land

MDPI

Article

The Effect of the Major-Grain-Producing-Areas Oriented Policy on Crop Production: Evidence from China

Wenyuan Hua [1,2], Zhihan Chen [1] and Liangguo Luo [1,*]

[1] Institute of Environment and Sustainable Development in Agriculture, China Academy of Agricultural Science, Beijing 100089, China
[2] Environmental Economics and Natural Resources Group, Wageningen University, 6708 PB Wageningen, The Netherlands
* Correspondence: luoliangguo@caas.cn

Abstract: As a powerful actor in the global food system, China experienced a significant drop in crop production from 1998 to 2003, which posed a substantial threat to national food security and led to the establishment of 13 major grain-producing areas (MGPA). Although some qualitative research has found that the MGPA policy plays an important role in ensuring the national food security, quantitative evidence on the effect of the MGPA policy and its potential mechanism remains scarce. Based on China's interprovincial panel data from 1998 to 2018, this study used a difference-in-differences (DD) estimation strategy to analyze the treatment effect of the MGPA policy by taking the assignment of 13 MGPA as a quasi-experiment. The results showed that the enforcement of the MGPA policy significantly increased crop production, especially in terms of grain, rice and wheat yields. The average grain yields were raised by 27.5%. The results of the event study analysis showed that the treatment effects were sustainable in the following years of the policy implementation. This study also explored alternative causal channels and found that the MGPA policy raised crop yields mainly by expanding planting areas, improving the level of mechanization and increasing transfer payments. These findings demonstrate the effectiveness of the MGPA policy in increasing crop production in a developing country setting, which could enlighten policymakers in some less well-developed countries on boosting crop production and maintaining food security.

Keywords: major grain-producing areas; crop production; food security; China

Citation: Hua, W.; Chen, Z.; Luo, L. The Effect of the Major-Grain-Producing-Areas Oriented Policy on Crop Production: Evidence from China. *Land* **2022**, *11*, 1375. https://doi.org/10.3390/land11091375

Academic Editors: Sanzidur Rahman and Uttam Khanal

Received: 7 July 2022
Accepted: 14 August 2022
Published: 23 August 2022

1. Introduction

"Food security" literally translates as "grain security" in Chinese, which is not only related to the security of a country, but also to world peace and social stability [1]. The United Nations post-2015 sustainable development agenda has set the eradication of hunger as one of important targets of the 17 Sustainable Development Goals (SDGs) in 2030. However, nearly 750 million people were exposed to severe levels of food security globally in 2019, and the number of people with food insecurity has been slowly increasing since 2014 (FAO, 2020). It was estimated that between 720 and 811 million people went hungry in 2020 according to the State of Food Security and Nutrition in the World 2021 report. Meanwhile, in addition to the climate change [2] and economic inequality [3], the widespread of COVID-19 pandemic also triggered a crisis on the global food security [4]. The COVID-induced economic shock has threatened food security by reducing incomes and disrupting supply chains, resulting in people's reduced availability and affordability of food in both higher and lower-income countries [5]. Therefore, transformations to increase the productive capacity and stability of agricultural production are urgently needed, which requires the building of a knowledge base to support.

As a powerful actor in the global food system, China has traditionally struggled to feed its large population. China feeds approximately 18% of the world population with only 8% of the global cultivated land (FAO, 2020). It is evident that China's food security is closely related to the stability of the global food system. To ensure its food security, the Chinese government has long put it high priority on the national political agenda [6]. However, from 1998 to 2003, China experienced a significant drop in crop production with the production of rice, wheat and corn in 2003 falling down almost 18 percent from the harvest in 1998. It posed a substantial threat to the national food security. After this crop production crisis, 13 major grain-producing areas (MGPA) were established by Ministry of Finance China, and a package of MGPA-oriented policies was implemented in the 13 regions. Although some qualitative research has found that the MGPA regions play an important role in ensuring the national food security and improving the production capacity [7,8], quantitative evidence on the effect of the MGPA policy and its potential mechanism remains scarce. Quantitatively verifying the efficacy of the implementation of the MGPA policy is important for China, as the ineffectiveness of such agricultural policy may deepen China's food crisis and threaten its food security. Furthermore, if the MGPA policy failed to increase China's crop production sustainably, the international crop price would increase as a result of increased crop imports from China. This would threaten the food security of low-income countries. Thus, the effectiveness of China's MGPA policy is not only a concern nationally but globally too.

A line of literature closely related to our work studies a certain set of factors affecting agricultural production. The theoretical and empirical literature acknowledges that the determinants of agricultural production can be categorized into mainly four types: physical factors (e.g., terrain, topography and climate), infrastructural factors (e.g., irrigation, roads and crop insurance), technological factors (e.g., farm machinery, pesticides and chemical fertilizer) and institutional factors (e.g., land tenure, land tenancy and land reforms). In terms of physical factors, they are defined as some natural resources including biophysical framework of soils, water, temperature, flora and fauna. It is worth mentioning that these factors do not work in isolation but the agricultural activity of a place is the product of combinations of different physical factors [9–11]. In terms of infrastructural factors, following the World Bank Report (1994), the definition of agricultural infrastructure was narrowed down to comprise long-lived engineered facilities and other services which include roads, electricity supplies and telecommunication. As illustrated by empirical studies, roads, electricity supplies, telecommunication and other infrastructure are important stimulants to agricultural output [12–15]. In terms of technological factors, empirical studies have found the adoption of improved agricultural technologies remains to be a promising strategy to achieve food security in many developing countries [16–18]. Institutional factors, which refers to the particular system under which land is owned and managed, have a direct bearing on agricultural production [19]. In practice, many developing countries have implemented many institutional reforms in agriculture sector, including providing security of tenure, computerization of land records and ceilings on agricultural holdings. Many of these institutional reforms have been empirically evaluated their effectiveness [20,21]. Despite the growing interests and enthusiasm for analyzing agricultural production from the perspectives of physical, infrastructural and technological dimensions, many studies note that these practices are still finite and farmers in developing countries are faced with a challenging environment [22], hence more focus should be on the role of institutional factors in agriculture. In particular, for China's MGPA policy, an institutional reform of redistributing regions for agricultural production, the research on its effectiveness still remains scarce. Given these, there is dire need to investigate the impact of the institutional factors on agricultural production.

Another strand of literature related to our analysis is research on the agricultural production in the MGPA regions. So far, many studies have been done to understand the agricultural production in the MGPA regions. Zhang et al. [23] estimated the grain production efficiency of the 13 MGPA regions between 2008 and 2017 and found that the overall level of total factor productivity of grain production in China's MGPA regions was relatively high and fluctuated, with an average annual rise rate of 1.85%. Yang et al. [24] identified the efficiency of the crop insurance in increasing crop production of the MGPA regions which exhibit a higher level of spatial farming risk accumulation and larger natural disaster pressures on farmers. Zhang et al. [25] empirically estimated the impact of the farmland protection on the security of grain supply in the MGPA areas using the panel data from 2010 to 2019 and found that the protection of cultivated land resources positively impacted the security of grain supply. Although all results in these studies have shown a significant increase in crop production in the MGPA regions, none of them empirically examined the causality between the establishment of the MGPA policy and crop production. The MGPA policy pertains to land management practices as it involves the allocation of land resources for agricultural growth. Theoretically, the exchange of inputs may avoid resource misallocation, which achieves higher marginal products and therefore improves input elasticities in agriculture [26].The effective land and resource governance systems that provide improved access, control, and rights to land and other natural resources is a necessary condition for achieving stable crop production [27]. Besides, land management practices are often with some production-oriented policies, which can be categorized as input support [28,29] (e.g., subsidies for fertilizers and seeds and farm equipment), output support [30,31] (e.g., countercyclical payments and price incentives), technical support [32,33] (e.g., extension services and investment in structural development) and financial support [34,35] (e.g., cash subsidies, loan aid and insurance aid). Although the four types of agricultural policies often interact with each other, previous studies have rarely treated them as a whole to investigate their impact on crop production.

Although China's food security is now guaranteed [6], in the long run, it is still faced with great challenges such as the rapid urbanization and spatial mismatch in agriculture resources. The rapid urbanization coincides with a large-scale transfer of China's cropland to "marginal land", which substantially imperiled food security and environmental sustainability [36]. This urbanization trend has led a large number of people to migrate from rural areas to cities. This rural-to-urban migration pattern intensifies the abandonment of cultivated land, while increasing its non-agricultural use [37]. Furthermore, a serious spatial mismatch exists between grain production and farmland resources in China, which also poses a threat to China's food security [38]. Thus, identifying the impact of the MGPA policy on crop production and clarifying its mechanism could provide insightful policy implications for alleviating food crisis in the future.

Given the above practical and theoretical background, to our knowledge, systematic empirical evidence on the effectiveness of the implementation of the MGPA policy remains scarce. Therefore, the objectives of this study are twofold: (i) The first is to investigate the effects of the MGPA policy on crop production by carrying out a difference-in-differences (DD) estimation and taking the assignment of 13 MGPA as a quasi-experiment based on China's interprovincial panel data from 1998 to 2018. To consolidate the reliability of the baseline results, several robustness checks are also performed. (ii) The second objective is to identify alternative causal channels of the treatment effects of the MGPA policy in terms of agricultural planting areas, mechanization level and transfer payments using a causal steps approach. This analysis could shed new light on maintaining food security from a perspective of land management practice.

2. Major-Grain-Producing-Areas Oriented Policy in China

China's production of rice, wheat and corn fell to around 400 million tons in 2003, down almost 18 percent from the record harvest of 486 million tons in 1998, according to statistics from the US Department of Agriculture. Meanwhile, this food crisis was accompanied by a growing population and shrinking arable land area. To eliminate the threat to food security, 13 major grain-producing areas were established at the end of 2003 by the Ministry of Finance China. These areas were Heilongjiang, Liaoning, Jilin, Inner Mongolia, Hebei, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, and Sichuan. Before 2003, the MGPA regions had been unofficially identified and were slightly different from those announced in 2003. Specifically, Guangdong, Guangxi, Zhejiang, Gansu and Shanxi had been classified as MGPA pre-2003, however, they were not included in the list of 2003. Figure 1 illustrates the geographic distribution of the MGPA regions in China. Dark grey areas indicate the 13 MGPA regions, and white areas the non-MGPA regions. The 13 MGPA regions cover 64% of the geographical area, are home to more than 50% of the population, and produce 75.4% of China's grain output [7]. Geographically, seven of the 13 MGPA regions are located in northern China, which is to the north of the Qinling-Huai line[1]. This is consistent with the current observation that China's agricultural center is shifting from the south to the north, especially to the northeast of China.

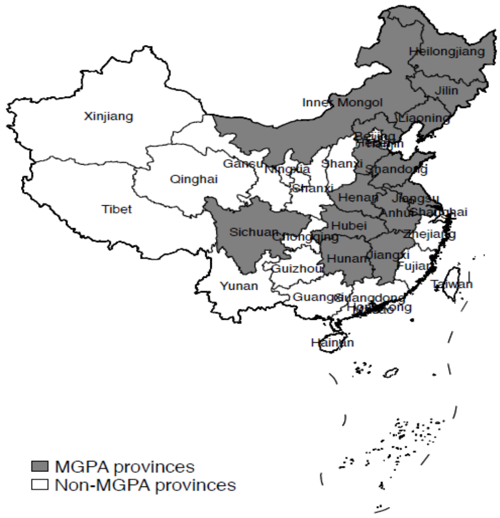


Figure 1. MGPA provinces.

The establishment of the MGPA is supplemented by some MGPA-specific policies. After carefully sorting out the MGPA oriented policies during our research period from 1998 to 2018, as Table 1 shows, we classify these policies into three types: production support, market management and natural resources management. Such classification is based on the food and agriculture policy classification of FAO. Among these MGPA oriented policies, several MGPA-specific policies are widely recognized. In terms of the production support policy, rewarding counties that produced large harvests, was added to the MGPA policy package in 2005. Specifically, a county was deemed to have produced a large harvest when its average yearly crop yields for the past five years were above 200 thousand tons and commodity crops above 5000 tons. Also, when a county's yields were ranked in the top 100 of all areas in the MGPA, it received some extra bonus subsidy from the central government. This MGPA-specific policy not only increased the willingness of farmers to plant crops, but also reduced the financial pressure on local government. In terms of the agricultural risk management policy, subsidies for the disaster prevention and mitigation in agriculture were implemented in 2012. The central government implemented for the first time the subsidy policy for agricultural disaster prevention and mitigation by subsidizing six key technologies for winter wheat, northern corn and southern early rice production. Abdur and Wang [39] found that these policies played an important role in helping farmers restore production and living. For the value-chain-development oriented policy, China formulated a plan for the construction of a high-quality grain industry (2004–2010) immediately after identifying the 13 MGPA regions. This policy was designed to accelerate the upgrading of the grain industry for the 13 MGPA regions by cultivating superior crop breeds, promoting the construction of standard farmland, improving agricultural mechanization and advancing disease and pest control techniques. Meanwhile, it also incorporated technology advancement into the existing agricultural value chain through better training, financing and fertilizer. As for the conservation and management of resources policy, the central government of China officially launched the Action Plan for the Zero Increase of Fertilizer Use in 2015. The goal of this plan was to reduce the fertilizer use without reducing food production especially in the MGPA regions. Lastly, the establishment of grain production functional area in 2017 scientifically demarcated the grain production functional areas of rice, wheat and corn, the production and protection areas of soybean, cotton and rapeseed, and management of groundwater overexploitation funnel areas in North China.

