand, this policy can reduce farmers' planting costs, increase their income, boost their enthusiasm for growing feed grain, and expand the planting area and supply of feed grain [38]. On the other hand, the policy facilitates the integrated development of planting and breeding industries, optimizes the agricultural industry structure, and creates economies of scale, which both reduces the cost of feed grain and increases its demand [39].

In terms of boosting farmers' production enthusiasm, compared to ration grain, feed grain has a higher yield per acre and simpler production processes, which can significantly reduce farmers' planting costs and increase their income, thereby enhancing their production enthusiasm. For instance, the average yield per acre of silage corn is 2.9 tons, with an average purchase price of CNY 365 per ton, leading to an income of CNY 1058.5 per acre. In contrast, the average yield per acre of grain corn is 538 kg, with an average purchase price of CNY 1320 per ton, resulting in an income of CNY 710.2 per acre. Thus, compared to traditional ration crops, planting feed grain provides a higher yield per acre and increases income by CNY 348.3 per acre, greatly enhancing farmers' production enthusiasm. Additionally, silage corn eliminates the need for harvesting, threshing, and drying, reducing the opportunity cost for farmers, increasing their chances and income from non-farming work, and further boosting their enthusiasm for planting feed grain. The increased enthusiasm for production helps to expand the planting area of feed grain and increase its production.

Regarding the economies of scale in agriculture, the "grain-to-feed" policy promotes the deep integration of planting and breeding industries, achieving integrated production, expanding agricultural production scale, and leveraging economies of scale. According to the theory of industrial integration, the integration of upstream and downstream industries in the same industrial chain can not only reduce the production costs of each individual industry through economies of scale but also effectively improve the quality and demand for each industry's products through supply–demand alignment. The realization of agricultural economies of scale reduces the cost of feed grain, increases its demand, and indirectly boosts its production. Based on this, the theoretical hypothesis of this paper is as follows:

H1. *The implementation of the "grain-to-feed" policy can effectively increase the production of feed grain in pilot areas.*

China is vast, with significant differences in natural resource endowments and economic development levels across regions. This results in the "grain-to-feed" policy having varying spatial effects in different areas, exhibiting clear spatial heterogeneity.

Regarding natural resource endowments, there are considerable differences in arable land quality, topography, and climate conditions across China's regions, leading to distinct spatial heterogeneity in the policy's implementation. For instance, the climate in the Northwest region of China is arid, the terrain is at a higher altitude, and the quality of arable land is lower, limiting the capacity for ration grain production and making it more suitable for feed grain crops. Consequently, the spatial driving effect of the "grain-to-feed" policy may be relatively better in these areas.

Regarding economic development levels, there are significant disparities in industrial development levels and farmers' income levels across China, leading to distinct spatial heterogeneity in the policy's implementation. For example, in the southeastern coastal areas of China, the level of non-agricultural industry development is higher, farmers' non-agricultural income levels are higher, and their willingness to engage in agricultural production is lower. Therefore, the spatial driving effect of the "grain-to-feed" policy is poorer in these areas.

In summary, the significant differences in arable land quality, topography, climate conditions, economic development levels, and farmers' income levels across China's regions result in distinct spatial driving effects of the "grain-to-feed" policy, leading to spatial heterogeneity. Based on this, the theoretical hypothesis of this paper is as follows:

H2. *There is significant spatial heterogeneity in the implementation of the "grain-to-feed" policy.*

3.2. Impact Pathways

The production of feed grain is inseparable from the input and allocation of production factors such as agricultural inputs, land, labor, and technology. The in-depth implementation of the "grain to feed" policy will greatly increase the input of various production factors, drive the sustained growth of feed grain output, and ensure the safety of feed grain. Figure 1 depicts the influence path of the "grain to feed" policy to improve the output of feed grain.

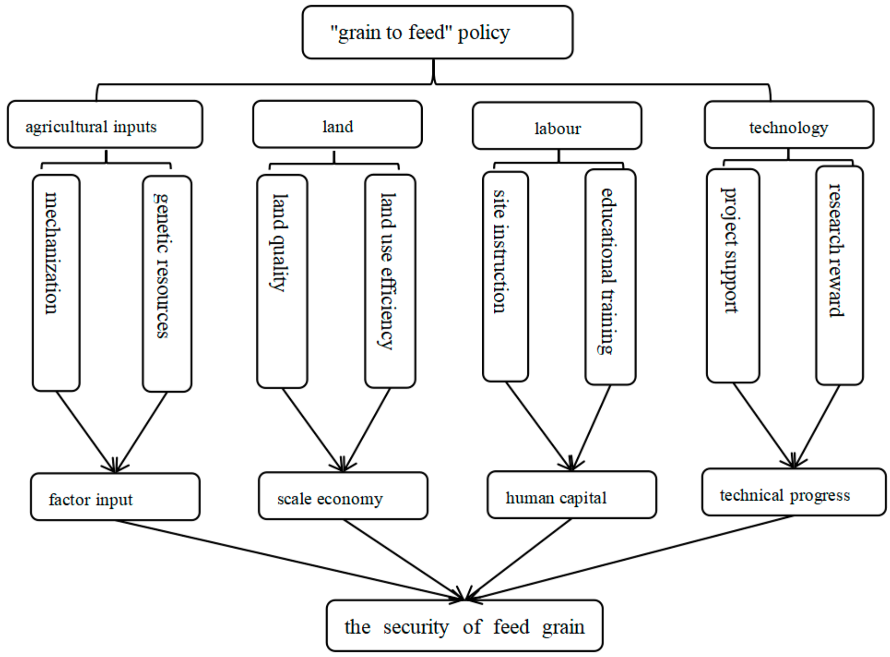

Figure 1. The impact pathways of the "grain-to-feed" policy to improve the output of feed grain.

The implementation of the "grain-to-feed" policy has driven more agricultural inputs into the production of feed grain. This policy not only enhances the mechanization level of feed crop cultivation but also optimizes the genetic resources of feed grain. Feed crops require a high level of mechanization, and the "grain-to-feed" policy provides special subsidies for the purchase of agricultural machinery for feed crops. Additionally, it actively explores the introduction of financial leasing and financing leasing to support pilot areas in improving the modern equipment capabilities for feed grain production, thereby increasing the mechanization level of feed crop cultivation and boosting feed grain production.

At the same time, the "grain-to-feed" policy promotes the cultivation of special varieties such as silage corn and high-yield, high-quality feed grain varieties, further increasing feed grain production.

The implementation of the "grain-to-feed" policy has not only improved land quality but also enhanced the utilization efficiency of land resources. Feed grain, such as alfalfa, helps with soil nitrogen fixation. Planting feed grain can improve the land quality of medium- and low-yield fields, increasing soil organic matter content by about 20%. This improvement in land quality is also beneficial for the subsequent increase in feed grain production. Compared to ration grain, feed grain requires fewer production processes and has shorter production cycles. This allows for more inter-cropping with other crops, thereby improving land utilization efficiency and increasing feed grain production.

