



Article Evaluation of the Response of Grain Productivity to Different Arable Land Allocation Intensities in the Land Use Planning System of China

Guanyi Yin *, Yi Lou, Shuai Xie and Wei Wei

College of Geography and Environment, Shandong Normal University, Jinan 250358, China; 2019020678@stu.sdnu.edu.cn (Y.L.); 2020020735@stu.sdnu.edu.cn (S.X.); 2021020785@stu.sdnu.edu.cn (W.W.) * Correspondence: 616071@sdnu.edu.cn

Abstract: This study measured the spatio-temporal change of the Arable Land Allocation Intensity (ALAI), and established a toughness index to evaluate the responses of grain productivities to the ALAIs in 31 provinces. The results show that the ALAI decreased in 31 provinces during 2005–2020, whereas the grain productivity responses differed. Though China's Major Grain producing areas (CMGPA) experienced decreasing arable land allocation intensities compared with the non-CMGPAs, they still showed a robust toughness of grain productivity. The spatial barycenter of grain productivity moved towards Northeast China, which was much faster and further than the northwest movement of the ALAI, indicating a dislocated motion of grain production and ALAI. In all, both the toughness of grain productivity and the tightening arable land allocation intensities were apparent in the CMGPAs, especially in the northeastern CMGPAs in China. In order to improve the grain productivity on shrinking arable land resources, this study suggests that we tighten the quota of arable land transformed into construction land, improve the per-unit grain yield, and enhance the remote sensing technology and field surveys to better monitor the local governments' performance in arable land management.

Keywords: response of grain productivity; toughness; arable land allocation intensity; land use planning system; China's major grain producing area

1. Introduction

In the United Nations Millennium Development Goals, eliminating human hunger is one of the most important goals in the rapidly changing 21st century [1]. Until 2021, 9% of the people in the world were experiencing severe food insufficiency [2]. As the largest developing country in the world, the way in which to feed the 1.4 billion people has become an important long-term development issue in China. "Keeping the bowl firmly in our own hands" and "maintain a high grain self-sufficiency" were considered to be the basic national policies of China. Since the 1970s, China has assigned 13 provinces as "China's major grain producing areas" (abbreviated as CMGPA hereafter)—including Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Henan, Shandong, Jiangsu, Jiangsu, Hubei, Hunan, Anhui and Sichuan—in order to guarantee the long-term national food supply [3].

Accompanied by the increasing concern regarding grain production, the rapid urbanization in China has brought about challenges for arable land use. In 1994, China implemented the tax-sharing system reform, which stipulated that the central and local governments share the value added tax at 75 percent and 25 percent (before 1994, the local governments gave only a small percentage of value added tax to the central government, and keep the rest for themselves). As a result, the fiscal revenue of local governments plunged massively [4]. In order to seek more local fiscal income, up to 36% of local government revenue began to rely on land transfer fees, which lead to extremely hot land finance in local areas [5]. Affected by local land finance, a large amount of arable land was



Citation: Yin, G.; Lou, Y.; Xie, S.; Wei, W. Evaluation of the Response of Grain Productivity to Different Arable Land Allocation Intensities in the Land Use Planning System of China. *Sustainability* **2022**, *14*, 3109. https://doi.org/10.3390/su14053109

Academic Editors: Riccardo Testa, Giuseppina Migliore, Giorgio Schifani and József Tóth

Received: 7 February 2022 Accepted: 1 March 2022 Published: 7 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). changed to non-agricultural land, and was then sold by the local government for profit. During 2000–2010, affected by the hot transformation from arable land to construction land, the arable land in China decreased by 1.04 million hm², at a speed of 0.104 million hm² annually [6]. Until 2016, about 63% of the construction land in China was converted from arable land [7]. The public land ownership system in China formed a unique kind of fragmented arable land-use pattern: each rural household managed a small area of arable land, which contributed to the fragmentation of land property rights. The fragmentation of arable land inevitably increased the cost of grain production, i.e., a 1% increase of land fragmentation may increase the cost of grain production by 7.1–12.2% [8]. Among the CMGPAs, Sichuan and Inner Mongolia show the highest level of land fragmentation [9]. The decrease of high-quality arable land has caused pressing concerns for the protection of arable land resources and grain production stability.