In general, the MGPA policy can be summarized as following features: (i) The spatial agglomeration of the MGPA regions. China's agricultural center had been in the south for a quite long time and the traditional pattern of grain transportation was from the southern regions to the northern regions during the long-term historical accumulation of agricultural production [40]. However, with the establishment of MGPA policy, seven of the 13 MGPA regions are located in northern China and the spatial pattern of the food production has shifted from transporting grain to the north to relying mainly on the northern regions as a result of the conversion of farmland in the southern regions, the expansion of cultivated land in the northern regions [41], the transfer of agricultural labor to non-agricultural industries [42] and the adjustment of the planting structure [40]. The regions with high grain output per capita are now concentrated in northern and eastern China, while regions with low grain output per capita are mainly in southern and western China [43]. The proportion of grain output in 15 northern provinces in the national grain output has increased from 45.65% in 2000 to 59.22% in 2020, while for the southern areas, it declined from 54.35% in 2000 to 40.78% in 2020. In addition, the MGPA regions agglomerate to the relatively less developed areas when compared with the non-MGPA regions. Existing studies indicate that the MGPA regions sacrifice their economic development for China's food security [44]. In contrast, the food supply of the non-MGPA regions is largely supported by the MGPA regions' grain production, and the development of the non-MGPA regions is more economic-oriented. For example, Zhejiang was not included in the 2003 list, despite being one of the unofficial major grain-producing provinces and having better agricultural resources. Zhejiang was not included on the list because it may take more economic responsibility with its well-equipped industry and intensified city groups. (ii) The comprehensiveness of the MGPA policy. The MGPA policy is not merely a land management practice for reallocating land resources for food production. It is also followed by a comprehensive MGPA-regions-specific agricultural policies. The MGPA policy has multiple areas of action, mainly including financial subsidies (e.g., rewarding the county for large harvests), technical support (e.g., upgrading local agricultural infrastructure) and input support (e.g., promoting the adoption of superior crop breeds). These integrated sub-policies support and complement each other to increase grain output. In terms of the source of funds, formal financial institutions are less interested in financing the agricultural sector because it is a high-risk business with high transaction costs, asymmetric information and low profits [45]. However, the funds for implementing the MGPA policy are provided by both the central financial budget and local supporting funds, which can safeguard the stability and sustainability of the MGPA policy from financial constraints. In addition, the MGPA policy is also a dynamic policy which, through successive reforms, has adapted to new challenges faced by China's agriculture. The Chinese government has so far created and implemented a series of MGPA sub-policies to meet new challenges such as addressing national market fluctuations and price volatility, using natural resources in a more sustainable manner and contributing to climate change mitigation.

Table 1. The brief summary of the MGPA oriented policy.

	Policy Classification	Policy Sub-Classification	Policy	Time	Policy Specification
MGPA oriented agricultural policy	Production support	Production subsidy	Rewarding counties that produce large harvests.	2005	When a county's yields were ranked in the top 100 of all areas in the MGPA, it will receive some extra bonus subsidy from the central government.
			The subsidy policy for soil testing and fertilizer recommendation.	2005	Focusing on five segments of "testing, formulating, producing, supplying and fertilizing", agricultural agencies launched soil testing, formulated scientific fertilization scheme and generalized the scientific technique of fertilization.
			Supporting policies for agricultural standardized production.	2006	The subsidy funds were mainly used for the integration of grain production standards, the publicity of standards, the construction of core demonstration areas, the establishment of leading enterprises and and the brand cultivation.
			The construction of large grain commodity bases.	2007	More than 60 large grain commodity bases have been built in several areas of the MGPA to upgrade local agricultural infrastructure and strengthen scientific and technological support for grain production.
			The construction of high standard farmland.	2010	It is a key measure to consolidate and improve grain production capacity and ensure national food security, which mainly focuses on arable land protection, soil fertility improvement, and efficient water-saving irrigation.
	Market management	Agricultural risk management	Subsidies for the disaster prevention and mitigation in agriculture.	2012	Special funds were allocated to provide subsidies for the implementation of drought resistant technique in the northeast region and the implementation of "one spraying and three prevention" technique in the winter wheat producing areas.
		Value chain developments	The construction of high-quality grain industry.	2004	The plan was designed to improve the quality of grain production by cultivating superior crop breeds, promoting the construction of standard farmland, improving agricultural mechanization and advancing disease and pest control techniques.
			The construction of modern agriculture demonstration zone.	2010	Taking green and recycling agriculture as the leading industry, it strived to build a pilot area with efficient grain production and quality improvement, a model area for sustainable development in agriculture.
	Natural resources management	Conservation and management of resources	A pilot scheme for agricultural resources recuperation.	2014	Returning farmland to forests and grasslands for steep slopes, seriously desertified farmland and important water sources areas. Carrying out comprehensive management of groundwater overexploitation funnel areas in North China.
			Policy of reducing fertilizer application and increasing efficiency.	2015	It was designed to reduce the amount of fertilizers and increase the efficiency on the premise of stable food production growth and adequate protection of food security.
		Land policy	The establishment of grain production functional area.	2017	It was aimed to scientifically demarcate the grain production functional areas of rice, wheat and corn, and the production and protection areas of soybean, cotton, rapeseed, sugar cane and natural rubber.

3. Methodology and Data

3.1. Regression Model

3.1.1. Difference-in-Differences Model

In order to identify the effect of the MGPA policy, a difference-in-differences model (DD) is widely used as an effective method for separating the time trend effect and the policy effect [46]. DD is a quasi-experimental design that makes use of longitudinal data from treatment and control groups to obtain an appropriate counterfactual to estimate a causal effect. It is typically used to estimate the effect of a specific intervention or treatment by comparing the changes in outcomes over time between the intervention group and the control group. In our analysis, the provincial variations in the adoption of MGPA policy enables us to carry out DD analysis. Specifically, there are two groups of provinces: those designated as MGPA (treated provinces) and those not (control provinces). There are two sample periods, pre-MGPA and post-MGPA, with the pre-MGPA period ranging from 1998 to 2004 and the post-MGPA period ranging from 2005 to 2018. The grain yield of MGPA provinces was compared to that of non-MGPA provinces (the first difference) before and after the implementation of the MGPA policy (the second difference).

The DD estimation specification is as follows:

$$Y_{it} = \alpha + \beta(D_i \times T_t) + \gamma Z_{it} + \lambda_i + \delta_t + \varepsilon_{it} \tag{1}$$

where Y_{it}, our measure of grain yield from province i in year t, is proxied by grain yield, rice yield and wheat yield; D_i indicates whether the province has been designated as MGPA i.e., $D_i = 1$ if province i is a MGPA province and $D_i = 0$ if province i is a non-MGPA province; $T_t = 1$ indicates the post-treatment period and $T_t = 0$ indicates the pre-treatment period[2]; Z_{it} are other independent variables; λ_i are province fixed effects, capturing province i's time-invariant characteristics, such as natural, climate and geographic features; δ_t are year fixed effects, capturing all yearly shocks common to all provinces, such as monetary policy and business cycles; ε_{it} is the error term.

One concern with the above specification is that province-specific annual variations may bias the estimation. One of these potential variations is natural disaster. Specifically, if grain yield was affected by some specific disasters, the estimates could be mistakenly attributed to the implementation of the MGPA policy. For example, during China's 2008 snow storms, the excessive snowfall and ice in February paralyzed the southern provinces and badly damaged their crops. To address such province-specific annual variations, we followed the approach of Li et al. [47] and included the interaction of province i and year t ($\lambda_i \times \delta_t$) into Equation (1). We therefore used the following equation for DD estimation to account for province-fixed, year-fixed and province-specific annual effects:

$$Y_{it} = \alpha + \beta(D_i \times T_t) + \gamma Z_{it} + \lambda_i + \delta_t + \mu(\lambda_i \times \delta_t) + \varepsilon_{it} \tag{2}$$

3.1.2. Event-Study Difference-in-Differences Model

DD relies on the parallel trends assumption which requires that in the absence of treatment, the difference between the treatment and control group is constant over time [46]. Despite the estimated coefficients of treatment effects being statistically significant in the DD estimation, the parallel trends assumption might still be a cause of concern. One estimation strategy widely used is to implement an "event-study difference-in-differences" estimator (ET-DD) [48]. The ET-DD estimation can also show the dynamic effects of the MGPA policy on crop production if the parallel trends assumption is satisfied. The specification of the ET-DD estimation model is:

$$Y_{it} = \alpha + \sum_{k=-6}^{14} \beta_k(D_i \times T_t) + \gamma Z_{it} + \lambda_i + \delta_t + \mu(\lambda_i \times \delta_t) + \varepsilon_{it} \tag{3}$$

where k describes the year before or after the enactment of the MGPA policy and $k = 0$ is normalized to 2004. In the regressions, $k = -1$ is left out as the reference year of 2003.

3.1.3. Propensity Score Matching Method

China exhibits appreciable regional differences across its huge territory and some of these differences are closely associated with the enactment of the MGPA policy. It suggests that the MGPA policy is more easily implemented in provinces with developed agricultural resources. If so, this reduces the comparability between the treatment and control provinces and confounds our estimation. To provide a good counterfactual for the treatment provinces in the period studied, the propensity score matching (PSM) method was used to mitigate selection bias by matching observations of treatment provinces with control provinces. Besides, PSM can also serve as a robustness check of our baseline estimation using DD method. Following Rosenbaum and Rubin [49], the PSM is modeled as:

$$p(X) = Pr(D = 1|X) = E(D|X) \tag{4}$$

where D = 0, 1 is an indicator of whether the province has been assigned as a MGPA province; X is a vector of pre-treatment characteristics.

Following Heckman et al. [50], we let Y_1 be the grain yield if the province i is a MGPA province (D = 1) and Y_0 if the province i is a non-MGPA province (D = 0). Thus, the average treatment effect on the treated (ATT) is specified as:

$$ATT = E(Y_1 - Y_0|D = 1) = E(Y_1|D = 1) - E(Y_0|D = 1) \tag{5}$$

Then the treatment effects based on the propensity score is estimated as follows:

$$ATT = E(Y_1|D = 1, p(X)) - E(Y_0|D = 0, p(X)) \tag{6}$$

3.2. Indicators and Variable Selection

3.2.1. Explained Variables

As discussed in Section 2, the major grain-producing areas were established as a result of China's falling grain production. The MGPA policy is aimed at increasing grain-oriented production. Hence we select the yearly provincial grain yield as the outcome of interest, which is defined as the output of grain, wheat, maize, sorghum, tubers, soybean and several other crops by China Agricultural Statistical Yearbooks. Besides, rice and wheat yield are also incorporate as two supplementary dependent variables because they are the two most important crops [51]. In 2021, the outputs of rice and wheat were respectively 21.29 million tons and 13.70 million tons, both ranking the highest in the world and accounting for about 55% of China's total food production. The increase of grain yield is expected to be mainly illustrated by the increase of the rice and wheat yield. Therefore, the estimation of the MGPA policy's effect on the two supplementary dependent variables can also serve as a robustness check for our baseline regression which employs the yearly provincial grain yield as the explained variable .

3.2.2. Key Explanatory Variable

According to the DD model setting, the core explanatory variable of this paper is the implementation of the MGPA policy, which is a dummy variable. Specifically, the core explanatory variable equals to 1 when the province has been designated as a MGPA province and 0 if province is a non-MGPA province. In addition, a dummy variable is often used in regression analysis to distinguish different treatment groups [52]. In our paper, whether the province has been assigned as a MGPA province is our interest. In other words, we just focus on whether the MGPA policy has been implemented, which does not involve building an explicit index system for the implementation of the MGPA policy. Therefore, a dummy variable can represent the implementation status with two distinct categories in our analysis.