The implementation of the "grain-to-feed" policy helps improve farmers' grain cultivation techniques and increases their human capital. On the one hand, the policy supports agricultural technicians in visiting villages and providing on-site guidance on corn silage techniques. On the other hand, it encourages agricultural training institutions to offer free feed crop cultivation training to farmers. This enhances farmers' technical skills in growing feed crops, increases their human capital, and ultimately boosts feed grain production.

The "grain-to-feed" policy has promoted the investment of more technological elements. To address the technical shortcomings in feed crop cultivation, the policy provides special financial support for research on technologies such as biological fermentation feed preparation, grass–livestock energy (fertilizer) cycling, and grass–livestock efficient coupling. This support has effectively increased feed grain production.

4. Methodology

4.1. Data Sources and Selection of Variables

This study uses spatial panel data for 30 provinces in China (excluding Tibet and Taiwan) from 2005 to 2020 for the empirical analysis. The data were obtained from the China Feed Industry Statistical Yearbook and the China Statistical Yearbook.

4.1.1. Dependent Variable

This paper uses the total annual feed grain production of each province during the sample period as a proxy variable for feed grain security. Currently, the China Statistical Yearbook does not have a dedicated metric for feed grain production. The existing literature estimates feed grain production using three main methods: the variety input method, the gross reduction method, and the direct coefficient method. Each method calculates feed grain production from different perspectives, offering unique insights.

Given the aim of this paper to estimate feed grain production across various provinces in China, and considering the availability of data and the actual feed production process, the variety input method is employed. Feed grain involves numerous varieties, with soybeans, corn, tubers, and bran accounting for the majority. Thus, it is practical to use the production of soybeans, corn, tubers, wheat, and rice, which are applicable for feed grain production, to represent the output level of feed grain. The calculation of feed grain production is as follows:

$$Y_{it} = \mathrm{a} \times S_{it} + \mathrm{b} \times C_{it} + \mathrm{c} \times T_{it} + d \times W_{it} + e \times R_{it} \quad (1)$$

In Equation (1), Y_{it} represents the feed grain production of province i in year t. S_{it}, C_{it} T_{it}, W_{it}, and R_{it} denote the production of soybeans, corn, tubers, wheat, and rice, respectively, for province i in year t. a represents the conversion rate for corn into feed production, set at 70%. b is based on the soybean meal rate of 79% from the Chinese Ministry of Agriculture database. c is determined to be 40% for tubers based on studies [40]. d and e are set at 23% and 10%, respectively, following research findings by Yao et al. (2022) for wheat and rice bran rates [41]. Therefore, the total feed grain production data in this paper includes feed production, with higher total feed grain production indicating sufficient feed grain supply and greater feed grain security.

4.1.2. Policy Variables

In 2015, Document No. 1 of the Central Committee proposed a "grain-to-fodder" policy. Subsequently, Document No. 1 of the Central Committee in 2017 proposed that the "grain-to-fodder" policy should be further promoted and that the "grain-to-feed" policy should continue to be subsidized on a pilot basis. At this time, the pilot counties of the "grain-to-feed" policy were expanded from the original 30 counties to 431 counties. They were mainly concentrated in Hebei, Liaoning, Jilin, Heilongjiang, Guangxi, Yunnan, Anhui, Shandong, Henan, and other large corn production and feed processing provinces [42]. Up to this point, the "grain-to-feed" policy has realized its policy effectiveness. Therefore, this study selects the above provinces as the policy treatment group and 2017 and later as the policy treatment period and constructs the "grain-to-feed" policy treatment variables.

4.1.3. Control Variables

To accurately assess the policy effect of the "grain-to-feed" policy on the security of feed grain, this study controlled the influence of relevant factors from the three levels of residents' consumption, industrial structure, and regional development, respectively. This study chose the ratio of per capita consumption expenditure of urban and rural residents to control for the impact of residents' consumption levels. The larger the ratio of per capita consumption expenditure of urban and rural residents, the more prominent the phenomenon of urban–rural consumption inequality; the higher the consumption level of urban areas, the greater the demand for meat, eggs, milk, and other products, resulting in an increase in the production of grain for fodder. The proportion of the total agricultural output value to the total regional agricultural, forestry, animal husbandry, and fishery output value is used as a proxy variable for industrial structure [43]. A larger ratio indicated more food-based agricultural production and less food production for feed. In contrast, the larger the sown area of crops, the greater the production of food for feed while guaranteeing the absolute security of regional food rations. The main factors affecting grain production for feed at the regional development level include the level of fiscal revenue, urbanization, population growth rate, and proportion of talented people [44]. The regional public budget revenue was selected to control the effect of economic development on grain feed production. Higher fiscal revenues indicate a more developed economy, higher demand for high-quality protein food, and more production of feed grain. Similarly, the higher the level of urbanization, the greater the production of food for feed. The higher the population growth rate, the higher the demand for food and the greater the production of food. The demand for meat, eggs, and milk shows a tendency to increase and then decrease as the level of education and learning increases. The reason for this is that the increase in education level firstly brings about a significant increase in income, which will increase people's consumption and demand for meat, eggs, and milk. However, excessive intake of meat, eggs, and milk will lead to obesity and over-nutrition; out of the consideration of health and nutritional balance, the demand for meat, eggs, and milk from highly educated and high-income people gradually decreases. Therefore, with the more highly educated people above the tertiary level in a region, the impact on the production of feed grain is uncertain and needs to be determined on a case-by-case basis.

4.1.4. Spatial Weighting Matrix

Usually, the closer the spatial distance, the closer the spatial connection between the provinces, the more distant the spatial distance between provinces. This spatial connection can be either a spatial spillover effect through imitation and learning, exchange and communication, technology diffusion, or a spatial siphoning effect through coordination and matching, industrial support, or other mechanisms. To accurately capture the spatial effect of the "grain-to-feed" policy on feed grain security, this study constructs an inverse geographic distance weight matrix for the spatial distance between different provinces. $W_{ij}^{1} = 1/d_{ij}$ is the matrix used as the basis for analyzing the spatial relationship between similar provinces.

Additionally, spatial spillover effects are more likely to occur between spatially neighboring provinces. To avoid Hainan Province becoming an "isolated island", this study artificially sets Hainan Province with Guangxi and Guangdong Province according to the de facto neighboring relationship. Similarly, both collaboration and competition exist between provinces with similar distances and development levels; therefore, their spatial relationships are relatively close. Therefore, this study additionally constructs a spatial neighbor weight matrix and an economic–geographical distance weight matrix to ensure the robustness of the analysis results.

In terms of data processing, we avoided the effects of inflation and price increases. Using 2000 as the base period, the gross domestic product (GDP) and price index were used to deflate various types of gross product and income consumption data, respectively. To minimize the effect of magnitude and excessive variance, data from various areas were logarithmized to reflect the effect of changes in elasticity. Descriptive statistics for all variables are shown in Table 1.

Table 1. Descriptive statistics of all variables.