Land-use policy has a great influence on grain production, especially in a socialist country like China. Recently, research found that a trade-off between grain production and economic development exists in reasonable land policy design [10]. Taking the Grain-for-Green Policy (i.e., the return of the grain plots to forestry) at the national level as an example, research showed that Grain-for-Green would not cause a grain shortage or threaten food security criteria [11]. Moreover, village-scale agricultural land use strategy (for instance, "one village, one product" policy requires villages to produce one kind of dominant crop) has a large impact on the local non-grain production [12]. Furthermore, the prime farmland policy (i.e., once classified as prime farmland, the land use is not allowed to be changed) failed to inhibit the non-grain production in some areas in China [13]. As a result, it can be seen that various land policies work both ways on grain productivity, which may cause long-term uncertainties regarding the response of grain production.

In order to protect grain productivity under the scarcity of arable land resources, the Chinese central government released two rounds of National General Land use planning. The first plan was released in 1999, which was used to guide the land use in 1997–2010, and the second plan was released in 2008, which was used to guide the land use in 2006–2020 [14,15]. In the unique Chinese top-down quota-oriented land use planning system, the central government allocates the land quotas (such as arable land, grassland, construction land, etc.) and land-change limitations (such as arable land transferred to construction land) to each province. The provincial governments then set the provincial-level land use planning, and allocate land-use quotas to the city-level governments. After this, the city-level governments allocate land protection is enhanced by following the limitation of land quotas in level-by-level government work.

However, the county-level and town-level government have the rights to readjust the boundaries of prime farmland after the local land use planning is implemented [16], which causes the loss of farmland in some areas after the readjustment of the boundaries [17]. What's more, different areas set different land quotas related with arable land, which forms different local arable land allocation intensities. Facing the unique national land management system, in order to find better pathways of the grain production and reasonable land policy designation, the deep discussion of the response of grain productivity to the changing land allocation intensity is urgently needed (Figure 1).

How to understand the response of grain productivity in the changing socioeconomic environment of China has drawn many researchers' focus. Although much success of arable land protection has been achieved in some regions, the continuous reduction of high-quality farmland has been uncontrollable [18]. In light of food security goals, the performance of land planning was discussed, and inefficiencies were found in the arrangement of arable land protection policies [19]. In terms of grain production, research has also revealed that the arable land protection policies had double-side effects on grain production. A Cobb–Douglas production function-based study proved a 0.023% increase in the total grain output with a 1% increase in the intensity of arable land protection policy [20]. Similarly, a study in Zhejiang Province (non-CMGPA) revealed that increasing the quota of arable land transferred to other land use types would cause a reduction in both the total grain production and grain output per-unit area. In China's market of land indicators, developed areas buy quotas of construction land from less-developed areas, and the seller is required to replenish a certain area of arable land. In this invisible trade, the seller actually fulfills the task of replenishing cultivated land on behalf of the buyer. A piece of research proposed that both buyers and sellers are experiencing a loss of grain yield [21]. Moreover, a piece of research on the policy pressure index revealed that the arable land use protection intensity experienced an inverted U-shaped evolution in 1997–2014, and was positively affected by agricultural efficiency and negatively affected by the economic scale [22]. A piece of research used a PMC-index model to reveal the increase of the intensity of eight arable land protection policies, and found good consistency among the policies [23]. Conversely, focused on the non-grain production phenomenon on arable land, Yue insisted that the implementation of basic farmland policies failed to inhibit—and actually encouraged—non-grain plantation on arable land [24].



Figure 1. Background of the arable land use, grain production and land use planning system in China.

The above studies provide valuable references for the observation of the relationship between grain productivity and arable land protection policy. Due to the diversified research perspectives, the research conclusions are mostly inconsistent. Three research gaps still need deeper discussion. First, the relevant research mostly focuses on the change of grain productivity and arable land area, with a lack of understanding of the influence of quota-oriented land planning policy on grain productivity. Although the National Land Use Planning (2006–2020) came to an end, rare studies investigated whether the top-down land use planning system with Chinese characteristics contributed to the promotion of grain productivity. Second, as a vast country with multiple climatic-geographic zones, the internal differences in natural endowment among various areas will result in different responses in grain productivity. However, few studies have paid attention to the spatial response of grain productivity to different arable land allocation intensities in China, which is still an unanswered question, especially for the major grain producing areas. Third, spatial visualization is crucial for the understanding of a country's grain production patterns. The way in which to show the spatial interaction of grain productivity with land use planning policies has not been found. In order to fulfill the above gaps, this paper aims to answer the following questions:

- i. What is the spatio-temporal change of arable land allocation intensity (hereafter abbreviated as "ALAI") in the top-down land use planning system in China?
- ii. How should we measure the spatio-temporal response of grain productivity to the arable land allocation intensity?
- iii. What does the response of grain productivity to arable land allocation intensity indicate for urban–rural development and management?