3.2.3. Control Variables

A number of control variables relating to crop production have been included. Fertilizer consumption and pesticide consumption per mu[3] are two important inputs for agricultural production [53]. As China's agricultural growth has mainly been attributed to the improvement of productivity, especially the improvement of mechanization level in agriculture [26], the fixed asset which is closely related to the investment of technical equipments in agriculture is also included. Research shows that participation in rural non-farm activities exerts a pronounced impact on agriculture, household farm decisions and household food security [54]. Hence, non-agricultural income earned from non-farm activities has been included as a control variable. Following Janvry et al. [55], non-agricultural income was measured as the farmer's wage income per capita[4]. Due to the fact that the agricultural production system can benefit from participation in trade through the introduction of new skills and techniques [56], trade openness which is defined as the ratio of a province's sum of exports and imports to that province's GDP is also incorporated. The rate of urbanization is also included because a person's diet and demand for agricultural products will be transformed by urban expansion [57]. Zhong et al. [58] suggest that the frequent use of modern technologies resulting from the industrial revolution has increased crop yields, thus we included industrialization which is measured as the ratio of the output in the secondary industry to GDP. Lastly, rural financial efficiency also affects agricultural yields by extending agriculture-oriented financial services to farmers. Following Wang and Sun [59], we use the ratio of yearly rural loans to deposits as an indicator of rural financial efficiency, with data obtained from Chinese Rural Credit Cooperatives (1998–2018).

A threat to the identification is that the treatment effects would be confounded when there were other policies being enacted around the same time as implementation of the MGPA policy. After studying Chinese government documents, we found two agricultural policies that may have biased the estimation. One was the enactment of Law of Rural Land Contract (LRLS) in 2002[5], which enabled farmers to legally transfer, re-contract, enter into share-holding ventures and exchange the rights of land use. The other was the abolition of China's agricultural tax in 2006[6], which had been in existence over 2600 years. Existing studies have found that these two policies can affect farmers' grain production [60,61]. To relieve any confounding effects of these policies, two dummy variables were included. *LRLS* indicated the enactment of Law of Rural Land Contract in 2002 and *Tax* indicated the abolition of agricultural tax in 2006.

3.3. Data Sourcing

Our list of provinces designated as MGPA was derived from an official Ministry of Finance of the People's Republic of China document from December 2013, "The Plan for the Reform and Improvement of Agricultural Development.". The 13 MGPA were Heilongjiang, Liaoning, Jilin, Inner Mongolia, Hebei, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, and Sichuan. During the sample period, this list remained unchanged.

In order to estimate the treatment effects, a balanced panel of provincial data was constructed to estimate the effects of interest. The sample periods covered 1998 to 2018, as Chongqing was separated from Sichuan and designated a provincial-level municipality in 1997. In almost all cases, data were collected from various sources, including China Rural Statistical Yearbooks (Ministry of Agriculture, 1998–2018), National Agricultural Product Cost and Revenue Survey Data books (Ministry of Agriculture, 1998–2018), China Agricultural Statistical Yearbooks (Ministry of Agriculture, 1998–2018), China Statistical Yearbooks on Environment (Ministry of Environment, 1998–2018), and China Statistical Yearbooks (NBSC, 1998–2018). In addition, all economic variables were deflated using 1997's CPI. Detailed descriptive statistics are presented in Table 2.

Table 2. Descriptive statistics of variables.

Variables	Definition of Variables	Mean	S.D.	Min	Max
Grain	Annual grain yields (log)	16.16	1.23	12.74	18.15
Rice	Annual rice yields (log)	5.11	2.45	−2.30	7.94
Wheat	Annual wheat yields (log)	4.10	2.40	−3.22	8.22
Pesticide	Pesticide use per 10,000 yuan of the primary industry output (log)	−7.81	1.15	−11.68	−5.73
Fertilizer	Fertilizer use per 10,000 yuan of the primary industry output (log)	−1.18	0.62	−6.14	3.59
Fixed-asset investment	Fixed-asset investment per capita (log)	5.91	0.69	3.48	7.62
Non-agricultural income	Non-agricultural income per capita (log)	6.76	0.97	3.49	9.07
Trade openness	The ratio of a province's sum of exports and imports to that province's GDP	0.29	0.37	0.02	1.70
Urbanization	The ratio of urban population to rural's	0.43	0.18	0.10	0.90
Industrialization	The ratio of the secondary industry output to GDP	0.44	0.08	0.19	0.60
Rural financial level	The ratio of annual rural loans to deposits	0.68	0.14	0.33	1.97
Grain planting areas	Grain planting areas per capita (log)	0.09	0.06	0.00	0.38
Wheat planting areas	Wheat planting areas per capita (log)	0.02	0.02	0.00	0.06
Rice planting areas	Rice planting areas per capita (log)	0.02	0.02	0.00	0.10
Transfer payment	Transfer payment per capita (log)	5.26	1.25	2.58	8.13
Mechanization	Mechanization level per capita (log)	−0.04	0.81	−1.57	9.49

4. Results

4.1. Tests for Some Statistical Problems

To check for the variable collinearity, we perform a variance inflation factor (VIF) analysis, which has been widely used to test collinearity. The VIF test results of the explanatory variables in this study are summarized in Table 3. Among all variables, the largest VIF value is 2.75. Generally, a VIF above 4 indicates that multicollinearity might exist, therefore multicollinearity is free from concern in our analysis.

Table 3. The result of VIF test.

Variables	Pesticide	Fertilizer	Fixed-Asset Investment	Non-Agricultural Income	Trade Openness	Urbanization	Industrialization	Rural Financial Level
VIF	2.03	1.28	2.50	2.75	1.73	2.05	1.30	1.12
$\frac{1}{VIF}$	0.49	0.78	0.40	0.36	0.58	0.49	0.77	0.89

To verify whether the regression model contains a heteroskedastic error, White's test proposed by White [62], has been widely used. White's test, which compares the estimated variances of regression coefficients under homoskedasticity with the ones under heteroskedasticity, has an asymptotic chi-squared distribution and works well in large samples [63]. We perform a White's test and the p-value is 0.492, suggesting that the null hypothesis of homoscedasticity or no heteroscedasticity should be accepted. For the possible autocorrelation, a test proposed by Wooldridge [64] is very attractive because it requires relatively few assumptions and is easy to implement [65]. The result of the Wooldridge test shows that p-value is 0.0751, indicating that there is no first-order autocorrelation at a 5% confidence level in our linear panel-data model. Besides, following most empirical studies using panel data, all our empirical estimation is built on a robust-standard-errors technique for panel regression which is invented by Hoechle [66]. The code program presented by Hoechle not only could enable the estimates to be heteroskedasticity consistent but also make the standard error estimates be robust to general forms of cross-sectional and temporal dependence, i.e., autocorrelation. Therefore, the statistical problems of the heteroscedasticity and autocorrelation are relieved by using the estimation program.

In terms of the linearity and adequacy of the model setting, on the one hand, our select of control variables are based on the literature review (Section 3.2) and hence these control variables' linear relationship with the dependent variable has been examined by previous studies. Besides, the adequacy of the model can be partly illustrated by R^2, and the R^2 of our baseline regression model is above 92%, as reported in the baseline regression, suggesting that at least 92% of variance in the dependent variable that can be explained by the independentvariables. Therefore, the performance of our regression model is good. On the other hand, linearity in parameters within linear regression requires that model equation has correct functional form specification. This can be evaluated through Ramsey RESET test [67] which evaluates whether linear regression fitted values non-linear combinations explain dependent variable. If linear regression fitted values non-linear combinations explain dependent variable, then model equation has incorrect functional form specification. The result of Ramsey RESET test reported in Table 4 shows that the linearity is valid and model specification is correct.

Table 4. The results of White's test, Wooldridge test and Ramsey RESET test.

Test	Null Hypothesis	For χ^2-Statistic	*p*-Value
White's test	There is no heteroscedasticity.	555.000	0.492
Wooldridge test	There is no first-order autocorrelation.	3.385	0.076
Ramsey RESET test	Model has no omitted variable.	1.660	0.175

For the normality, the assumption requires a normal distribution that applies only to the residuals, not to the independent variables as is often believed [68]. We have tested the residuals' normality of the model and the result below (Table 5) shows that the residuals of our model are normally distributed.

Table 5. The results of skewness/kurtosis tests for normality.

Variable	Observations	Pr(skewness)	Pr(kurtosis)	χ^2	*p*-Value
Residuals	535	0.359	0.944	0.870	0.647

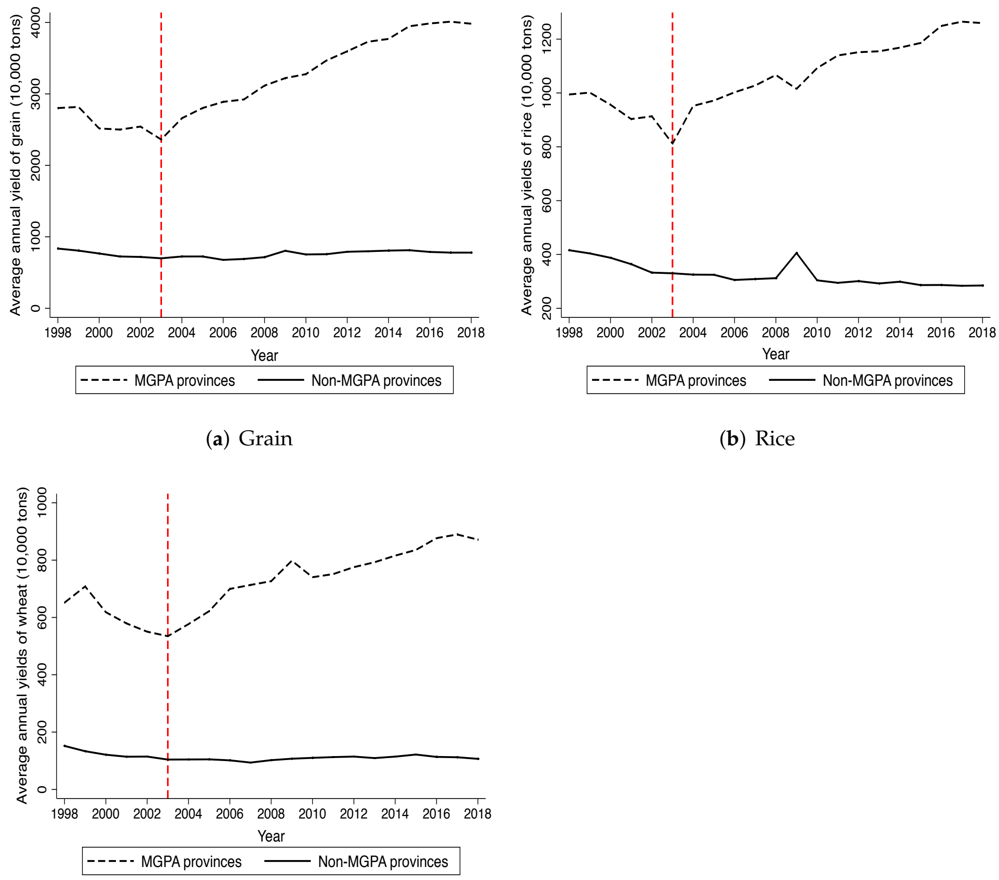
H0: the variable is normally distributed.

Lastly, in terms of the endogeneity which may result from the omission of variables, errors-in-variables, and simultaneous causality [64], we have employed an instrumental variables (IV) estimation in the section of robustness check to relieve potential endogeneity and our baseline results remain significant after using an IV estimation. IV estimation is a widely used approach to relieve potential endogeneity in many empirical studies [69]. Besides, to avoid the omission of variables, we also include some topographic and meteorological factors that may affect crop production in the section of robustness check and our baseline results remain significant after controlling for other variables. Such treatment could relieve the potential estimation bias resulted from the endogeneity.

4.2. DD Estimation

Figure 2 shows the annual yield of grain, rice and wheat in the treated and control groups, namely MGPA and non-MGPA provinces. These graphs show that the yields for the three crops approximately perform some similarity in the years before the enactment of the MGPA policy, which agrees with the parallel historic paths assumption of DD estimation. The trends tentatively suggest that the MGPA provinces saw a higher output growth after 2003 than the non-MGPA provinces, and this will be examined in more detail next.