Variable	Mean	Standard Deviation	Minimum	Median	Maximum	Sample Size
Output of feed grain	447.5	453.5	4.970	290.8	3209	480
"Grain-to-feed" policy	0.100	0.310	0	0	1	480
The ratio of per capita consumption Expenditure	2.380	0.430	1.510	2.320	3.920	480
The ratio of the agricultural output value	0.510	0.090	0.320	0.500	0.790	480
The sown area of crops	8.170	1.120	4.490	8.500	9.610	480
The level of fiscal revenue	19.40	19.48	0.340	14.35	121.8	480
Urbanization	0.550	0.140	0.270	0.530	0.900	480
Population growth rate	4.980	2.820	−4.480	5.010	11.78	480
The proportion of talented people	0.110	0.070	0.030	0.100	0.500	480

Source: China Statistical Yearbook, Statistical Yearbook by Province.

The results of descriptive statistics show that, overall, the mean and median of all variables do not differ significantly, indicating that the sample is more evenly distributed and that the possibility of bias in the estimation results caused by extreme values and outliers is low. Locally, the difference between the maximum and minimum values is relatively large, indicating that spatial heterogeneity is more evident, and there is the possibility of high-value–high-value clustering and low-value–low-value clustering, which requires spatial correlation tests.

4.2. Spatial Correlation Test Methods

A spatial correlation test of feed grain production in each province was conducted before the spatial analysis. To enhance the reliability of the test results, this study used the global Moran [45] and the Geary index [46] to test whether there is a spatial correlation in feed grain production in each province. The global Moran index is between −1 and 1, reflecting the overall spatial correlation of feed grain production. The closer the absolute value of the global Moran index is to 1, the stronger the spatial correlation, and the closer it is to 0, the weaker the spatial correlation. The Gillet index ranges from −2 to 2, with a value greater than 1 indicating negative spatial correlation, a value equal to 1 indicating spatial irrelevance, and a value less than 1 indicating positive spatial correlation.

Table 2 shows the Moran and Geary indices for the production of feed grain in each province under the three different spatial weighting matrices. The results show that (1) no matter which spatial weight matrix is used, the Moran index is all greater than 0, and the Gilley index is less than 1, indicating that there is a significant positive correlation between the production of feed grain. That is, the closer the spatial relationship between the provinces, the more obvious the spatial spillover effect of the production of feed grain, the existence of high-value–high-value agglomeration, and the low-value–low-value agglomeration. (2) The test statistics under the three spatial weight matrices are all significant, indicating that the geographic location relationship is an important factor influencing the spatial diffusion effect of feed grain production. With the implementation of regional integration strategies, the relationship between economic and social development in geographically proximate provinces is becoming stronger. Therefore, the inverse geographic distance weight matrix can accurately portray the real spatial impact of the “grain-to-feed” policy on feed grain security.

Table 2. Global spatial correlation.

	Economic Geographic Weight Matrix		Inverse Geographical Distance Weight Matrix		Adjacent-Weight Matrix	
Test statistics	Moran’s I	Geary’s c	Moran’s I	Geary’s c	Moran’s I	Geary’s c
	0.464 ***	0.531 ***	0.457 ***	0.554 ***	0.471 ***	0.527 ***

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *** represent significance at the 10%, 5%, and 1% levels, respectively. Due to the length of this study, this paper will not report the results of the annual global spatial correlation test, local spatial correlation test, and Moran scatter plot; these can be obtained upon request from the author if necessary.

4.3. Spatial Double-Difference Econometric Modeling

Assumptions y_1 denotes provinces that are part of the “grain-to-feed” policy pilots and y_0 denotes provinces that are not part of the “grain-to-feed” policy pilot. y_{it} denotes the production of feed grain in province i in period t. x_{it} denotes the vector of observable variables for province i in period t. For each province, there are two states before (b) and after (a) the implementation of the “grain-to-feed” policy, so the results before and after the two different types of provinces are as follows:

$$y^a_{it,0} = y^b_{it,0} + \mathrm{w_i} D_{it}\beta \tag{2}$$

$$y^a_{it,1} = y^a_{it,0} + \alpha \tag{3}$$

Among Equations (2) and (3), the $\mathrm{w_i}$ is the $1 * \mathrm{n}$ the spatial weight matrix that represents the spatial relationship between the provinces. $\mathrm{D_{it}}$ is $\mathrm{nt} * 1$ the vector of $\mathrm{D_{it}} = 1$ denotes a province that is a pilot province in period t, and $\mathrm{D_{it}} = 0$ indicates a non-pilot province in period t. Parameter α denotes the direct treatment effect of the “grain-to-feed” policy, parameter β denotes the spatial treatment effect of the “grain-to-feed” policy in all regions and is mainly determined by $\mathrm{w_i D_{it}}$. The parameter α denotes the direct treatment effect of the policy, and the parameter β denotes the spatial treatment effect of the policy on all regions. The above equation can be obtained by taking the above equation into the spatial panel benchmark model [47]:

$$\mathrm{y_{it}} = \rho \mathrm{w_i y_{it}} + \gamma \mathrm{w_i x_{it}} + \vartheta \mathrm{x_{it}} + (\alpha + W\beta)\mathrm{D_{it}} + \mathrm{v_{it}} \tag{4}$$

$$\mathrm{v_{it}} = \lambda \mathrm{w_i v_{it}} + \varnothing_\mathrm{i} + \theta_\mathrm{t} + \varepsilon_\mathrm{it} \tag{5}$$

Among Equations (4) and (5), the W is an $\mathrm{nt} * \mathrm{nt}$ matrix of dimensions, which is $\mathrm{w_i}$ expanded over the spatio–temporal relationships to represent the spatio–temporal relationships between regions. $\varnothing_\mathrm{i}$ denotes individual fixed effects and θ_t denotes time-point fixed effects. ε_it is a $\mathrm{nt} * 1$ dimensional vector of error terms. The parameters ρ, γ, and λ denote the explanatory variables, the explanatory variables, and the corresponding parameters of the error terms on the space, respectively. A spatial Durbin model is used when $\lambda = 0$ is the spatial Durbin model; when $\lambda = 0$ and $\gamma = 0$ is the spatial autoregressive model; and when $\gamma = 0$ and $\rho = 0$ is the spatial error model.

To avoid model selection bias, a parallel trend test was performed first. Second, fixed and random effects were chosen based on the Hausman test. Finally, LR, Wald, and LM tests were performed to determine whether the spatial Durbin model can be reduced to a spatial autoregressive model or a spatial error model.

4.4. Decomposition of Spatial Processing Effects

In model (2), the $\mathrm{W\beta D_{it}}$ denotes the average spatial treatment effect of the “grain-to-feed” policy for all regions. In practice, the treatment effects of a policy may differ across regions. For the pilot policy regions, the direct treatment effect of the FFS policy was stronger, and the spatial treatment effect was relatively weaker. For non-policy pilot areas, the spatial treatment effect is clearly stronger as it is the only policy effect affecting this type of area. In this case, the parameter β as an estimate of the average spatial treatment effect of the policy across all regions would underestimate the true spatial treatment effect of the policy.