The remainder of this paper is organized as follows. Section 2 describes the methodology. Section 3 presents the major results. Section 4 interprets the deep discussion of the findings, and Section 5 sums up the conclusions.

2. Materials and Methods

2.1. Evaluation of the Arable Land Allocation Intensity (ALAI) in the Land Use Planning System

Due to the limited total land resources in an administrative area, the arable land quotas, the garden quotas, the construction land quotas and other land use types work together to influence the final arable land allocation intensity. For instance, higher forestland quotas means the stronger protection of the ecological system, which may bring a positive impact on arable land productivity, similarly to garden and grassland quotas. On the contrary, higher construction land quotas mean higher pressure on arable land protection (much of the construction land comes from the occupation of arable land), which may cause a negative impact on arable land productivity. This study chose the provincial land quota indicators related to arable land protection in the land use planning for 2006–2020, in order to analyze the spatio-temporal change of ALAI (Table 1).

Table 1. Indicators involved in the analysis of the ALAI.

Indicators of Land Use Quotas	Explanation			
The lower limit of arable land (P_1)	Local governments have to keep arable land area no less than this value			
Prime farmland (P_2)	Local governments need to follow the lower limit of prime farmland areas. (Prime farmland is strictly banned to be transformed to non-agricultural use)			
Garden plot (P_3)	Local governments should keep the lower limit of the given garden plot area, to provide an ecological buffer for arable land protection			
Forest land (P_4)	Local governments should keep the lower limit of forestland, which helps to provide an ecological buffer for arable land protection			
Grassland (P_5)	Local governments should keep the lower limit of grassland, which helps to provide an ecological buffer for arable land protection			
The upper limit of construction land (P_6)	To release a certain space for arable land use, local governments have to keep the construction land no larger than the given area			
City and rural construction land (P_7)	Including the construction land in cities, towns and villages			
Industrial and mining land in cities and towns (P_8)	Local governments need to follow the limit of given land are used for industrial production and mining in cities and towns			
Transportation, water conservancy & other lands (P_9)	Local governments needs to follow the quota of land used for railways, roads, airports, ports and piers, pipeline transportation, reservoir, etc.			
Per capita urban industrial and mining land (P_{10})	To protect the local environmental bearing capacity, local governments have to abide by the quota of per capita urban industrial and mining land area			

In order to eliminate the dimensional effects of the indicators, the indicators are standardized as follows:

$$P'_{i} = \begin{cases} \frac{P_{i} - P_{i}}{P_{i}} & \text{if } P_{i} \text{ is a positive indicator} \\ \frac{P_{i}}{P_{i}} & \text{max} - P_{i} \text{ min} \\ \frac{P_{i}}{P_{i}} & \frac{P_{i}}{P_{i}}$$

where the P_i refers to the standardized value of P_i ($P_1 \sim P_{10}$ in Table 1), and P_i_{max} and P_i_{min} refer to the maximum and the minimum values of P_i , respectively. According to the influences of the indicators in Table 1 on arable land protection, $P_1 \sim P_5$ were identified as positive indicators (which have positive effects on arable land protection), and $P_6 \sim P_{10}$ were identified as negative indicators (which may cause negative effects on arable land protection).

The calculation of the ALAI is as follows:

$$ALAI = \sum_{i=1}^{12} P'_i w_i \tag{2}$$

where ALAI refers to arable land allocation intensity. P_i refers to the indicators $P_1 \sim P_{10}$, and w_i refers to the weights of the indicators, which were scored by ten relative academic experts, and this study finally took the average value. A greater ALAI implies higher arable land allocation intensity.