Table 6 shows the results for grain, rice and wheat. Columns (1), (3) and (5) include the controls of province-specific annual effects except year and province effects to reduce the estimation bias caused by potential province-specific annual variations. To control for other ongoing policies that may bias the estimation, columns (2), (4) and (6) also include the dummy variables for the two agricultural policies discussed above. The coefficients for the treatment effects, $D_i \times T_t$, are all positively significant suggesting that across the three crops, the implementation of MGPA policy increased crop yields, with an average increase of 27.5% for grain yields, 47.8% for rice yields and 35.5% for wheat yields. These treatment effects seem to be greater than expected, but are better explained after controlling other independent variables (planting areas per capita, mechanization and transfer payment per capita) in the following mechanism analysis which explores the potential causal channels of the treatment effects.



(**a**) Grain (**b**) Rice

(**c**) Wheat

Figure 2. Yields of grain, rice and wheat.

In addition to the baseline result, there are also several interesting findings concerning factors affecting crop production. First, the positive relationship between crop production and pesticide use is valid for all three crops. However, only wheat production is positively associated with fertilizer use. The non-significant estimates for grain and rice yields may be attributed to the overuse of fertilizer. Chemical fertilizer overuse is common and serious in China with fertilizer use already severely exceeding international standards [70]. Second, the statistically significant coefficients for urbanization agree with previous findings showing that crop production increases with urban expansion because people's diets and demand for agricultural products are changed and diversified food consumption needs greater crop production [57]. Third, improving rural finances is beneficial to the increase in crop production. China has many smallholder farmers who are extremely vulnerable to unexpected events, so rural financial services, such as agricultural insurance, could protect farmers when these events occur and therefore encourage farmers to increase their investment in crops.

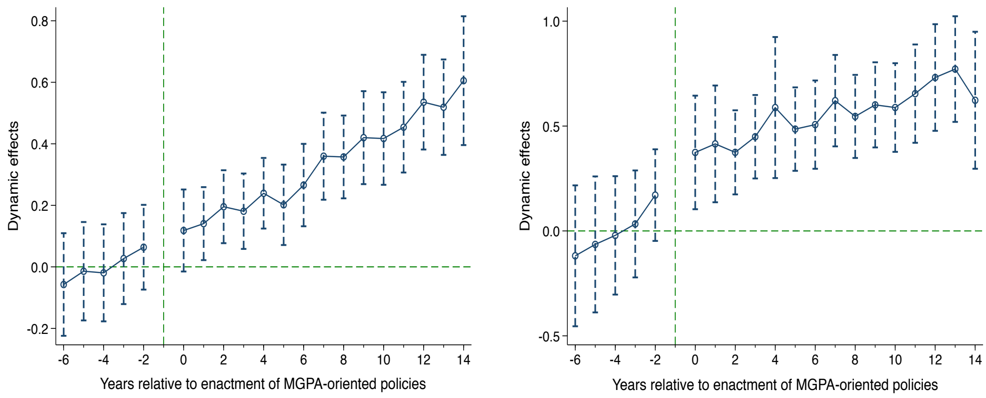
Table 6. The baseline DD estimation.

Dep. Var.: Yields	Grain		Rice		Wheat	
	(1)	(2)	(3)	(4)	(5)	(6)
$D_i \times T_t$	0.271 ***	0.275 ***	0.481 ***	0.478 ***	0.350 ***	0.355 ***
	(0.027)	(0.027)	(0.055)	(0.055)	(0.106)	(0.107)
Pesticide	0.275 ***	0.280 ***	0.178 ***	0.174 ***	0.535 ***	0.524 ***
	(0.029)	(0.029)	(0.056)	(0.054)	(0.163)	(0.160)
Fertilizer	0.016	0.022	0.032	0.017	0.214 *	0.231 *
	(0.020)	(0.022)	(0.032)	(0.029)	(0.124)	(0.126)
Fixed-asset investment	0.099 ***	0.095 ***	−0.040	−0.042	0.372 ***	0.362 ***
	(0.030)	(0.030)	(0.064)	(0.066)	(0.112)	(0.111)
Non-agricultural income	−0.008	−0.010	0.243 ***	0.249 ***	1.071 ***	1.083 ***
	(0.063)	(0.065)	(0.073)	(0.069)	(0.195)	(0.195)
Trade openness	−0.116	−0.115	−0.172	−0.168	1.025 ***	1.030 ***
	(0.090)	(0.090)	(0.105)	(0.105)	(0.318)	(0.318)
Urbanization	−0.429 ***	−0.374 ***	−0.221 **	−0.339 **	−0.862 **	−0.750 **
	(0.093)	(0.087)	(0.153)	(0.149)	(0.417)	(0.372)
Industrialization	−0.023	0.082	0.727 *	0.372	−2.007 ***	−1.812 **
	(0.231)	(0.227)	(0.387)	(0.387)	(0.762)	(0.811)
Financial level	0.166 ***	0.164 ***	0.156 *	0.167 *	0.242 *	0.237 *
	(0.054)	(0.053)	(0.087)	(0.091)	(0.101)	(0.100)
LRLS		Yes		Yes		Yes
Tax		Yes		Yes		Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	555	555	535	535	535	535
R^2	0.929	0.927	0.986	0.986	0.962	0.962

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

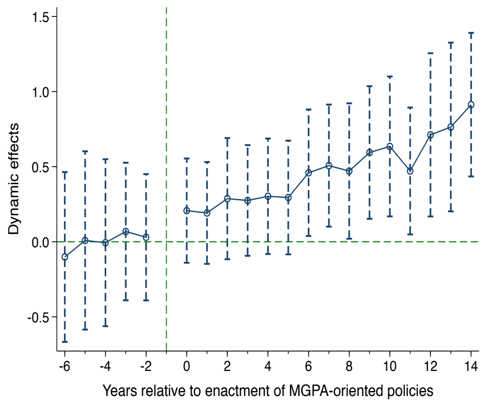
4.3. ET-DD Estimation

Figure 3 shows the estimated coefficients along with the 95% confidence intervals for the dynamic treatment effects. The coefficients for the pre-MGPA years (k = −2∼k = −6) are all statistically distinguishable from zero, suggesting that the parallel trends assumption holds. After the implementation of MGPA policies, there is an immediate and lasting increase in grain and rice yields implying that the treatment effects of the MGPA policy are sustainable. For wheat yields, the treatment effect becomes significant six years after the policy's implementation. Such a delayed treatment effect may be attributed to farmers being less motivated to plant wheat as a result of its decreasing profitability[7].



(**a**) Grain (**b**) Rice

Figure 3. *Cont.*



(**c**) Wheat

Figure 3. Tests for parallel trends.

4.4. PSM-DD Estimation

When selecting matching covariates, one rule for selection is that the covariates are meant to be predictors of post-intervention outcomes, which are not themselves affected by the event [50]. To this end, our matching covariates include rural family size, sex ratio, educational attainment and agricultural land per capita. To improve the sample efficiency of the estimates [71], we removed treated observations whose propensity scores were out of the range of those of the control groups. The PSM-DD estimates based on the matched sample are shown in Table 7. The coefficients of the treatment effect ($D_i \times T_t$) for grain, rice and wheat are all positively significant whether controlling for province-specific annual effects or two other ongoing policies. The magnitudes of the coefficients are quite similar to the results of the DD estimation. Thus, our baseline findings from the DD estimation remain valid after using the PSM-DD for mitigating selection bias.

Table 7. The PSM-DD estimation.

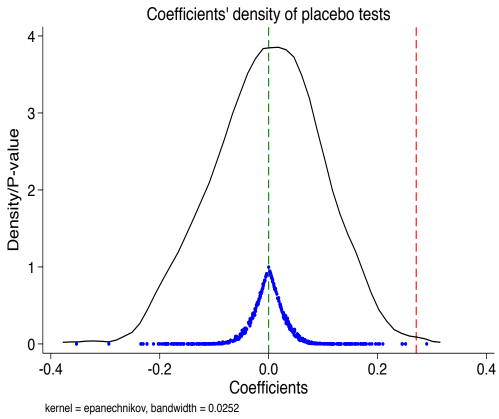
Dep. Var.: Yields	Grain		Rice		Wheat	
	(1)	(2)	(3)	(4)	(5)	(6)
$D_i \times T_t$	0.246 ***	0.253 ***	0.448 ***	0.442 ***	0.382 ***	0.383 ***
	(0.026)	(0.025)	(0.054)	(0.054)	(0.107)	(0.108)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
LRLS		Yes		Yes		Yes
Tax		Yes		Yes		Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	546	546	526	526	526	526
R^2	0.928	0.926	0.987	0.987	0.963	0.963

Standard errors in parentheses. *** $p < 0.01$.

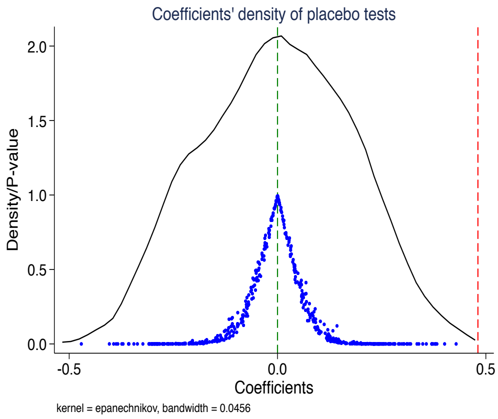
4.5. Robustness Checks

In this section, we perform three further robustness checks on our baseline findings. They are placebo tests using alternative treatment provinces, an instrumental variables estimation using local annual production of raw coal as the instrumental variable for the enactment of the MGPA policy, and case studies using synthetic control methods.

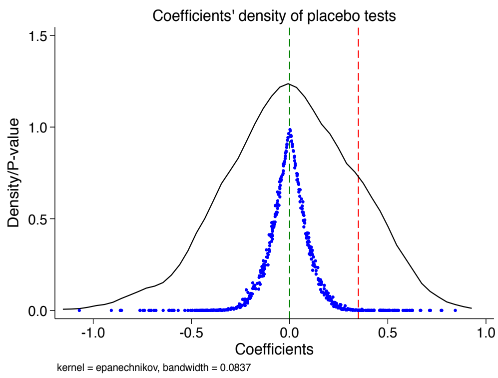
Placebo tests: To verify DD estimation, Chetty et al. [72] recommended using "fake" treatment groups, namely, randomly assigning policy shocks to sample areas. Specifically, for our estimation sample, 13 fake MGPA provinces were randomly selected from the 31 provinces and the remaining 18 provinces become fake control groups. Then, a series of fake treatment variables i.e., $D_i^{fake} \times T_t$, were constructed based on that random assignment. Given that these randomly constructed treatment provinces were not necessarily implemented with real MGPA oriented policies, the outcome of interest should be insignificant. In other words, any significant coefficients for fake treatment effects, β^{fake}, would suggest the invalidity of our baseline DD estimation. Following the method of Cai et al. [73], to rule out bias from any rare events, we carried out this random data generating procedure for 500 times. Figure 4 shows the kernel density of 500 random estimates and associated p-values for grain, rice and wheat yields. The mean values of the fake treatment effect for three crops are all around zero, specifically, the mean coefficient is -0.001 for grain, 0.003 for rice and 0.001 for wheat. The distribution center of 500 random estimates for three crops are all close to zero and their associated p-values are mostly larger than 0.1. Our real coefficients for treatment effects, represented by the red line, clearly differ from that of the placebo tests. Thus, these results again lend support to our baseline DD estimation.



(**a**) Grain



(**b**) Rice



(**c**) Wheat

Figure 4. Placebo tests.

Instrumental variables (IV) estimation: Using IV estimation can help remove potential bias arising from the pre-existing differences between the treatment and control groups [74]. Specifically, instrumental variables can rule out the pre-trends caused by confounders between the treatment and control groups [47]. In this study, we selected local annual production of raw coal as the instrumental variable for the enactment of the MGPA policy. There are two reasons that display the validity of using this instrumental variable. First, the origin of most coal is plant debris in wetlands from hundreds of millions of years ago in swampy forests. Hence, regions that have a large production capacity of raw coal are often agriculture-friendly places with rich natural resources, and MGPA policy is more likely to be implemented in such provinces. Second, to our knowledge, there is no direct relationship between the production of raw coal and crop yields.

Table 8 shows the two-stage least squares (2SLS) regression of the instrumental variables estimation. The first-stage results are presented in columns (1), (3) and (5). The coefficients of the instrumental variable, $Rawcoal_i \times T_t$, are all significantly positive suggesting that the large production capacity of raw coal is a valid indicator for the enactment of MGPA policies. Columns (2), (4) and (6) show the second-stage results for grain, rice and wheat, respectively. The treatment effects remain statistically positive and significant, with the magnitude of coefficients being even bigger. These 2SLS results imply that our baseline findings in DD estimation are robust.