To assess the magnitude of the policy spatial treatment effect more accurately, each period's W matrix was decomposed as follows:

$$W = W_{T,T} + W_{T,NT} + W_{NT,T} + W_{NT,NT} \tag{6}$$

where $D_t^D = \mathrm{diag}(D_{it})$ is a matrix whose main diagonal is D_{it} diagonal matrix of $D_t^C = \mathrm{diag}(\tau - D_{it})$ and τ is a unit vector with element 1. $W_{T,T} = D_t^D * W * D_t^D$ denotes the spatial treatment effect of the policy pilot region on itself. $W_{T,NT} = D_t^D * W * D_t^C$ denotes the spatial treatment effect of the non-policy pilot region on the treatment region. $W_{NT,T} = D_t^C * W * D_t^D$ denotes the spatial treatment effect of the policy pilot region on the non-policy pilot region. $W_{NT,NT} = D_t^C * W * D_t^C$ denotes the spatial treatment effect of the non-policy pilot region on itself. Theoretically, $W_{T,NT}$ and $W_{NT,NT}$ are close to zero; therefore, we focused on the sizes of the $W_{T,T}$ and $W_{NT,T}$.

5. Results

5.1. Empirical Models

As there is a spatial correlation in the production behavior of feed grain among different provinces, the production of feed grain in a province is not only affected by its own "grain-to-feed" policy. However, it may also be affected by the implementation of the "grain-to-feed" policy in spatially related provinces. In particular, the spatial interactions between the implementation behaviors of the grain-to-feed policy in this province and other provinces reflect the spatial spillover effect of the grain-to-feed policy. To assess this effect accurately, the following spatial double-difference econometric model was constructed:

$$yield_{it} = \rho w_i yield_{it} + \gamma w_i X_{it} + \vartheta X_{it} + (\alpha + w_i \beta)\mathrm{policy}_{it} + \varnothing_i + \theta_t + \varepsilon_{it} \tag{7}$$

In the above equation, the yield_{it} denotes the total amount of feed grain production in province i in period t. policy_{it} denotes whether province i is a pilot area of the "grain-to-fodder" policy in period t. X_{it} denotes the vector set of control variables, including the ratio of urban and rural residents per capita consumption expenditures and the proportion of agricultural production, gap_{it}; the share of agricultural production, agri_{it}; the crop sown area (log), lnsonw_{it}; the level of fiscal revenue, fiscal_{it}; the urbanization level, urban_{it}; the population growth rate, pop_{it}; and the talent ratio, $\mathrm{college}_{it}$. $\varnothing_i$ denotes individual fixed effects, θ_t denotes time-point fixed effects, and ε_{it} denotes random disturbance term. ρ γ, and β are the spatial lag coefficients. ρw_i, and γw_i, and $w_i\beta$ represents the spatial lag effect.

5.2. Model Testing

A parallel trend test was performed before the spatial correlation test to ensure that the use of the spatial double-difference method was justified. Figure 2 shows a parallel trend plot obtained using the ordinary double-difference method. The results show that, except for 2014, the parallel trend hypothesis is satisfied in the pilot and non-pilot areas of the "grain-to-feed" policy from 2005 to 2016. The reason for the anomaly in 2014 is that the state temporarily increased the minimum purchase price in the main grain-producing areas in 2014, and the pilot areas of the "grain-to-feed" policy happened to be among them. The state canceled the temporary corn storage policy in 2015, which led to a return to parallel feed grain production in the main grain-producing regions and other regions after 2015.

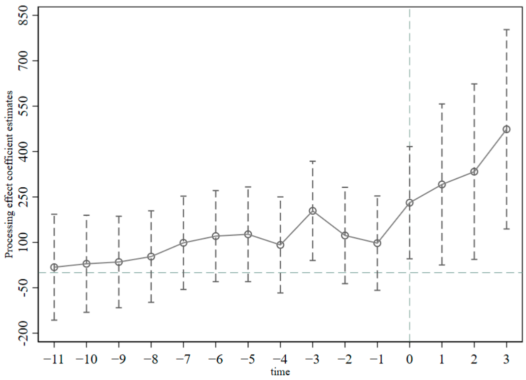

Figure 2. Parallel trend chart.

5.3. Empirical Results

In this study, the inverse geographic distance matrix is first chosen for the empirical analysis. Hausman test results show that the chi2 value of the spatial lag model (SAR) is 79.47 with a p-value of 0.0001, and the chi2 value of the spatial Durbin model (SDM) is 29.78 with a p-value of 0.028. Therefore, regardless of the spatial empirical model adopted for the estimation, the fixed-effects model estimates that efficiency is better than the random effects. Under fixed effects analysis, the LR test results show that the spatial Durbin model (SDM) cannot be transformed into a spatial lag model (SAR) or spatial error model (SEM). The chi2 value for determining whether SDM could be transformed into SAR was 38.04, with a p-value of 0.0001, and the chi2 value for determining whether SDM could be transformed into SEM was 39.12, with a p-value of 0.0001. The test of the joint significance of the spatial coefficients using the Wald statistic indicates that the SDM cannot be simplified to either SAR or SEM. The chi2 value for determining whether the SDM can be simplified to SAR was 39.79, with a p-value of 0.0001, and the chi2 value for determining whether the SDM can be simplified to SEM was 37.42, with a p-value of 0.0001. In summary, it is optimal to use the fixed-effects SDM as the final explanatory model for spatial double differences. The estimation results are shown in Table 3.

Table 3. Regression results of different spatial econometric models.

Variable	Output of Feed Grain			
	SDM-Main	**SDM-Wx**	**SAR**	**SEM**
"Grain-to-feed" policy	271.483 *** (33.85)	−330.179 *** (65.29)	202.357 *** (30.11)	193.917 *** (32.06)
The ratio of per capita consumption expenditure	46.315 (42.04)	49.911 (87.68)	77.885 ** (38.74)	80.687 ** (38.17)
The ratio of the agricultural output value	−242.715 (202.26)	1014.205 ** (469.07)	−425.807 ** (204.64)	−431.769 ** (204.52)
The sown area of crops	272.654 *** (70.99)	217.719 (172.68)	281.329 *** (65.14)	305.690 *** (63.80)
The level of fiscal revenue	11.303 *** (0.91)	7.952 *** (2.57)	11.348 *** (0.83)	11.134 *** (0.80)
Urbanization	686.347 * (399.15)	−410.757 (619.51)	845.809 *** (260.34)	727.788 *** (238.85)
Population growth rate	11.704 (8.02)	−9.821 (13.68)	17.029 *** (5.98)	17.201 *** (5.84)
The proportion of talented people	−396.920 (323.53)	−840.999 * (500.28)	−870.064 *** (253.87)	−900.248 *** (249.60)
R2	0.543		0.584	0.556
Log-likelihood	−3035.7254		−3054.7461	−3055.2878

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

5.4. Analysis of Results

The results in Table 3 show that after stronger controls for other disturbances, the implementation of the “grain-to-feed” policy reduced the production of feed grain by about 3.3 million tons in adjacent districts without the policy. Combined with the hypothesis of parallel trends, it can be seen that if the “grain-to-feed” policy is not implemented, the output of feed grains in the adjacent districts without the policy will increase slowly according to the change in parallel trends. However, after the implementation of the policy, because the “siphon effect” of the policy is greater than the diffusion effect, the output of feed grain in the adjacent districts without the implementation of the policy is reduced. This is mainly because the higher the output of feed grain in the pilot area of the “grain-to-feed” policy, the greater the market competitiveness, the stronger the supply capacity of feed grain in the adjacent non-pilot districts, and the lower the output of feed grain in the adjacent non-pilot districts.