2.2. The Toughness Index

This study established the toughness index to quantify the response of grain productivity to ALAI. Based on different trends of grain productivity and arable land allocation intensity, the toughness index can clearly identify the link between two changing systems. The grain yield (to reflect the total grain productivity), grain-sown area (to reflect the spatial scale of grain production) and per-unit grain yield (to reflect the grain production efficiency on per-unit area) can be used as three dimensions of the grain productivity; this study applied three sensitivity indexes, as follows:

$$Toughness_{GY} = \left[(GY_{t2} - GY_{t1}) / GY_{t1} \right] / \left[(ALAI_{t2} - ALAI_{t1}) / ALAI_{t1} \right]$$
(3)

$$Toughness_{SA} = [(SA_{t2} - SA_{t1})/SA_{t1}]/[(ALAI_{t2} - ALAI_{t1})/ALAI_{t1}]$$
(4)

$$Toughness_{PUY} = \left[(PUY_{t2} - PUY_{t1}) / PUY_{t1} \right] / \left[(ALAI_{t2} - ALAI_{t1}) / ALAI_{t1} \right]$$
(5)

where *GY*, *SA* and *PUY* are the grain yield, grain-sown area and per-unit yield of grain, respectively. $Toughness_{GY}$, $Toughness_{SA}$ and $Toughness_{PUY}$ refer to the toughness of the grain yield to the arable land allocation intensity, the toughness of the grain-sown area to the arable land allocation intensity, and the toughness of the per-unit grain yield to the arable land allocation intensity, respectively. *t*1 and *t*2 refer to the starting year and ending year, respectively. Based on the possible relationships between the grain productivity and arable land allocation intensity, the toughness index can be divided into five levels, i.e., the highest toughness, high toughness, medium toughness, lowest toughness and no toughness (Figure 2).



Figure 2. Sketch map of the classification of the toughness index. The blue line indicated that both grain productivity (ΔGY , ΔSA or ΔPUY) and ALAI increase or decrease synchronously at the same speed. The yellow line indicates that the increase and decrease of grain productivity (ΔGY , ΔSA or ΔPUY) and ALAI are opposite, but the change speeds of both are the same.

Specifically, the grain productivity is tough when it is positively responsive to the arable land allocation intensity. For instance, a $Toughness_{GY}$ higher than 0 means that the grain

yield increases when the ALAI decreases. At this point, the response of the grain yield is punchy in the face of the disadvantage of a scarce arable land quota. A detailed explanation of the classification of the toughness index is given in Table 2.

Table 2. Classification of the toughness index.

Classes	Change of Grain Productivity	Change of ALAI	Toughness Index	Characteristic	
No toughness	>0	>0	0 < Toughness < 1	Both grain productivity and ALAI increases. ALAI increases faster	
No toughness	<0	>0	−1 < Toughness < 0	Grain productivity decreases when ALAI increases, the decrease of grain productivity is slower than the increase of the ALAI	
No toughness	<0	>0 Toughness < -1 Grain productivity decreas ALAI increases, the decreas productivity is faster than th of the ALAI			
No toughness	<0	<0	Toughness > 1	Both grain productivity and ALAI decreases. Grain productivity decreases faster	
Lowest toughness	<0	<0	Both grain productivity and ALAI decreases. ALAI decreases faster		
Medium toughness	>0	>0	Toughness > 1	Both grain productivity and ALAI increases. Grain productivity increases faster	
High toughness	>0	<0	Toughness < -1	Grain productivity increases though ALAI decreases. ALAI decreases faster than the increase of grain productivity	
Highest toughness	>0	<0	−1 < Toughness < 0	Grain productivity increases though ALAI decreases. Grain productivity increase faster than the decrease of ALAI	

Note: Considering the wide distribution of the data, when the Toughness < -1 or the Toughness > 1, the grade of the toughness can be further divided into more sub-grades in order to better show the characteristics of the value.

2.3. Standard Deviation Ellipse and Spatial Barycenter Analysis

This study uses the Standard Deviation Ellipse (*SDE*) analysis and spatial barycenter in ArcGIS to discuss the spatial distribution of the grain productivity and ALAI. The spatial barycenter refers to the arithmetical mean center of the standard deviation ellipse. The coordinates of the spatial barycenter are calculated as follows:

$$\begin{cases} SDE_x = \sqrt{\frac{\sum_{i=1}^n (x_i - \overline{X})^2}{n}}\\ SDE_y = \sqrt{\frac{\sum_{i=1}^n (y_i - \overline{Y})^2}{n}} \end{cases}$$
(6)

where \overline{X} and \overline{Y} are the coordinates of the center of the standard deviation ellipse. x_i and y_i are the coordinates of the ith element inside the ellipse. SDE_x and SDE_y are the variance of the long axis and the short axis of the ellipse, which indicate the distribution direction of the data and the range, respectively.