Table 8. Instrumental variables estimation.

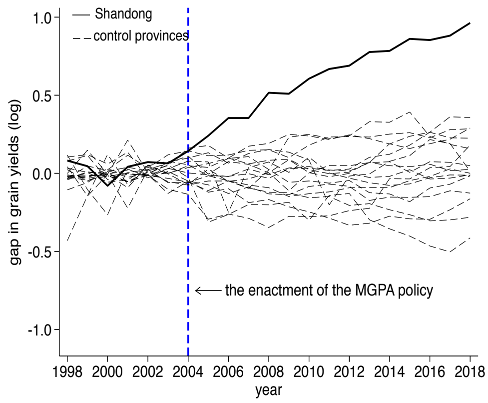
	Grain		Rice		Wheat	
Dep. Var.:	$D_i \times T_t$	**Grain Yields**	$D_i \times T_t$	**Rice Yields**	$D_i \times T_t$	**Wheat Yields**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$Rawcoal_i \times T_t$	0.055 ***		0.052 ***		0.052 ***	
	(0.010)		(0.002)		(0.010)	
$D_i \times T_t$		1.332 ***		1.072 ***		3.116 ***
		(0.231)		(0.360)		(0.962)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	571	571	550	550	563	563
R^2	0.783	0.927	0.784	0.978	0.782	0.873

Standard errors in parentheses. *** $p < 0.01$.

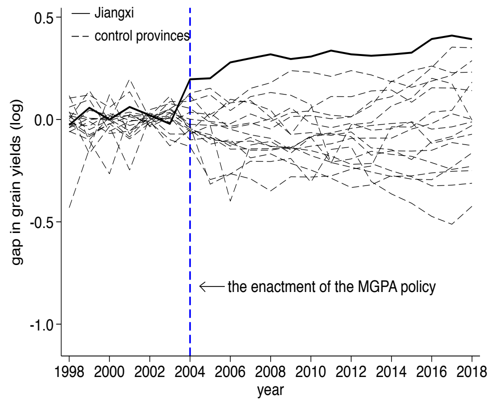
Synthetic control methods: The synthetic control method, proposed by Abadie et al. (2007) [75], can effectively be used for comparative studies when exact matches are unavailable, which offers a sensible generalization of DD estimation [76]. We carried out comparative case studies focusing on the grain yields of three MGPA provinces. The three provinces were Shandong, Jiangxi and Liaoning, located in three traditional agricultural zones, specifically the Yellow River, Huai River and Hai River, the middle reaches of the Yangtze River, and the northeast of China.

We first constructed a synthetic Shandong, Jiangxi and Liaoning from the donor pool, all the non-MGPA provinces. The synthetic Shandong, Jiangxi and Liaoning mirrored the values of the predictors[8] of grain yields in real Shandong, Jiangxi and Liaoning before the establishment of MGPA. We then estimated the treatment effect of the MGPA policy on grain yields as the difference in grain yields between case provinces and their synthetic versions in the years after the MGPA were established. Figure A1 shows that the post-intervention growth paths of the three provinces significantly increased over the growth paths of their synthetic versions.

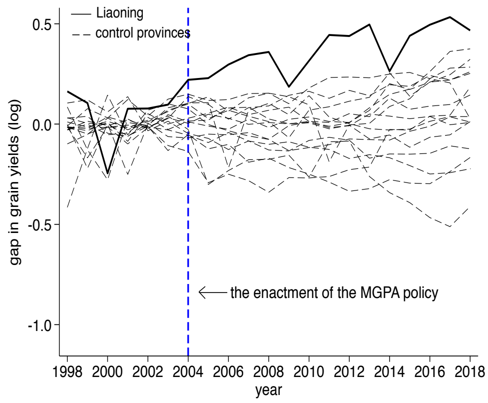
We further carried out a series of placebo tests confirming that our estimated treatment effects for the three case provinces were unusually larger relative to the distribution of fake treatment effects obtained from applying the same synthetic control analysis to the donor provinces. Figure 5 shows the results of the placebo tests for Shandong, Jiangxi and Liaoning. The dotted lines show the difference in grain yields between each province in the donor pool and their synthetic versions. The superimposed solid lines indicate the differences for case provinces. As the graphs show, the estimated difference for case provinces during the 2004–2018 period was unusually larger relative to the distribution of the differences for the donor provinces. These results illustrate the link between the MGPA policy and grain yields, which further support our baseline findings.



(**a**) Shandong



(**b**) Jiangxi



(**c**) Liaoning

Figure 5. Synthetic control methods.

Controls for other variables: It is evident that the agricultural activity is closely related to some topographic and meteorological factors. To test the validity of our baseline result, several topographic and meteorological variables are incorporated into the regression analysis. Given the data accessibility at the provincial level, relief degree of land surface (RDLF), surface water resources (SF), sunshine hours (SH), temperature (TEM) and precipitation (Pre) are included as control variables. Following Feng et al. [77], RDLS is defined as the topographic relief above the horizontal surface of average elevation in a certain area, and it is an important index for evaluating environment conditions[9]. The dataset uses provinces as the statistical unit and is based on 1 km × 1 km raster data for extraction which serves as a macro scale regional assessment [78]. The surface water resources data is collected from China Water Statistical Yearbook (1998–2018). The data of sunshine hours, temperature and precipitation are collected from China Meteorological Data Network.

Table 9 reports the result of controlling for the topographic and meteorological factors. The coefficients for the treatment effects, $D_i \times T_t$, are still positively significant and similar to the baseline results, suggesting that the treatment effect of the MGPA policy is still significant even after controlling the topographic and meteorological factors. One interesting finding is that RDLS is negatively associated with the agricultural output, which shares the similar conclusion of Krummel and Su [79].

Table 9. Controls for other variables.

Dep. Var.:	**Grain**		**Rice**		**Wheat**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$D_i \times T_t$	0.277 ***	0.277 ***	0.496 ***	0.496 ***	0.346 ***	0.346 ***
	(0.026)	(0.026)	(0.055)	(0.055)	(0.109)	(0.109)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
RDLS	−5.258 ***	−5.258 ***	−13.296 ***	−13.296 ***	−10.102 ***	−10.102 ***
	(1.785)	(1.785)	(3.741)	(3.741)	(9.205)	(9.205)
SF	−0.027 **	−0.027 **	−0.010	−0.010	−0.006	−0.006
	(0.014)	(0.014)	(0.017)	(0.017)	(0.043)	(0.043)
SH	0.002	0.002	0.024	0.024	−0.838	−0.838
	(0.154)	(0.154)	(0.205)	(0.205)	(0.529)	(0.529)
TEM	0.114	0.114	−0.123	−0.123	−0.224	−0.224
	(0.177)	(0.177)	(0.235)	(0.235)	(0.542)	(0.542)
Pre	0.139	0.139	−0.188	−0.188	−0.173	−0.173
	(0.085)	(0.085)	(0.153)	(0.153)	(0.305)	(0.305)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	571	571	550	550	563	563
R^2	0.985	0.985	0.987	0.987	0.962	0.962

Standard errors in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Controls for other cultivated land spatial planning schemes: A threat to the identification is that the treatment effects would be confounded by some other cultivated land spatial planning schemes. After studying Chinese government documents, we found two land spatial planning schemes that may have biased the estimation. One is the cultivated land balance program (CLB). In 1999, given the magnitude of the cultivated land loss in China, the National Bureau of Land Management (the predecessor of the MLRC) adopted the CLB of maintaining the existing amount of cultivated land nationally. CLB focused particularly on the balance between cultivated land losses by construction occupation and cultivated land supplement. According to this approach, if a plot of cultivated land was replaced by construction, the land developer should create another plot of cultivated land [80]. Another one is the main functional areas planning (MFAP) which incorporated national nature reserves, world cultural and natural heritage sites, national scenic attractions and forest parks into the national list of prohibited development areas. Specifically, it divided the national land space into four main functional areas: optimized development areas, key development areas, restricted development areas and prohibited development areas. It was aimed to effectively improve the efficiency of space utilization and realize the goal of sustainable development, which also incorporated the space utilization of arable lands [81]. Therefore, both land planning programs had the potential to involve the redistribution of cultivated land and confound the treatment effect of the MGPA policy. To relieve any confounding effects of the two land planning programs, two dummy variables for the implementation of these land planning programs were included. CLB indicates the enactment of the cultivated land balance program and $MFAP$ indicates the implementation of the main functional areas planning.

Table 10 shows the estimation result of controlling for the cultivated land balance program and the main functional areas planning. The coefficients for the treatment effects, $D_i \times T_t$, are still positively significant, suggesting that the contribution of the MGPA policy to the increase in grain production is still significant even after controlling the potential confounding effect of other land spatial planning schemes. For the empirical comparison between the MGPA policy and other land spatial planning schemes, it may require systematic evaluation and is waiting for future research.

Table 10. Controls for other cultivated land spatial planning schemes.

Dep. Var.:	Grain		Rice		Wheat	
	(1)	(2)	(3)	(4)	(5)	(6)
$D_i \times T_t$	0.296 ***	0.293 ***	0.415 ***	0.415 ***	0.285 **	0.288 **
	(0.025)	(0.025)	(0.042)	(0.042)	(0.105)	(0.106)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
CLB	0.155 ***		0.158 *		0.256 *	
	(0.042)		(0.084)		(0.149)	
MFAP		0.178 ***		0.093 **		0.101
		(0.033)		(0.041)		(0.104)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	571	571	550	550	563	563
R^2	0.982	0.982	0.985	0.985	0.956	0.956

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.6. Alternative Causal Channels

The analysis so far has provided evidence that the MGPA policy can significantly increase local grain, rice and wheat yields. In this section, we will further explore the causal channels of such positive treatment effects in terms of agricultural planting areas, mechanization level and transfer payments using the causal steps approach built by Heerink et al. (2006) [82]. The analysis of causal channels here only focuses on grain yields and the results for rice and wheat can be found in the Appendix A.

Expanding planting areas: Column (1) of Table 11 shows the first-step results, suggesting that the implement of the MGPA policy significantly increased local grain planting area per capita. Specifically, the grain planting area increased by 2.7% on average, with the figures for rice and wheat being 0.92% and 0.48%, respectively (in Appendix A Tables A1 and A2).

Column (3) of Table 11 shows the second-step results. The coefficients of $D_i \times T_t$ and planting area per capita are all positively significant at the 1% level indicating that, combined with the first-step result, the causal channel of expanding planting areas is statistically valid for grain. The coefficient of $D_i \times T_t$ fell from 0.271 (column (2)) to 0.166 after controlling for planting area per capita. This consolidates the idea that the implementation of the MGPA policy raised grain yields by increasing planting areas. This is also the case for the increase in rice yields with the treatment effect decreasing from 0.48 to 0.39 when the rice planting area is included in regression. However, no causal link was found between wheat yields and expanding planting areas.

Table 11. Channel 1—expanding planting areas.

Dep. Var.:	Planting Area per Capita	Grain Yields	Grain Yields
	(1)	(2)	(3)
$D_i \times T_t$	0.027 ***	0.271 ***	0.166 ***
	(0.003)	(0.027)	(0.048)
Planting area per capita			3.895 ***
			(1.410)
Control Variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes
N	555	555	555
R^2	0.940	0.984	0.987

Standard errors in parentheses. *** $p < 0.01$.

Improving mechanization level: Column (1) of Table 12 shows that the estimated impact of the MGPA policy on local mechanization, $D_i \times T_t$, was significant and positive. Specifically, the implementation of the MGPA policy improved local mechanization by 21.8%. This can be attributed to the MGPA-preferred agricultural machinery subsidies, a sub-project of the MGPA policies. Many studies suggest that agricultural mechanization in China, and especially in MGPA, has been accelerated by the government's increase of the subsidy for agricultural machinery purchases since 2004 [83].

The coefficients in the first two rows of column (3) are significantly positive. The treatment effect, the coefficient of $D_i \times T_t$, in regression (3) is slightly smaller than that in regression (2). These results suggest that the treatment effect of the MGPA policy is partially caused by boosting mechanization. For rice, such a causal channel exists, however, it is statistically insignificant for wheat.

Table 12. Channel 2—improving mechanization.

Dep. Var.:	Mechanization	Grain Yields	Grain Yields
	(1)	(2)	(3)
$D_i \times T_t$	0.218 ***	0.271 ***	0.263 ***
	(0.040)	(0.027)	(0.027)
Mechanization			0.037 *
			(0.021)
Control Variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes
N	555	555	555
R^2	0.783	0.984	0.985

Standard errors in parentheses. * $p < 0.1$, *** $p < 0.01$.