In contrast, the higher the share of agriculture in the region, the stronger the promotion effect on the production of feed grain in spatially neighboring regions. For every 1% increase in the share of agriculture, the production of feed grain in adjacent regions increases by 10.14 million tons on average. A higher share of agricultural output in the region’s agriculture, forestry, fisheries, and services implies a lower share of forestry, fisheries, and services. To meet a region’s demand for meat, eggs, milk, and other proteins, the demand for feed grain from neighboring regions will increase; thus, feed grain production in neighboring regions will be significantly higher. Similarly, the higher the financial income of a region, the more developed the economy; the more robust the demand for meat, eggs, milk, and other high-quality proteins, and the greater the demand for feed grain in neighboring regions. For every CNY 100 million increase in the region’s fiscal revenue, feed grain production in neighboring regions increased by an average of 80,000 tons.

In terms of main effects, the GFS policy significantly increased the production of feed grain in the pilot districts. From the coefficients of the “grain-to-feed” variables, on average, the implementation of the “grain-to-feed” policy can significantly increase the production of feed grain in the pilot areas by about 2.71 million tons. Subsidizing the “grain-to-feed” policy can effectively increase farmers’ incentives to grow fodder grains, thus increasing the overall production of fodder grains. The larger the area planted with crops, the more adequate the supply of feed grain. For every 1% increase in the crop planting area, the supply of feed grain increases by 2.72 million tons on average. Under the condition of ensuring the absolute security of food rations, the larger the area under crop cultivation, the more area that can be used for growing feed grain crops, and the higher the output of feed grain. The higher the local fiscal revenue, the greater the feed grain production. For every CNY 100 million increase in fiscal revenue, feed grain production increases by 110,000 tons, on average. The higher the local fiscal revenue, the greater the infrastructure investment available to promote feed grain production, and the higher the production of feed grain. The coefficients of the consumption expenditure ratio, urbanization rate, population growth rate, and talent share variables are not significant at the 5% level. However, they are significant in the SAR and SEM models, indicating that further robustness tests need to be carried out.

6. Further Analysis

6.1. Robustness Tests

To ensure the robustness of the results, this study adopted the economic–geographical distance weight matrix and the adjacency weight matrix based on the fixed-effects double-difference SDM model for the robustness test to mitigate the interference of different spatial adjacencies on the estimation results. In addition, the difference between supply and demand (demand minus supply) of feed grain was used to replace feed grain supply as a proxy variable for feed grain security to enhance the persuasiveness of the impact mechanism of the “grain-to-feed” policy on feed grain security. The estimated results are presented in Table 4.

Table 4. Robustness test.

Variable	Output of Feed Grain				Supply and Demand Difference of Feed Grain	
	Economic Geographic Weight Matrix		Adjacent-Weight Matrix		Inverse Geographical Distance Weight Matrix	
	Main	Wx	Main	Wx	Main	Wx
"Grain-to-feed" policy	217.362 *** (33.80)	−98.436 ** (46.07)	245.481 *** (39.74)	−96.431 (68.42)	−194.462 *** (34.72)	334.143 *** (66.91)
The ratio of per capita consumption expenditure	79.331 * (40.81)	52.478 (68.45)	72.323 * (43.36)	−13.372 (75.32)	45.819 (43.15)	−123.444 (90.33)
The ratio of the agricultural output value	−494.364 ** (202.86)	564.142 * (325.17)	−393.613 * (207.05)	129.009 (392.12)	−225.722 (207.68)	−1335.44 *** (488.69)
The sown area of crops	180.364 ** (75.80)	830.991 *** (168.41)	344.945 *** (70.42)	42.461 (132.77)	−75.512 (72.81)	590.689 *** (173.67)
The level of fiscal revenue	13.488 *** (1.01)	1.233 (1.68)	10.791 *** (0.94)	3.698 ** (1.63)	−10.034 *** (0.93)	1.776 (2.19)
Urbanization	−6.856 (449.84)	523.955 (585.66)	782.586 * (404.23)	−393.036 (606.24)	−55.020 (410.02)	−141.991 (638.82)
Population growth rate	11.113 (8.17)	0.230 (11.66)	24.174 *** (8.20)	−12.465 (12.31)	3.208 (8.24)	19.102 (14.13)
The proportion of talented people	−834.102 ** (376.33)	−285.129 (570.06)	−417.135 (364.86)	−820.354 (535.52)	302.626 (332.70)	512.692 (508.75)
R2	0.5566		0.5309		0.3838	
Log-likelihood	−3038.3523		−3050.5651		−3047.4082	

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

The results in Table 4 show that, in terms of main effects, the "grain-to-feed" policy is effective in increasing fodder grain production in the policy pilot areas, regardless of the spatial weighting matrix. Similarly, the conclusion that the larger the area planted with local crops and the higher the fiscal revenue, the higher the production of feed grain is robust to the estimation of different spatial weighting matrices. When only the dual spatial adjacencies of economy and geography are considered, the share of local agriculture and the proportion of talented people have significant impacts on the production of feed grain in the region. The higher the share of agricultural output in the region's agriculture, forestry, fisheries, and services sectors, the lower the feed grain production. For every one percentage point increase in the share of agriculture, feed grain production decreases by approximately 4.94 million tons. The higher the share of agriculture, the lower the share of the forestry, animal husbandry, fishery, and service industries; the smaller the demand for local feed grain, and the lower the supply of feed grain. The more highly educated the local talent, the lower the feed-grain production. For every 1% increase in the proportion of talent, feed grain production is reduced by 8.34 million tons on average. With the growth in learning, people pay more attention to the adjustment of diet structure, the lower demand for high-protein substances, and the subsequent reduction in feed grain production. When considering only spatial adjacency, the higher the population growth rate, the greater the feed grain production. For every one percentage point of population growth, feed grain production increased by approximately 240,000 tons. This is because protein is a fundamental part of the human food system, and population growth inevitably increases the demand for protein intake, thus boosting feed grain production. Adopting the difference between the supply and demand of feed grain as an explanatory variable also proves that the "grain-to-feed" policy can effectively guarantee the security of feed grain in the pilot areas, and the effect of the policy has initially appeared. On average, the implementation of the "grain-to-feed" policy can significantly reduce the difference between the supply and demand of feed grain in the pilot areas by about 1.94 million tons. Similarly, an improvement in regional financial income can also effectively increase the supply of feed grain, narrow the difference between the supply and demand of feed grain in the region, and guarantee the security of feed grain. For every CNY 100 million increase in fiscal revenue, the difference between the supply and demand for feed grain in the region will be reduced by approximately 100,000 tons on average.