The direction of the standard deviation ellipse is determined as follows:

$$\begin{cases} \tan \theta = \frac{A+B}{C} \\ A = \sum_{i=1}^{n} \tilde{x}_{i}^{2} - \sum_{i=1}^{n} \tilde{y}_{i}^{2} \\ B = \sqrt{\left(\sum_{i=1}^{n} \tilde{x}_{i}^{2} - \sum_{i=1}^{n} \tilde{y}_{i}^{2}\right)^{2} + 4\left(\sum_{i=1}^{n} \tilde{x}_{i} \tilde{y}_{i}\right)^{2}} \\ C = 2\sum_{i=1}^{n} \tilde{x}_{i} \tilde{y}_{i} \end{cases}$$
(7)

where θ shows the direction of the standard deviation ellipse, which begins from the north direction ($\theta = 0$); θ increases along with the clockwise rotation. \tilde{x} and \tilde{y} are the difference of the coordinates between the arithmetical mean center and the *i*th elements. *A*, *B* and *C* are intermediate parameters.

The length of the *x*-axis and *y*-axis of the standard deviation ellipse is calculated as follows:

$$\begin{cases} \sigma_x = \sqrt{2}\sqrt{\frac{\sum_{i=1}^n (\tilde{x}_i \cos \theta - \tilde{y}_i \sin \theta)^2}{n}} \\ \sigma_y = \sqrt{2}\sqrt{\frac{\sum_{i=1}^n (\tilde{x}_i \sin \theta + \tilde{y}_i \cos \theta)^2}{n}} \end{cases}$$
(8)

where the σ_x and σ_y are the standardized deviation of the *x* and *y* axis of the ellipse. The greater the difference between the length of the long axis and the short axis is, the more obvious the directivity of the distribution of the spatial data will be.

Taking the grain yield as an example, the procedures of the standard deviation ellipse and spatial barycenter of the grain yield are as follows:

- i. Import the data of the grain yield of the different provinces into the attribute table of the Chinese provincial map in ArcGIS.
- ii. In the standard deviation elliptic analysis tool in ArcToolbox, choose the grain yield as the analysis target; then, the standard deviation ellipse and the coordinates of the spatial barycenter of 31 provinces' grain yield are shown.
- iii. Observe the movement direction and speed of the spatial barycenter of the grain yield in different years in order to find the characteristic of the spatial distribution of the grain yield along time. If the location and the migration direction of the spatial barycenter of the ALAI does not coincide with the grain productivity, a spatial mismatch may exist for the performance of the ALAI and grain productivity.



The holistic research framework is summarized in Figure 3.

Figure 3. Research framework of this study.

2.4. Data Sources

The land use quotas of the land use planning system come from the webline of The Central People's Government of the People's Republic of China: http://www.gov.cn/zxft/ft149/content_1144625.htm (accessed on 24 October 2008). The grain yield, grain-sown area and the grain yield per-unit area come from the National Bureau of Statistics: http://www.stats.gov.cn/tjsj/ndsj/ (accessed on 24 February 2019). The provincial administrative

zoning map comes from the Resource and Environment Science and Data Center: https://www.resdc.cn/ (accessed on 24 August 2004).

3. Results

3.1. Spatiotemporal Change of the Arable Land Allocation Intensity

According to the national land use planning announced by the Ministry of Land and Resource, each province gets different quotas for different land use types. Among the 31 provinces of China, the detailed land use quotas vary largely (Table 3). The lower limit of the arable land area among the 31 provinces ranges from 21.47×10^4 hm² to 1166.95×10^4 hm². The quota of prime farmland ranges from 18.67×10^4 hm² to 1017.16×10^4 hm², and the construction land ranges from 6.32×10^4 to 266.99×10^4 hm². In total, the average quota of grassland and forestland were the highest, followed by the quota of arable land. Various land quotas may constitute different provincial arable land allocation intensities (ALAIs), which ultimately may affect the provincial grain productivity. Hence, the observation of the local difference of arable land allocation intensities should be an important precondition to gain higher grain productivity.