Increasing transfer payments: As column (1) in Table 13 shows, the transfer payments for MGPA have increased by 30.2% since the enactment of the MGPA policy. The second-stage results in columns (2) and (3) illustrate that the causal channel that the MGPA policy boosts grain yields by increasing the transfer payments to MGPA farmers. Such direct financial support can be realized in many ways, including rewarding counties for producing a large harvest. This MGPA-specific policy not only motivates farmers to plant more crops, but also reduces the financial pressure on local governments. Heilongjiang, one of the MGPA, was offered a 21.13 billion yuan reward in total from 2005 to 2013. Meanwhile, Heilongjiang has doubled its crop yields in under five years.

The causal channel for transfer payments is very obvious for wheat yields. The results, reported in Appendix A Table A2, show that the treatment effect falls from 0.350 to 0.244 when including the transfer payments into the baseline DD regression. Combined with the fact that the profit from planting wheat is shrinking, expanding direct transfer payments for wheat-growing farmers has become one of the few effective ways of increasing their motivation to plant the crop. However, for rice, there is no robust causal link between rice yields and increased transfer payments.

Table 13. Channel 3—increasing transfer payments.

Dep. Var.:	Transfer Payment	Grain Yields	Grain Yields
	(1)	(2)	(3)
$D_i \times T_t$	0.302 ***	0.271 ***	0.229 ***
	(0.059)	(0.027)	(0.026)
Transfer payment per capita			0.140 ***
			(0.023)
Control Variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes
N	555	555	555
R^2	0.942	0.984	0.986

Standard errors in parentheses. *** $p < 0.01$.

5. Discussion

5.1. The Policy Recommendations

The global food security challenge is straightforward in the context of the climate change and widespread of COVID-19 pandemic. As China feeds approximately 18% of the world population, China's food security is closely related to the stability of the global food system. In the long run, China's stable food production is still faced with great challenges, e.g., the rapid urbanization and spatial mismatch in agriculture resources. Looking back to history, China experienced a significant drop in crop production in 2003 which posed a substantial threat to national food security. After this crop production crisis, 13 MGPA regions were established by Ministry of Finance China. However, the empirical evidence of such land management practice's effect on crop production remains unclear. Identification of the mechanism that how the MGPA policy affect crop production will provide important policy implications for maintaining food security from a perspective of land management practices.

This paper focuses on exploring the impact of the MGPA policy on food security from the perspective of crop (grain, rice and wheat) production. The baseline results of this paper demonstrated that the establishment of the MGPA regions provided favorable conditions for increasing crop production. This result is consistent with the findings of the research on the relationship between land management policy and food production, which finds that the effective land and resource governance system that provides improved access, control, and rights to land and other natural resources is a necessary condition for achieving stable crop production [27]. Therefore, the implementation of the MGPA policy is without doubt a successful land management policy for achieving food security. Given the uncertainty in future trends of global food production due to a series of challenges, China should continue to consolidate policy support in the MGPA regions. Meanwhile, the fact that natural resources, especially land resources, is irreversible [84] reminds policymakers that they should fundamentally recognize the value of natural resources in the MGPA regions. Then the future policy preference in agriculture should be given more to the MGPA regions. Besides, the features of the MGPA policy could provide some policy implications for maintaining food security by some land management practice. First, as the MGPA policy is followed by some sub-policies which aim at dealing with different issues in China's agriculture at different times, the land management policy should be a dynamic policy which could be adaptive to new challenges faced by agricultural production. The reason is that the global food problem concerns the dynamics of economic growth, trade policy and even climate change [53]. The land management practice must be designed for continual improvement and adjustment to meet the needs of a changeable environment. Second, the MGPA policy is not merely for reallocating land resources for food production, but an integrated policy which is combined with some monetary and technical support policies. Similarly, such finding is acknowledged by Barry and Augustinus [85], who find that the comprehensive land policies which utilize sub-policies with different domains could exert a larger impact. Hence, the design of land management policy should incorporate other policy packages. In this way, these integrated sub-policies support and complement each other to realize the policy objective.

The findings in investigating alternative causal channels of the treatment effect found that the MGPA policy raised crop yields mainly by expanding planting areas, improving the level of mechanization and increasing transfer payments. It is evident that the irreversible land resource is the most important factor for agricultural production. However, in the context of China's rapid urbanization, the expansion of large cities and regions that have experienced rapid economic growth and urban development, causing the loss of cultivated land [86,87]. Hence, the policies designed to protect cultivated land, especially in the MGPA regions, are urgently needed. To preserve arable land, it is necessary not only to maintain quantity but also to improve quality, and to keep the double red line of quantity and quality [88]. It is also necessary to invest in agricultural research as agricultural technology is considered the main driver in solving China's shortage of arable land [89]. In terms of the second causal channel of improving the level of mechanization, it is consistent with many empirical research's finding. For example, Gong finds that over the past 25 years, China's agricultural growth has mainly been attributed to the improvement of productivity, especially the improvement of mechanization level in agriculture [26]. Therefore, the government should enhance the knowledge and skills of adult members, including household head, to adopt the latest mechanization technologies for land management. Agricultural policy should also focus on promoting agricultural mechanization technologies that are economically viable and friendly to females and older people to increase the adoption of agricultural mechanization. For the last causal channel of increasing transfer payments, it is also in keeping with the conclusion of Hu et al. that the financial support significantly improves agricultural TFP growth [90]. With the easy access to financial support, farmers can use these financial resources to adopt and foster technology innovations, which are well documented to improve agricultural production [91]. Local governments and banks should continue to improve the financial support for farmers, particularly the usage of financial services in rural areas and in agricultural production. In addition, paying attention to the financial services usage and the availability of credit to individuals with real needs is effective in promoting agricultural production.

5.2. The Methods' Applicability and Results' Reliability

In this paper, the DD model has been employed as a starting point for identifying the treatment effect of the MGPA policy. The applicability of this method is illustrated by other research on identifying treatment effects in policy analysis (see Cheng et al. [92]; Tan et al. [93] and Wang [94]). In general, different from the case of randomized experiments that allow for a simple comparison of treatment and control groups, DD is an evaluation method used in non-experimental settings, which has been widely used in economics, public policy, health research, management and other fields. The use of the DD model is detailedly discussed by Fredriksson et al. [95]. Due to the DD model relies on the parallel trends assumption which requires that in the absence of treatment, the difference between the treatment and control group is constant over time [48], an ET-DD model was employed to not only perform a parallel trends but also served as a robustness check for the baseline DD estimation. Although the DD method is a common strategy for evaluating the effects of policies or programs that are instituted at a particular point in time, sometimes the cross-sectional difference may reduce the comparability between the treatment and control group which eventually leads to a biased estimate. To relieve such concern and provide a good counterfactual for the treatment group, the PSM method was used to mitigate selection bias by matching observations of treatment provinces with control provinces. Such treatment has gained popularity in many empirical studies [96,97].

Although the results in this study could be comparable with the previous findings arguing that land management policy is one of the major driving forces for agricultural development [27,98], however, this research has certain drawbacks. First, agricultural production is a complicated process which is influenced by many factors. The results will be more unbiased if these factors, especially some climatic and topographic factors, are comprehensively considered. Second, this paper evaluated the effectiveness of the MGPA policy merely from the perspective of crop production. However, the indicator system for the MGPA policy can be improved and the results will be more reliable if future research is built in other perspectives. Third, this study used provincial data and could only provide insights into practice at the level of provincial areas and could not be refined at the municipal level. One possible direction for future work is to use more detailed county data, even micro-data to study the effectiveness of the MGPA policy.

6. Conclusions

Based on China's interprovincial panel data from 1998 to 2018, this study used a difference-in-differences (DD) estimation strategy to analyze the treatment effect of the MGPA policy by taking the assignment of 13 MGPA as a quasi-experiment. It primarily draws the following conclusions: (i) the MGPA policy did indeed increase crop production, specifically, grain, rice and wheat yields, and such positive treatment has been sustainable over the long term. Across the three kinds of crops, the MGPA policy led to an average rise of 27.5% for grain yields, 47.8% for rice yields and 35.5% for wheat yields. (ii) After the implementation of the MGPA policy, there is an immediate and lasting increase in grain and rice yields, however, for wheat yields, the treatment effect became significant six years after the policy's implementation. Such a delayed treatment effect may be attributed to farmers' being less motivated to plant wheat as a result of its decreasing profitability in the first few years after the policy implementation. (iii) The MGPA policy has increased grain yields mainly by expanding planting areas, improving mechanization levels and increasing transfer payments. Specifically, due to the establishment of the MGPA regions, the grain planting area increased by 2.7% on average, with the figures for rice and wheat being 0.92% and 0.48%, respectively. The implementation of the MGPA policy improved local mechanization by 21.8% and increased the transfer payments by 30.2%. These findings from the evaluation of the MGPA policy greatly increase understanding of how land management policies positively affect crop production in such a large developing country. Given the great similarity to agriculture production in developing countries, these findings may enlighten policymakers in some less well-developed countries on boosting crop production and eradicating hunger.

Author Contributions: Conceptualization, W.H.; methodology, W.H.; software, W.H.; validation, W.H. and L.L.; data curation, W.H.; writing—original draft preparation, W.H.; writing—review and editing, W.H., L.L. and Z.C.; visualization, W.H.; funding acquisition, L.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by The National Key Research and Development Program of China (Grant no. 2018YFE0107000) and Ministry of Science and Technology of the People's Republic of China (Grant no. 2016YFD0201306).

Institutional Review Board Statement: Not applicable.

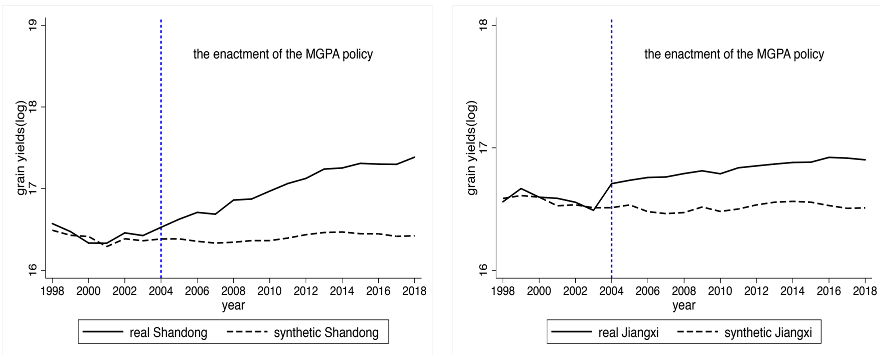
Informed Consent Statement: Not applicable.

Data Availability Statement: The data were collected from various sources, including China Rural Statistical Yearbooks (Ministry of Agriculture, 1998–2018), National Agricultural Product Cost and Revenue Survey Data books (Ministry of Agriculture, 1998–2018), China Agricultural Statistical Yearbooks (Ministry of Agriculture, 1998–2018), China Statistical Yearbooks on Environment (Ministry of Environment, 1998–2018), and China Statistical Yearbooks (NBSC, 1998–2018).

Acknowledgments: We would like to express our great gratitude to Xi Yang from Gansu State Grid for her companion in drafting the manuscript.

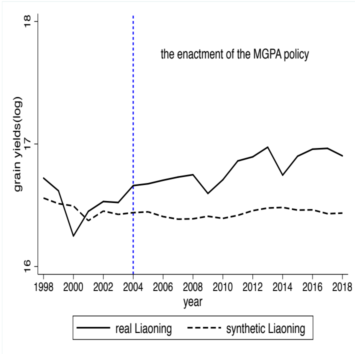
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A



(**a**) Shandong (**b**) Jiangxi

Figure A1. *Cont.*



(**c**) Liaoning

Figure A1. Synthetic control methods without placebo tests.

Table A1. The channels of rice.

	Channel 1			Channel 2			Channel 3		
Dep. Var.:	**Planting Area per Capita**	**Rice Yields**	**Rice Yields**	**Mechanization**	**Rice Yields**	**Rice Yields**	**Transfer Payments**	**Rice Yields**	**Rice Yields**
$D_i \times T_t$	0.009 ***	0.481 ***	0.391 ***	0.218 ***	0.481 ***	0.475 ***	0.302 ***	0.481 ***	0.483 ***
	(0.001)	(0.055)	(0.064)	(0.040)	(0.055)	(0.055)	(0.059)	(0.055)	(0.061)
Planting area per capita			9.752 ***						
			(1.953)						
Mechanization						0.029 **			
						(0.043)			
Transfer payment									−0.006
									(0.041)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	537	535	535	555	535	535	555	535	535
R^2	0.942	0.986	0.987	0.783	0.986	0.987	0.942	0.986	0.986

Standard errors in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Table A2. The channels of wheat.