Regarding the spatial effect, the results of the estimation by choosing the economic and geographical weight matrix and the difference between the supply and demand of feed grain show that the grain-to-feed policy, while promoting an increase in the production of feed grain in the pilot areas, replaced the production of feed grain in some neighboring areas. In the context of establishing a unified national market, the increase in feed grain production in the pilot areas effectively releases potential space for the development of other industries in the neighboring areas, which is conducive to the formation of an integrated, left-right, and right-right supporting industrial system. From the estimation results of the economic geography weight matrix alone, the larger the area of crop cultivation in the region, the higher the output of feed grain in economically and geographically similar regions. To ensure the absolute security of the food ration, the larger the crop planting area, the higher the land utilization efficiency, and the more advanced the planting technology. Through the effect of technology diffusion, planting technology in neighboring areas has also improved, and the area that can be used for planting fodder grain crops has increased accordingly, resulting in a significant increase in fodder grain production. In terms of the difference between the supply and demand of feed grain, the higher the proportion of agriculture in a region, the more conducive it is to reduce the difference between the supply and demand of feed grain in neighboring regions in space. The higher the proportion of agriculture in a region, the higher the production of feed grain in spatially neighboring regions, the smaller the difference between supply and demand, and the safer the feed grain. This conclusion corroborates the previous estimation results. Taken together, the estimation results of this study are robust.

6.2. Decomposition of Effects

To further explore the differences in the magnitude of the effect of the food-for-feed policy on spatially adjacent pilot and non-pilot areas, this study decomposed the spatial effects of the food-for-feed policy on spatially adjacent areas. Table 5 shows the estimation results using the inverse geographic distance weight matrix, economic–geographic weight matrix, and the difference between the supply and demand of food as the dependent variable.

The results in Table 5 show that when fodder grain production was the subject of the study, the direct effect of the food-for-feed policy on the pilot areas was always positive, regardless of the matrix used. Meanwhile, the spillover effect of the policy pilot areas on spatially neighboring pilot areas was significantly positive, and the spatial effect on non-pilot areas was insignificant. Taking the inverse geographic distance weight matrix as an example, after the implementation of the grain-to-feed policy, the grain output of the pilot areas themselves increased by an average of 1.17 million tons, and the grain output of the spatially adjacent pilot areas increased by an average of 449.47 million tons, which is an obvious policy effect. The overall negative spatial effect of pilot regions on neighboring regions is mainly caused by the fact that there are more non-pilot regions, and the spatial effect of pilot regions on non-pilot regions is insignificant. In particular, it should be noted that the negative impact of the policy on the output of feed grain in adjacent non-pilot districts does not mean that the implementation of the policy is ineffective. Because we found that there is a significant and positive promoting effect between the feed grain output in the pilot area and the adjacent pilot area, it also means that we can reduce the negative impact of the "grain-to-feed" policy on the feed grain output in the adjacent non-pilot districts by expanding the implementation scope of the "grain-to-feed" policy.

Table 5. Effect decomposition.

Variable	Output of Feed Grain		Supply and Demand Difference of Feed Grain	
	Inverse Geographical Distance Weight Matrix	Economic Geographic Weight Matrix	Inverse Geographical Distance Weight Matrix	Economic Geographic Weight Matrix
"Grain to feed"policy	116.685 *** (44.34)	128.694 *** (36.03)	−28.727 (45.58)	−39.616 (36.96)
Pilot area to pilot area	44,946.87 *** (12,982.32)	895.376 *** (174.83)	−50,289.3 *** (13,339.87)	−986.149 *** (179.16)
Pilot areas versus non-pilot areas	1640.725 (3697.41)	64.158 (52.90)	−2130.546 (3805.46)	−15.190 (54.27)
The ratio of per capita consumption expenditure	32.098 (41.34)	36.866 (40.74)	76.568 * (41.08)	69.967 * (40.34)
The ratio of the agricultural output value	−200.030 (205.03)	−247.094 (201.63)	−248.455 (203.30)	−202.900 (199.15)
The sown area of crops	299.718 *** (72.21)	271.954 *** (71.39)	−142.593 ** (71.56)	−118.296 * (70.46)
The level of fiscal revenue	11.668 *** (0.94)	11.812 *** (0.92)	−10.556 *** (0.93)	−10.760 *** (0.91)
Urbanization	567.615 (397.39)	739.482 * (391.88)	357.734 (397.64)	151.917 (391.09)
Population growth rate	9.065 (8.68)	11.798 (8.55)	2.666 (8.64)	0.097 (8.48)
The proportion of talented people	−458.195 (325.44)	−458.744 (319.71)	280.269 (323.76)	292.135 (316.86)
R2	0.5528	0.5653	0.3742	0.3927
Sample size	480	480	480	480

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

When using the difference between feed grain supply and demand as the dependent variable for estimation, it was found that after the implementation of the grain-to-feed policy, the policy effect of the pilot regions on neighboring pilot regions was more obvious.

Overall, the implementation of the grain-to-feed policy has significantly promoted feed grain security between the pilot regions and spatially neighboring pilot regions. By imitating and learning from the successful experiences of neighboring pilot regions, healthy competition has been formed among the pilot regions of the grain-to-feed policy, which has effectively increased the total output of fodder grains in the pilot regions and strongly guaranteed the security of fodder grains.

6.3. The Impact on Farmers' Income

The "grain-to-feed" policy should not only guarantee the security of feed grain but also be able to promote farmers' income. Any policy reform that reduces farmers' income is unsustainable. In order to verify the sustainability of the "grain-to-feed" policy, this paper further analyses the impact of the "grain-to-feed" policy on the per capita disposable income of rural residents. At the same time, any policy reform that widens the income gap between urban and rural areas is not conducive to social stability. Therefore, the text also analyses the impact of the "grain-to-feed" policy on the ratio of urban residents' income to rural residents' income, and the results are shown in Table 6.

Table 6. Impact of "grain-to-feed" policies on farmers' income and income inequality.

Variable	Farmers' Income		The Ratio of Urban to Rural Residents' Income	
	Main	Wx	Main	Wx
"Grain-to-feed" policy	966.899 *** (166.29)	−683.717 (458.59)	−0.080 *** (0.02)	0.026 (0.05)
The ratio of per capita consumption expenditure	−132.994 (202.20)	1708.914 *** (561.25)	0.238 *** (0.02)	0.045 (0.07)
The ratio of the agricultural output value	2518.089 ** (1005.07)	−6660.82 ** (2919.25)	−0.264 ** (0.12)	0.105 (0.34)
The sown area of crops	−2258.57 *** (348.06)	−1508.65 (1040.87)	−0.122 *** (0.04)	−0.105 (0.11)
The level of fiscal revenue	45.203 *** (4.83)	87.068 *** (16.11)	0.002 *** (0.001)	0.001 (0.01)
Urbanization	−30,201.3 *** (1933.23)	4108.997 (6148.71)	−0.729 *** (0.22)	−3.631 *** (0.68)
Population growth rate	5.482 (42.35)	−73.352 (135.07)	−0.001 (0.001)	0.046 *** (0.02)
The proportion of talented people	993.088 (1588.78)	−5949.66 * (3579.55)	0.057 (0.18)	0.653 (0.42)
R2	0.186		0.494	
Sample size	480		480	