Table 3. Land use quotas in the land use planning system.

Indicators	Max	Min	Mean	Stdev	CV
Lower limit of arable land (10^4 hm^2)	1166.95	21.47	391.00	266.52	0.68
Prime farmland (10^4 hm^2)	1017.6	18.67	338.05	232.19	0.69
Garden plot (10 ⁴ hm ²)	191.14	0	43.34	39.64	0.91
Forest land (10^4 hm^2)	2419	0	767.56	678.51	0.88
Grassland (10 ⁴ hm ²)	6571.96	0	725.61	1788.24	2.46
Upper limit of construction land (10 ⁴ hm ²)	266.99	6.32	105.78	63.52	0.60
City and rural construction land (10 ⁴ hm ²)	200.74	3.55	78.54	49.46	0.63
Industrial and mining land in cities and towns (10^4 hm ²)	571.04	1.44	42.42	86.28	2.03
Transportation, water conservancy and other land (10 ⁴ hm ²)	81.02	2.31	30.43	18.21	0.60
Per capita urban industrial and mining land (m ²)	314	81	141.82	50.78	0.36

The ALAI in each province decreased in 2005–2020. The area with a high ALAI value contracted, especially in the eastern province (Figure 4A,B). Contrary to expectations, except for Heilongjiang, Inner Mongolia and Hebei, most CMGPAs did not show a higher ALAI than the non-CMGPAs. Only 5 of the 13 CMGPAs were listed in the top ten ALAIs, whereas the other 8 CMGPAs were at the bottom (Figure 4C). Compared with the non-CMGPAs, most CMGPAs in China didn't show prominent advantages of arable land allocation intensity. Affected by China's spatial differentiation of development pattern, many provinces are both national major grain producing areas and economically developed areas. Driven by the pressure of pursuing non-agricultural production and economic development, some CMGPAs are facing a tighter arable land quota and higher demand for construction land. The increasing pressure of arable land allocation resulted in the lower and decreasing ALAIs in Shandong and Jiangsu.



Figure 4. The value and distribution of the ALAI on the provincial level. Note: The yellow circles in (**A**,**B**) and the yellow stars in (**C**) refer to the CMGPAs.

In order to observe the internal difference of the ALAI, this study illustrated the major indicators of the ALAI in Figure 5. It was found that, except for Hubei, Hunan and Jiangxi Province, most CMGPAs (marked with yellow circles in Figure 5B–D) hold higher arable land quotas compared with the non-CMGPAs, which reflects that the arable land policy is still tilted towards the CMGPAs (Figure 5A). Moreover, the distribution of the garden quota is high in the southeast and low in northwest China (Figure 5B), whereas the grassland quota is high in the northwest and low in the southeast (Figure 5D); the forestland quota is high in the northwest line but low in other areas (Figure 5C). As an essential element of urbanization development, the quotas of the construction land in the eastern provinces showed obvious advantages (Figure 5E). More than 60% of the newly increased construction land in all of the provinces comes from the encroachment on agricultural land, and most of the occupied agricultural land comes from arable land, which will pose a high threat to arable land resources, especially in the CMGPAs (Figure 5F). In all, the low ALAI in CMGPAs was derived from the slightly higher quotas of arable land, the higher threat of construction land expansion, and the lower ecological land area.



Figure 5. Internal changes in the ALAI on the provincial level. (**A**): Arable land quotas. (**B**): Garden land quotas. (**C**): Forestland quotas. (**D**): Grassland quotas. (**E**): Construction land quotas. (**F**): Land quotas of changes between arable land and construction land.

3.2. Spatiotemporal Pattern of Grain Productivity

The grain yield experienced a general rise in 31 provinces during 2008–2018 (Figure 6). The characteristic of the spatial pattern of the grain yield transformed from a different eastern–western pattern to a different northeast–southwest pattern. The contributions of grain yields in the Northeast Plain and North China Plains is becoming more obvious, as they formed a clustered "double kernel" distribution. Unlike the aggregated distribution of the provincial grain yield, the per-unit yield of grain is more decentralized (Figure 7). A higher per-unit yield existed in the eastern grain production provinces, but in 2013 and 2018, Xinjiang in Western China became a new province with a high per-unit grain yield. The sown area of grain showed a more centralized distribution than the per-unit grain yield (Figure 8). From 2008 to 2013, the grain-sown area mainly increased in the southwest non-CMGPAs, i.e., Guizhou and Guangxi Province. In 2013–2018, the grain-sown area in the southwest decreased while it increased in Northeast China, and showed a spatial distribution of "high northeast–low southwest".