	Channel 1			Channel 2			Channel 3		
Dep. Var.:	**Planting Area per Capita**	**Wheat Yields**	**Wheat Yields**	**Mechanization**	**Wheat Yields**	**Wheat Yields**	**Transfer Payments**	**Wheat Yields**	**Wheat Yields**
$D_i \times T_t$	0.005 ***	0.350 ***	0.339 ***	0.218 ***	0.350 ***	0.351 ***	0.302 ***	0.350 ***	0.244 **
	(0.001)	(0.106)	(0.109)	(0.040)	(0.106)	(0.106)	(0.059)	(0.106)	(0.104)
Planting area per capita			2.297						
			(5.167)						
Mechanization						−0.003			
						(0.057)			
Transfer payment									0.365 ***
									(0.083)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	537	535	535	555	535	535	555	535	535
R^2	0.942	0.986	0.987	0.783	0.986	0.987	0.942	0.986	0.986

Standard errors in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Notes

1. The geographical dividing line of North-South China is formed by the Qinling Mountains and the Huai River, which are also environmental features affecting climate regulation, soil conservation, water maintenance and biodiversity conservation.
2. In this paper, the enactment year of MGPA policy is set to 2004 because the official release of MGPA documents was on 3 December 2003 and the MGPA policy started in 2004.
3. Mu is a Chinese unit of land measurement. It is commonly 806.65 square yards (0.165 acre, or 666.5 square meters).

[4] The income is classified into four types: (i) income earned from agriculture, forestry, livestock, and fishery; (ii) income earned from self-employment in non-farm activities such as industry, transportation, construction, and services, (iii) income earned from formal or informal wage, including salary, allowance, bonus, dividend, and other kinds of remuneration, and (iv) other non-productive incomes, such as pensions, transfers, grants/subsidies, rents, and financial income. (ii) and (iii) are normally considered as non-farm household income.

[5] This law was formulated in accordance with the Constitution for the purpose of stabilizing and improving the two-level management system based on household contract management, giving the people long-term and guaranteed land use rights, and protecting the legitimate rights and interests of the parties to the rural land contract.

[6] For a long time, China's industrialization and modernization have benefited from agricultural tax. However, agricultural tax was cancelled due to the decline of the relative importance of agricultural tax in the whole fiscal revenue.

[7] From 2008 to 2016, the profit from planting wheat decreased from 164.51 yuan per mu to 21.29 yuan per mu. This fall was mainly a result of the slow upward trend of wheat price relative to the rapid rise in planting costs. Meanwhile, the profit from planting rice is about 13 times higher than that of wheat.

[8] The predictors of grain yields are rural household size, sex ratio, educational attainment, agricultural land per capita, and grain yields in 1998, 2000 and 2002.

[9] RDLS is defined as follows: $RLDS = ALT/100 + \{((Max(H) - Min(H)) \times (1 - P(A)/A))\}/500$, where RDLS is relief degrees of land surface; ALT is the average elevation in a grid cell (m); Max(H) and Min(H) represent the highest and lowest altitudes in this grid cell respectively (m); P(A) is the area of flat land (km^2); and A is the total area of the extraction unit.

References

1. Liu, Y.; Zhou, Y. Reflections on China's food security and land use policy under rapid urbanization. *Land Use Policy* **2021**, *109*, 105699. [CrossRef]
2. Singh, R.K.; Joshi, P.K.; Sinha, V.S.P.; Kumar, M. Indicator based assessment of food security in SAARC nations under the influence of climate change scenarios. *Future Foods* **2022**, *5*, 100122. [CrossRef]
3. Rashidi Chegini, K.; Pakravan-Charvadeh, M.R.; Rahimian, M.; Gholamrezaie, S. Is there a linkage between household welfare and income inequality, and food security to achieve sustainable development goals? *J. Clean. Prod.* **2021**, *326*, 129390. [CrossRef]
4. Ma, N.L.; Peng, W.; Soon, C.F.; Noor Hassim, M.F.; Misbah, S.; Rahmat, Z.; Yong, W.T.L.; Sonne, C. Covid-19 pandemic in the lens of food safety and security. *Environ. Res.* **2021**, *193*, 110405. [CrossRef] [PubMed]
5. Dasgupta, S.; Robinson, E. Impact of COVID-19 on food insecurity using multiple waves of high frequency household surveys. *Sci. Rep.* **2022**, *12*, 1865. [CrossRef] [PubMed]
6. Chen, L.; Chang, J.; Wang, Y.; Guo, A.; Liu, Y.; Wang, Q.; Zhu, Y.; Zhang, Y.; Xie, Z. Disclosing the future food security risk of China based on crop production and water scarcity under diverse socioeconomic and climate scenarios. *Sci. Total Environ.* **2021**, *790*, 148110. [CrossRef]
7. Lu, S.; Liu, Y.; Long, H.; Guan, X. Agricultural Production Structure Optimization: A Case Study of Major Grain Producing Areas, China. *J. Integr. Agric.* **2013**, *12*, 184–197. [CrossRef]
8. Zhang, L.; Pang, J.; Chen, X.; Lu, Z. Carbon emissions, energy consumption and economic growth: Evidence from the agricultural sector of China's main grain-producing areas. *Sci. Total Environ.* **2019**, *665*, 1017–1025. [CrossRef]
9. Dawadi, B.; Shrestha, A.; Acharya, R.H.; Dhital, Y.P.; Devkota, R. Impact of climate change on agricultural production: A case of Rasuwa District, Nepal. *Reg. Sustain.* **2022**, *3*, 122–132. [CrossRef]
10. do Prado Tanure, T.M.; Miyajima, D.N.; Magalhães, A.S.; Domingues, E.P.; Carvalho, T.S. The Impacts of Climate Change on Agricultural Production, Land Use and Economy of the Legal Amazon Region Between 2030 and 2049. *EconomiA* **2020**, *21*, 73–90. [CrossRef]
11. Yadav, P.; Jaiswal, D.K.; Sinha, R.K. 7—Climate change: Impact on agricultural production and sustainable mitigation. *Glob. Clim. Chang.* **2021**, 151–174. [CrossRef]
12. Shamdasani, Y. Rural road infrastructure & agricultural production: Evidence from India. *J. Dev. Econ.* **2021**, *152*, 102686. [CrossRef]
13. Khan, M.T.I.; Ali, Q.; Ashfaq, M. The nexus between greenhouse gas emission, electricity production, renewable energy and agriculture in Pakistan. *Renew. Energy* **2018**, *118*, 437–451. [CrossRef]
14. Okakwu, I.; Alayande, A.; Akinyele, D.; Olabode, O.; Akinyemi, J. Effects of total system head and solar radiation on the techno-economics of PV groundwater pumping irrigation system for sustainable agricultural production. *Sci. Afr.* **2022**, *16*, e01118. [CrossRef]
15. Lasley, P.; Padgitt, S.; Hanson, M. Telecommunication technology and its implications for farmers and Extension Services. *Technol. Soc.* **2001**, *23*, 109–120. [CrossRef]
16. Khanh Chi, N.T. Driving factors for green innovation in agricultural production: An empirical study in an emerging economy. *J. Clean. Prod.* **2022**, *368*, 132965. [CrossRef]
17. da Silveira, F.; Lermen, F.H.; Amaral, F.G. An overview of agriculture 4.0 development: Systematic review of descriptions, technologies, barriers, advantages, and disadvantages. *Comput. Electron. Agric.* **2021**, *189*, 106405. [CrossRef]

18. Forkuor, G.; Amponsah, W.; Oteng-Darko, P.; Osei, G. Safeguarding food security through large-scale adoption of agricultural production technologies: The case of greenhouse farming in Ghana. *Clean. Eng. Technol.* **2022**, *6*, 100384. [CrossRef]
19. Rizov, M. Institutions, reform policies and productivity growth in agriculture: Evidence from former communist countries. *NJAS-Wagening. J. Life Sci.* **2008**, *55*, 307–323. [CrossRef]
20. Lele, U.; Goswami, S. Agricultural policy reforms: Roles of markets and states in China and India. *Glob. Food Secur.* **2020**, *26*, 100371. [CrossRef]
21. Totin, E.; Segnon, A.; Roncoli, C.; Thompson-Hall, M.; Sidibé, A.; Carr, E.R. Property rights and wrongs: Land reforms for sustainable food production in rural Mali. *Land Use Policy* **2021**, *109*, 105610. [CrossRef]
22. Mazhar, R.; Xuehao, B.; Wei, Z. Fostering sustainable agriculture: Do institutional factors impact the adoption of multiple climate-smart agricultural practices among new entry organic farmers in Pakistan? *J. Clean. Prod.* **2020**, *283*, 124620. [CrossRef]
23. Zhang, D.; Wang, H.; Lou, S. Research on grain production efficiency in China's main grain-producing areas from the perspective of grain subsidy. *Environ. Technol. Innov.* **2021**, *22*, 101530. [CrossRef]
24. Yang, R.; Wang, L.; Xian, Z. Evaluation on the Efficiency of Crop Insurance in China's Major Grain-Producing Area. *Hydrometallurgy* **2010**, *1*, 90–99. [CrossRef]
25. Zhang, Z.; Meng, X.; Elahi, E. Protection of Cultivated Land Resources and Grain Supply Security in Main Grain-Producing Areas of China. *Sustainability* **2022**, *14*, 2808. [CrossRef]
26. Gong, B. New Growth Accounting. *Am. J. Agric. Econ.* **2020**, *102*, 641–661. [CrossRef]
27. Olarinre, A.; Oladeebo, O. Effects of Land Management Practices on Food Insecurity among Farming Households in Osun State, Nigeria. Ph.D. Thesis, Ladoke Akintola University of Technology, Oyo, Nigeria, 2019. [CrossRef]
28. Guo, L.; Li, H.; Cao, X.; Cao, A.; Huang, M. Effect of agricultural subsidies on the use of chemical fertilizer. *J. Environ. Manag.* **2021**, *299*, 113621. [CrossRef]
29. Theriault, V.; Smale, M. The unintended consequences of the fertilizer subsidy program on crop species diversity in Mali. *Food Policy* **2021**, *102*, 102121. [CrossRef]
30. Lin, G.; Takahashi, Y.; Nomura, H.; Yabe, M. Policy incentives, ownership effects, and firm productivity—Evidence from China's Agricultural Leading Firms Program. *Econ. Anal. Policy* **2022**, *73*, 845–859. [CrossRef]
31. Hansen, H.O. Agricultural Policy Schemes: Price and Support Systems in Agricultural Policy. In *Encyclopedia of Dairy Sciences (Third Edition)*, 3rd ed.; McSweeney, P.L., McNamara, J.P., Eds.; Academic Press: Oxford, UK, 2022; pp. 703–713. [CrossRef]
32. Khafagy, A.; Vigani, M. Technical change and the Common Agricultural Policy. *Food Policy* **2022**, *109*, 102267. [CrossRef]
33. Carrer, M.J.; de Souza Filho, H.M.; de Mello Brandão Vinholis, M.; Mozambani, C.I. Precision agriculture adoption and technical efficiency: An analysis of sugarcane farms in Brazil. *Technol. Forecast. Soc. Chang.* **2022**, *177*, 121510. [CrossRef]
34. Assa, H.; Sharifi, H.; Lyons, A. An examination of the role of price insurance products in stimulating investment in agriculture supply chains for sustained productivity. *Eur. J. Oper. Res.* **2021**, *288*, 918–934. [CrossRef]
35. Alam, A.S.A.F.; Begum, H.; Masud, M.M.; Al-Amin, A.Q.; Filho, W.L. Agriculture insurance for disaster risk reduction: A case study of Malaysia. *Int. J. Disaster Risk Reduct.* **2020**, *47*, 101626. [CrossRef]
36. Long, H.; Tu, S.; Ge, D.; Li, T.; Liu, Y. The allocation and management of critical resources in rural China under restructuring: Problems and prospects. *J. Rural Stud.* **2016**, *47*, 392–412. [CrossRef]
37. Su, C.W.; Liu, T.Y.; Chang, H.L.; Jiang, X.Z. Is urbanization narrowing the urban-rural income gap? A cross-regional study of China. *Habitat Int.* **2015**, *48*, 79–86. [CrossRef]
38. Li, T.; Long, H.; Zhang, Y.; Tu, S.; Ge, D.; Yurui, l.; Hu, B. Analysis of the spatial mismatch of grain production and farmland resources in China based on the potential crop rotation system. *Land Use Policy* **2017**, *60*, 26–36. [CrossRef]
39. Rehman, A.; Jian, W. Agricultural Natural Disasters Mitigation in Hebei Province China. *Adv. Mater. Res.* **2014**, *962–965*, 1979–1988. [CrossRef]
40. Veeck, G. Delineating historical and contemporary agricultural production regions for China. *Int. J. Cartogr.* **2022**, *8*, 185–207. [CrossRef]
41. Xiao, P.; Xu, J.; Yu, Z.; Qian, P.; Lu, M.; Ma, C. Spatiotemporal Pattern Differentiation and Influencing Factors of Cultivated Land Use Efficiency in Hubei Province under Carbon Emission Constraints. *Sustainability* **2022**, *14*, 7042. [CrossRef]
42. Li, Y.-l.; Ma, W.-q.; Jiang, G.-h.; Li, G.-y.; Zhou, D.-y. The degree of cultivated land abandonment and its influence on grain yield in main grain producing areas of China. *J. Nat. Resour.* **2021**, *36*, 1439. [CrossRef]
43. Hu, T.; Ju, Z.; Zhou, W. Regional pattern of grain supply and demand in China. *Dili Xuebao/Acta Geogr. Sin.* **2016**, *71*, 1372–1383. [CrossRef]
44. Lu, C.; Liu, A.; Xiao, Y.; Liu, X.; Xie, G.; Cheng, S. Changes in China's Grain Production Pattern and the Effects of Urbanization and Dietary Structure. *J. Resour. Ecol.* **2020**, *11*, 358–365. [CrossRef]
45. Huirne, R.; Meuwissen, M.; Hardaker, J.; Anderson, J. Risk and risk management in agriculture: An overview and empirical results. *Int. J. Risk Assess. Manag.* **2000**, *1*, 125–136. [CrossRef]
46. Stuart, E.; Huskamp, H.; Duckworth, K.; Simmons, J.; Song, Z.; Chernew, M.; Barry, C. Using propensity scores in difference-in-differences models to estimate the effects of a policy change. *Health Serv. Outcomes Res. Methodol.* **2014**, *14*, 166–182. [CrossRef] [PubMed]
47. Li, P.; Lu, Y.; Wang, J. The effects of fuel standards on air pollution: Evidence from China. *J. Dev. Econ.* **2020**, *146*, 102488. [CrossRef]