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

The results in Table 6 show that the "grain-to-feed" policy was effective not only in raising the income of farmers in the pilot areas but also in narrowing the urban–rural income gap in the pilot areas. After the implementation of the "grain-to-feed" policy, the income of rural residents in the pilot areas increased by CNY 967, and the income ratio between urban and rural residents decreased by 0.08 units. Therefore, the "grain-to-feed" policy is not only sustainable but also conducive to social stability. On the one hand, it is because the production of feed grain is higher than that of ration grain, which increases farmers' farm income, and on the other hand, it is because the subsidies under the "grain-to-feed" policy increase farmers' transfer income. At the same time, we also found that the impact of the "grain-to-feed" policy on farmers' incomes and the urban–rural income gap in the neighboring areas of the pilot was not significant. On the one hand, the "grain-to-feed" policy reduced the production of feed grain in the neighboring areas, thus decreasing the farmers' operating incomes. On the other hand, however, it may also encourage farmers in neighboring areas to migrate to urban areas for work and increase their wage income, thus having a non-significant impact on farmers' income in neighboring areas and on the urban–rural income gap.

6.4. Impact of the Amount of Policy Subsidies

In addition to clearly delineating the pilot areas, the "grain-to-feed" policy mainly encourages and guides farmers to plant feed grain through policy subsidies. According to the requirements of the "grain-to-feed" Work Implementation Programme of the Ministry of Agriculture of China, the amount of subsidies under the "grain-to-feed" policy in each province is mainly determined by the planting area and storage volume of feed grain. In 2017, China's central financial administration arranged a total of RMB 2 billion in subsidies for the "grain-to-feed" policy, which was used to subsidize farmers who planted feed grain on 10 million mu and cooperatives who collected and stored 30 million tonnes of feed grain. At the same time, the central government broke down the tasks of 10 million mu and

30 million tonnes to 17 provinces and regions according to the factor method. Therefore, this paper estimates the amount of central financial subsidy for different provinces and regions according to their planting area and storage tasks and discusses the impact of the subsidy amount of the "grain-to-feed" policy on the output of feed grain accordingly. The results are shown in Table 7.

Table 7. Impact of the number of subsidies under the "grain-to-feed".

Variable	Output of Feed Grain			
	Main	**Wx**	**Main**	**Wx**
Subsidies for planting area	133.806 *** (23.17)	−168.907 *** (45.87)		
Subsidy for storage volume			146.529 *** (23.69)	−166.898 *** (45.72)
The ratio of per capita consumption expenditure	47.028 (43.36)	47.366 (90.81)	47.250 (43.15)	49.730 (90.29)
The ratio of the agricultural output value	−256.991 (207.20)	1029.535 ** (469.57)	−255.964 (206.21)	985.700 ** (467.53)
The sown area of crops	288.640 *** (73.52)	163.391 (184.34)	286.941 *** (73.25)	217.568 (184.33)
The level of fiscal revenue	10.386 *** (0.95)	9.277 *** (2.63)	10.378 *** (0.95)	9.392 *** (2.62)
Urbanization	540.443 (420.77)	−227.816 (652.55)	528.481 (417.74)	−212.280 (647.15)
Population growth rate	12.301 (8.27)	−7.447 (14.25)	12.275 (8.23)	−6.788 (14.18)
The proportion of talented people	−575.595 * (332.57)	−777.284 (520.06)	−559.187 * (331.06)	−809.206 (517.60)
R2	0.536		0.529	
Sample size	480		480	

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

The results in Table 7 show that the grain-to-feed policy subsidy funds, whether disbursed on the basis of planting area or storage volume, were effective in increasing the production of feed grain in the pilot areas. Controlling for other factors, for every CNY 100 million subsidy from the "grain-to-feed" policy, the production of feed grain in the pilot areas increased by 1.34 million tonnes and 1.46 million tonnes, respectively. Therefore, the conclusion is that the "grain-to-feed" policy has contributed to increasing feed grain production and ensuring feed grain security is robust.

6.5. Impact of Economic Price Signals

In addition to the impact of the number of subsidies under the "grain-to-feed" policy, economical price signals in pilot and non-pilot areas also have an impact on farmers' behavior in growing feed grain. Since China has a minimum purchase price policy for feed grain and feed grain prices fluctuate from region to region, it is difficult to use feed grain price signals to reflect the real market situation. Instead, we use the average wage of urban private sector workers in each province to indirectly reflect economic price signals in different regions in order to compare the impact of economic price signals in pilot provinces with those in non-pilot provinces.

The results in Table 8 show that the higher the wage–price signals, the lower the production of feed grain, but the implementation of the "grain-to-feed" policy in the pilot areas effectively mitigates the negative impact of wage–price signals on feed grain production compared to the non-pilot areas. The higher the wage–price signals, the higher the opportunity cost for farmers to grow feed grain, and the more likely they are to go out to work, which reduces the cultivation of feed grain and lowers the production of feed grain. Compared with the non-pilot areas, the implementation of the "grain-to-feed" policy in the pilot areas increased farmers' income from cultivating feed grain and reduced their opportunity cost of cultivating feed grain, thus mitigating the negative impact of the wage–price signal on feed grain production. Thus, the impact of wage–price signals on feed grain production varied across regions, with the negative impact of wage–price signals on feed grain production being weaker in the pilot regions than in the non-pilot regions.

Table 8. Impact of economic price signals.

Variable	Output of Feed Grain		Output of Feed Grain in the Next Period	
	Main	Wx	Main	Wx
"Grain-to-feed" policy	210.346 *** (48.56)	−198.881 * (101.48)	96.059 *** (21.90)	−40.553 (43.47)
Wage–price signal	−299.768 * (154.12)	36.845 (221.50)		
Wage–price signal * "grain-to-feed" policy	60.876 (67.59)	−284.173 (185.65)		
The ratio of per capita consumption expenditure	0.819 (63.80)	−138.755 (166.35)	−11.351 (29.02)	50.114 (59.06)
The ratio of the agricultural output value	−21.753 (291.19)	949.038 (689.59)	−143.101 (135.38)	−83.972 (313.03)
The sown area of crops	260.566 *** (98.77)	122.856 (244.64)	12.914 (48.19)	−30.102 (114.62)
The level of fiscal revenue	10.676 *** (1.27)	13.043 *** (3.82)	0.026 (0.62)	−0.673 (1.36)
Urbanization	−251.665 (595.02)	1022.458 (1081.49)	19.349 (277.72)	639.069 (423.52)
Population growth rate	7.299 (8.95)	−6.752 (15.00)	8.112 (5.33)	3.380 (9.02)
The proportion of talented people	−129.084 (342.92)	−1187.03 ** (544.56)	17.655 (212.95)	−935.388 *** (325.83)
R2	0.211		0.63	
Sample size	360		450	

Source: China Statistical Yearbook, Statistical Yearbook by Province. Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Heteroscedasticity robust standard error in parentheses.