Figure 6. Change of the grain yield in 31 provinces of China. (**A**): grain yield in 2008. (**B**): grain yield in 2013. (**C**): grain yield in 2018.



Figure 7. Change of the per-unit grain yield in 31 provinces of China. (**A**): per-unit grain yield in 2008. (**B**): per-unit grain yield in 2013. (**C**): per-unit grain yield in 2018.



Figure 8. Change of the grain-sown area in 31 provinces of China. (**A**): grain-sown area in 2008. (**B**): grain-sown area in 2013. (**C**): grain-sown area in 2018.

It is worth noting that, as one of the CMGPAs, Heilongjiang (in Northeast China) showed a characteristics of larger sown area but a lower per-unit grain yield. On the contrary, as a non-CMGPA, Xinjiang (in Northwest China) retained a low sown area but a high per-unit grain yield. We can infer that large differences hide in the internal grain productivity among different areas. Though the ALAIs in CMGPAs are not superior compared with the non-CMGPAs, most CMGPAs maintain a high and steady grain productivity. A higher grain-sown area or per-unit yield gave the CMGPAs a robust toughness of grain productivity to make up the disadvantages of arable land allocation intensity in the land use planning system. This kind of grain production toughness existed especially in the North China Plain area (including Shandong, Henan and Jiangsu), in which the local resource endowment and production conditions are remedying the pressure from the low arable land and high construction land quotas.

3.3. The Dislocated Spatial Movement Paths of ALAI and Grain Productivity

The standardized deviation ellipses of provincial the ALAI value showed a northeastsouthwest directional distribution (Figure 9A). By contrast, the standardized deviation ellipse of the arable land quota showed an obvious northeast-southwest directional distribution (Figure 9B), which indicated that the arable land quotas along the northeast-southwest areas of China had prominent advantages over the other areas. However, the standardized deviation ellipse of the construction land quota showed a rounded distribution (Figure 9C), which reflected the low directional distribution of the construction land quotas.

The movement paths of the spatial barycenter of the indicators of the ALAI vary greatly (Figure 9D). In 2005–2020, the spatial barycenter of the ALAI value moved towards the northwest of China. On the contrary, the arable land quotas moved northeast. The construction land quotas first moved southwest but then northwest. The opposite movement directions of the spatial barycenter of the arable land quota and construction land quota highlight the provincial difference of the internal structure of the local land use planning system. Over time, two kinds of spatial distribution patterns emerged, i.e., the increasing allocation of construction land quota in southwest provinces and arable land quotas in northeast provinces.



Figure 9. Movement of the spatial barycenter and standard deviation ellipses of the ALAI. (**A**) ALAI; (**B**) arable land quota in ALAI; (**C**) construction land quota in ALAI; (**D**) an enlarged map of the spatial gravity centers.

Compared with the ALAI, grain productivity showed a narrow standardized deviation ellipse (Figure 10), indicating an obvious directional distribution of the provincial grain productivity. Both the provincial grain yield (Figure 10A) and grain-sown area (Figure 10C) showed an elongated ellipse along the northeast–southwest direction, indicating that the northeast–southwest provinces of China showed a higher grain yield and sown area than the other provinces. By contrast, limited by different natural resource endowments, topographies and planting systems, the variation of the per-unit grain yield among the provinces did not form an obvious directional spatial distribution (Figure 10B).

The spatial barycenter of the provincial grain yield, per-unit grain yield and grainsown area all moved northeast in 2008–2018, though the movement path of the grain-sown area and per-unit grain yield took a turn around the year 2013 (Figure 10D). In all, ALAI and grain productivity have shown a dislocated movement of the spatial barycenter, which highlights the existence of the spatial toughness of grain productivity: the northeastern movement of grain production is helpful to stay away from the area with a high pressure of farmland quota contraction.



Figure 10. Movement of the spatial barycenter and standard deviation ellipses of grain production. (**A**) Grain yield; (**B**) per-unit grain yield; (**C**) sown area of grain; (**D**) spatial gravity centers of the indicators in (**A**–**C**).