48. Lawler, E.C. Effectiveness of vaccination recommendations versus mandates: Evidence from the hepatitis A vaccine. *J. Health Econ.* **2017**, *52*, 45–62. [CrossRef] [PubMed]
49. Rosenbaum, P.; Rubin, D. The Central Role of the Propensity Score in Observational Studies For Causal Effects. *Biometrika* **1983**, *70*, 41–55. [CrossRef]
50. Heckman, J.; Ichimura, H.; Todd, P. Matching As An Econometric Evaluation Estimator. *Rev. Econ. Stud.* **1998**, *65*, 261–294. [CrossRef]
51. Makino, A. Photosynthesis, Grain Yield, and Nitrogen Utilization in Rice and Wheat. *Plant Physiol.* **2010**, *155*, 125–129. [CrossRef]
52. Canela, M.; Alegre, I.; Ibarra, A. Dummy Variables. In *Quantitative Methods for Management*; Springer: Cham, Switzerland, 2019; pp. 57–63. [CrossRef]
53. Upton, M. The Economics of Food Production. *Ciba Found. Symp.* **1993**, *177*, 61–71; discussion 71. [CrossRef]
54. Osarfo, D.; Senadza, B.; Nketiah-Amponsah, E. The Impact of Nonfarm Activities on Rural Farm Household Income and Food Security in the Upper East and Upper West Regions of Ghana. *Theor. Econ. Lett.* **2016**, *6*, 388–400. [CrossRef]
55. de Janvry, A.; Sadoulet, E.; Zhu, N. *The Role of Non-Farm Incomes in Reducing Rural Poverty and Inequality in China*; Working Paper Series; Department of Agricultural & Resource Economics, UC Berkeley: Berkeley, CA, USA, 2005.
56. Schneider, A.; Kernohan, D. *The Effects of Trade Liberalisation on Agriculture in Smaller Developing Countries: Implications for the Doha Round*; CEPS Working Documents No. 244, 8 June 2006; CEPS: Brussels, Belgium, 2020.
57. Satterthwaite, D.; Mcgranahan, G.; Tacoli, C. Urbanization and its implications for food and farming. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* **2010**, *365*, 2809–2820. [CrossRef] [PubMed]
58. Zhong, C.; Hu, R.; Wang, M.; Xue, W.; He, L. The impact of urbanization on urban agriculture: Evidence from China. *J. Clean. Prod.* **2020**, *276*, 122686. [CrossRef]
59. Wang, Z.; Sun, G. An empirical analysis of the relationship between China's economic growth efficiency, financial structure and economic development. *Manag. World* **2003**, 13–20. [CrossRef]
60. Zhou, Y.; Li, X.; Liu, Y. Rural land system reforms in China: History, issues, measures and prospects. *Land Use Policy* **2020**, *91*, 104330. [CrossRef]
61. Heerink, N.; Kuiper, M.; Shi, X. China's New Rural Income Support Policy: Impacts on Grain Production and Rural Income Inequality. *China World Econ.* **2006**, *14*, 58–69. [CrossRef]
62. White, H. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica* **1980**, *48*, 237–268. [CrossRef]
63. Jeong, J.; Lee, K. Bootstrapped White's test for heteroskedasticity in regression models. *Econ. Lett.* **1999**, *63*, 261–267. [CrossRef]
64. Wooldridge, J. *Econometric Analysis of Cross Section and Panel Data*; MIT Press: Cambridge, MA, USA; London, UK, 2002; Volume 58.
65. Drukker, D. Testing for Serial Correlation in Linear Panel Data Models. *Stata J.* **2003**, *3*, 168–177. [CrossRef]
66. Hoechle, D. Robust Standard Errors for Panel Regressions With Cross-Sectional Dependence. *Stata J.* **2007**, *7*, 281–312. [CrossRef]
67. Peters, S. On the Use of the RESET Test in Micro-econometric Models. *Appl. Econ. Lett.* **2000**, *7*, 361–365. [CrossRef]
68. Meintanis, S. Testing for normality with panel data. *J. Stat. Comput. Simul.* **2011**, *81*, 1745–1752. [CrossRef]
69. Ullah, S.; Zaefarian, G.; Ullah, F. How to use instrumental variables in addressing endogeneity: A step-by-step procedure for non-specialists. *Ind. Mark. Manag.* **2020**, *96*, A1–A6. [CrossRef]
70. Zhang, Y.; Long, H.; Wang, M.; Yurui, l.; Ma, L.; Chen, K.; Zheng, Y.; Jiang, T. The hidden mechanism of chemical fertiliser overuse in rural China. *Habitat Int.* **2020**, *102*, 102210. [CrossRef]
71. Lechner, M.; Strittmatter, A. Practical Procedures to Deal with Common Support Problems in Matching Estimation. *Econom. Rev.* **2017**. [CrossRef]
72. Chetty, R.; Looney, W.; Kroft, K. Salience and Taxation: Theory and Evidence. *Am. Econ. Rev.* **2009**, *99*, 1145–1177. [CrossRef]
73. Cai, X.; Lu, Y.; Wu, M.; Yu, L. Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. *J. Dev. Econ.* **2016**, *123*, 73–85. [CrossRef]
74. Freyaldenhoven, S.; Hansen, C.; Shapiro, J.M. Pre-event Trends in the Panel Event-Study Design. *Am. Econ. Rev.* **2019**, *109*, 3307–3338. [CrossRef]
75. Abadie, A.; Diamond, A.; Hainmueller, J. Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. *J. Am. Stat. Assoc.* **2007**, *105*, 493–505. [CrossRef]
76. Hahn, J.; Shi, R. Synthetic Control and Inference. *Econometrics* **2017**, *5*, 52. [CrossRef]
77. Feng, Z.; Tang, Y.; Yang, Y.; Zhang, D. The relief degree of land surface in China and its correlation with population distribution. *Acta Geogr. Sin.* **2007**, *62*, 1073–1082.
78. You, Z.; Feng, Z.M.; Yang, Y.Z. Relief Degree of Land Surface Dataset of China (1km). *J. Glob. Chang. Data Discov.* **2018**, *2*, 151–155. [CrossRef]
79. Robert, P.; Rust, R.; Larson, W.; Krummel, J.; Su, H. Topographic Effect and Its Relation to Crop Production in an Individual Field. In Proceedings of the Third International Conference on Precision Agriculture, Minneapolis, MN, USA, 23–26 June 1996; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 1996. [CrossRef]
80. Pijanowski, B. The effects of China's cultivated land balance program on potential land productivity at a national scale. *Appl. Geogr.* **2014**, *46*, 158–170. [CrossRef]
81. Chen, A.; Ng, Y. *Dictionary of Geotourism*; Springer: Singapore, 2019.

82. Baron, R.; Kenny, D. The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Personal. Soc. Psychol.* **1986**, *51*, 1173–1182. [CrossRef]
83. Yang, J.; Huang, Z.; Zhang, X.; Reardon, T. The Rapid Rise of Cross-Regional Agricultural Mechanization Services in China. *Am. J. Agric. Econ.* **2013**, *95*, 1245–1251. [CrossRef]
84. Zhao, J.; Zilberman, D. Irreversibility and Restoration in Natural Resource Development. *Oxf. Econ. Pap.* **1999**, *51*, 559–573. [CrossRef]
85. Barry, M.; Augustinus, C. *Framework for Evaluating Continuum of Land Rights Scenarios*; UN-Habitat/GLTN: Nairobi, Kenya, 2016.
86. Liu, Y.; Fang, F.; Li, Y. Key issues of land use in China and implications for policy making. *Land Use Policy* **2014**, *40*, 6–12. [CrossRef]
87. Deng, X.; Huang, J.; Rozelle, S.; Zhang, J.; Zhihui, L. Impact of urbanization on cultivated land changes in China. *Land Use Policy* **2015**, *45*, 1–7. [CrossRef]
88. He, G.; Zhao, Y.; Wang, L.; Jiang, S.; Zhu, Y. China's food security challenge: Effects of food habit changes on requirements for arable land and water. *J. Clean. Prod.* **2019**, *229*, 739–750. [CrossRef]
89. Kastner, T.; Ibarrola-Rivas, M.J.; Koch, W.; Nonhebel, S. Global changes in diets and the consequences for land requirements for food. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 6868–6872. [CrossRef]
90. Hu, Y.; Liu, C.; Peng, J. Financial inclusion and agricultural total factor productivity growth in China. *Econ. Model.* **2021**, *96*, 68–82. [CrossRef]
91. Kou, M.; Yang, Y.; Chen, K. The impact of external R&D financing on innovation process from a supply-demand perspective. *Econ. Model.* **2020**, *92*, 375–387. [CrossRef]
92. Cheng, X.; Chen, J.; Jiang, S.; Dai, Y.; Shuai, C.; Li, W.; Liu, Y.; Wang, C.; Zhou, M.; Zou, L.; et al. The impact of rural land consolidation on household poverty alleviation: The moderating effects of human capital endowment. *Land Use Policy* **2021**, *109*, 105692. [CrossRef]
93. Tan, R.; Liu, P.; Zhou, K.; He, Q. Evaluating the effectiveness of development-limiting boundary control policy: Spatial difference-in-difference analysis. *Land Use Policy* **2022**, *120*, 106229. [CrossRef]
94. Wang, B. Housing market volatility under COVID-19: Diverging response of demand in luxury and low-end housing markets. *Land Use Policy* **2022**, *119*, 106191. [CrossRef]
95. Fredriksson, A.; Oliveira, G. Impact evaluation using Difference-in-Differences. *RAUSP Manag. J.* **2019**, *54*, 519–532. [CrossRef]
96. He, Z.; Zhao, C.; Fürst, C.; Hersperger, A.M. Closer to causality: How effective is spatial planning in governing built-up land expansion in Fujian Province, China? *Land Use Policy* **2021**, *108*, 105562. [CrossRef]
97. Li, L.; Liu, C.; Liu, J.; Cheng, B. Has the Sloping Land Conversion Program in China impacted the income and employment of rural households? *Land Use Policy* **2021**, *109*, 105648. [CrossRef]
98. Teka, K.; Van Rompaey, A.; Poesen, J. Assessing the role of policies on land use change and agricultural development since 1960s in northern Ethiopia. *Land Use Policy* **2013**, *30*, 944–951. [CrossRef]