Finally, this paper also considers the long-term impact of the "grain-to-feed" policy and examines the impact of the "grain-to-feed" policy on the production of feed grain in the next period. The results in Table 8 show that the "grain-to-feed" policy can effectively increase the production of feed grain in the next period. This is mainly due to the fact that the "grain-to-feed" policy has increased farmers' confidence and expectation of growing feed grain, thus increasing the production of feed grain in the next period, which further indicates that the implementation of the "grain-to-feed" policy has a stable, sustained and long-term effect.

7. Conclusions and Discussion

7.1. Conclusions

Using the panel data of 30 provinces in China from 2005 to 2020, this paper selects a spatial double difference to difference model to assess the policy impact of the "grain-to-feed" policy on the production of feed grain in pilot areas and spatially adjacent areas. It is found that the spatial distribution of feed grain production in each province in China has obvious spatial dependence and spatial agglomeration, which is characterized by the agglomeration of high values and high values and the agglomeration of low values and low values. The "grain-to-feed" policy can significantly increase the output of feed grain in the pilot areas with a certain degree of precision. To a certain extent, the "grain-to-feed" policy has reduced the production of feed grain in neighboring regions, indicating that the "siphoning effect" of the "grain-to-feed" policy on feed production in neighboring regions is greater than the spillover effect, exacerbating the impact of the policy on feed production. The results of the decomposition of spatial effects show that the policy has enhanced the positive linkages between the pilot areas and neighboring pilot areas, increased feed grain production, and had an obvious spatial spillover effect. The "grain-to-feed" policy intensified the negative linkage between the pilot areas and the neighboring non-pilot areas and reduced the production of feed grain, showing a certain "siphoning effect". The "siphon effect" is greater than the spillover effect, which is the root cause of the reduction in feed grain production in neighboring regions as a result of the "grain-to-feed" policy.

The results of the robustness test show that, regardless of the method used to measure spatial proximity, the "grain-to-feed" policy can significantly increase the production of feed grain in the pilot areas, reduce the gap between supply and demand of feed grain in the pilot areas, and guarantee the security of feed grain in the pilot areas. The "grain-to-feed" policy can not only guarantee the security of feed grain but also promote farmers' income increase, which has certain sustainability. Whether subsidies are granted based on the area planted with feed grain or the amount of feed grain harvested and stored, the "grain-to-feed" policy can significantly increase the production of feed grain in the pilot areas and guarantee the security of feed grain in the pilot areas. Due to the obvious differences in economic price signals in different regions, the implementation effect of the "grain-to-feed " policy in different regions is also obviously different. Compared with the non-pilot areas, the "grain-to-feed" policy can reduce the negative impact of wage–price signals on feed grain production. Finally, the "grain-to-feed" policy has the potential to increase feed grain production not only in the current pilot period but also in the next period, with a certain degree of long-term persistence.

7.2. Comparative Analysis with Existing Studies

Compared with previous studies, this paper will provide new insights for research related to the field of food structural transformation. First, this paper provides a new research direction for studies related to food structure transformation. Most of the studies related to food structure transformation have argued that the food structure should be transformed from ration crops to cash crops. This paper argues that, in addition to the transformation of ration crops to cash crops, ration crops can also be transformed to feed crops, which guarantees food security and improves farmers' incomes. Secondly, this paper fills the gap in analyzing the spatial effect of the "grain-to-feed" policy to a certain extent. The related research on the "grain-to-feed" policy mainly focuses on the direct effect of the "grain-to-feed" policy, but this paper not only examines the effect of the "grain-to-feed" policy on the production of feed grain in the pilot area but also examines the effect of the "grain-to-feed" policy on the production of feed grain in spatially adjacent areas. Thirdly, this paper provides a new research method for the study of spatial effect decomposition from the perspective of economics. At present, the research on spatial effect decomposition mainly focuses on statistics, and this paper is one of the few studies that apply spatial effect decomposition to economics.

7.3. Policy Recommendations

Based on the conclusions of this paper, this paper suggests that the government departments concerned should improve and perfect the "grain-to-feed" policy in the following aspects so as to give full play to the effectiveness of the "grain-to-feed" policy and realize the objectives of the “grain-to-feed” policy: (1) Accelerate the change in the perspective of food, and comprehensively set up the “Big Food Perspective”. Perspective influences attitudes, and attitudes change behaviors. It is necessary to accelerate the transformation of the traditional food perspective of “taking rations as an outline”; establish the new perspective of “food, economy, forage and grass diversification as a whole”; and pay more attention to the production of non-ration crops such as feed grain, and so on. (2) Further expand the scope of implementation of the “grain-to-feed “ policy. The “grain-to-feed” policy can effectively increase the production of feed grain in pilot areas, but it is slightly insufficient to guarantee the security of feed grain in non-pilot areas. In order to make up for this shortcoming, it is suggested that the implementation scope of the “grain-to-feed” policy be expanded further, starting from the main grain-producing areas, gradually expanding to the balanced production and marketing areas, and finally realizing the national promotion. (3) Increase the implementation of the “grain-to-feed” policy. On the one hand, it is suggested to increase that the number of subsidies for the “grain-to-feed” policy be increased, the financial fund integration in the grain field be strengthened, and the financial fund “reservoir” for the “grain-to-feed” policy be expanded. On the other hand, it is suggested to expand the subsidy standard of the “grain-to-feed” policy, and in addition to the two standards of planting area and storage volume of feed grain, it is suggested to increase the indicators of scientific and technological research and development rate of feed grain and the rate of transformation of achievements, so as to strengthen the financial support for scientific and technological research and development of feed grain and the transformation of achievements. (4) Strengthening the response to the impact of fluctuating economic price signals on feed grain production. It is recommended that priority be given to implementing the “grain-to-feed” policy in regions with large fluctuations in economic price signals so as to mitigate the negative impact of high wage prices on feed grain production.

7.4. Research Limitations and Areas for Future Research

Due to the absence of data and other objective reasons, the limitations of this paper are also obvious, which are mainly reflected in the following points: First, this paper lacks corresponding micro-analysis, especially the micro-analysis from a single farmer or farm. Second, this paper lacks an in-depth discussion on the impact of “grain-to-feed” policy subsidies on the ecological environment and social costs. In particular, there is a lack of in-depth analysis of the dependence of subsidies locking in high input production systems with associated social and environmental costs. Third, it does not take into account the effective response of local governments to the “grain-to-feed” policy. For example, local governments in non-policy pilot areas may reduce or circumvent the main responsibility of food security by “withdrawing counties and combining districts”. Fourth, this paper lacks the impact of international trade rules on the “grain-to-feed” policy, especially how to guide the subsidy direction of the “grain-to-feed” policy toward the “green box” policy.

Looking forward to the future, the subsequent relevant research can be supplemented and improved in the following aspects: First, in the research field, the “grain-to-feed” policy can be expanded to other policies, such as the “Northeast black land protection and utilization” policy. Second, the research dimension is expanded from the dimension of feed grain output to the dimension of quality and structure. The third is to broaden the research data from the provincial level to the prefecture-level city, county, family, and individual levels. The fourth is to broaden the research methods from multi-stage DID to intensity DID to continuously enrich the relevant research on food security in China.

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