In terms of the movement distances, the spatial barycenter of ALAI moved westward by 8827.29 m and northward by 5724.63 m (Figure 11). Specifically, the spatial barycenter of the arable land quota moved eastward by 1625.78 m and northward by 3139.3 m, respectively. Conversely, the spatial barycenter of construction land moved westward by 13,307.26 m and southward by 15,903.23 m, which was much faster and further than that of the arable land. The movement speed of the construction land barycenter was much faster than that of the arable land, respectively. Nevertheless, the movement speed slowed down in 2010–2020, indicating that the impact of construction land expansion on arable land may weaken further in the future.



Figure 11. Movement distance and speed of the spatial barycenter of ALAI and grain productivity. Positive black bar: eastward movement. Negative black bar: westward movement. Positive red bar: northward movement. Negative red bar: southward movement.

Remarkably, the movement distance of grain productivity was much greater than that of the ALAI (Figure 11). The spatial barycenter of the grain yield moved eastward by 22,172.95 m and northward by 115,994.98 m, the speed of which was more than 20 times and 55 times of that of the arable land quota, respectively. Similarly, the spatial barycenter of the grain-sown area moved eastward by 27,355.99 m and northward by 80,879.69 m, respectively, the speed of which was 25 and 38 times that of the arable land quota, respectively. The northeast movement speed of the barycenter of grain yield and grain-sown area accelerated after 2013, which proved to be an increasing contribution to the grain production of northeastern provinces in China. In all, the greater northeast movement of grain productivity and shorter western movement of ALAI revealed a dislocated motion phenomenon, which proved the importance of protecting the arable land in northeastern China and controlling the construction land expansion in southwestern China.

3.4. Different Responses of Grain Productivity to ALAI among 31 Provinces

The provincial responses of grain productivities to ALAIs are measured by the toughness indexes. Because many provinces showed a high toughness level of ALAI with discrete data distribution, this study further divided the "high toughness" into three sub-levels: L1 (-15 < toughness < -1), L2 (-30 < toughness ≤ -15) and L3 (toughness ≤ -30).

In terms of the response of grain yield to arable land allocation intensity (Figure 12A) except that Chongqing, Guizhou, Fujian, Zhejiang and Beijing (all of them are non-CMGPAs) showed "no toughness"—other provinces showed different levels of "toughness". Among the CMGPAs, only Inner Mongolia and Heilongjiang Province showed high toughness—(L3) and (L2), respectively—and the other ten CMGPAs showed high toughness (L1).

By contrast, the response of the grain-sown area to the arable land allocation intensity was more polarized (Figure 12B). Five provinces showed "the highest toughness" (including Yunnan, Hunan, Jiangxi, Jiangsu and Shanxi), whereas nine provinces turned out to be "no toughness" (including Ningxia, Shaanxi, Chongqing, Guizhou, Guangdong, Guangxi, Fujian, Zhejiang and Beijing). It is noteworthy that all of the provinces with "no toughness" are non-CMGPAs, which formed an obvious U-shaped distribution. By contrast, all of the members of CMGPAs showed either "the highest toughness" or "high toughness (L1)", which indicated a high toughness of the grain-sown area in the CMGPAs towards ALAI compared to the non-CMGPAs.

In terms of the response of the per-unit grain yield to the arable land allocation intensity (Figure 12C), only Qinghai Province showed "no toughness", whereas all of the other 30 provinces showed high levels of toughness. Among the CMGPAs, Jilin, Liaoning, Shandong, Hubei and Hunan showed "the highest toughness", and the others showed "high toughness (L1)". The desirable result of general high toughness of the per-unit grain yield highlighted the importance of improving the yield per-unit area to make up for the shrinking high-quality arable resources.

In total, the 31 provinces' grain productivities were resilient, and responded positively to the decrease of ALAIs in the land use planning system of China. Except for the slight poor toughness of the sown area in Sichuan Province, all of the CMGPAs have shown a much better toughness of grain productivity to a decreasing ALAI when comparing with the non-CMGPAs. Excellent resources of light, temperature, water and soil in the CMGPAs are helpful to offset the inferior arable land allocation intensity, which causes the CMGPAs to maintain a contribution of 78.69% of the grain yield to the whole country. The toughness is a favorable discovery, which is beneficial for guaranteeing national food security in a populous country. Nevertheless, facing the shrinking arable land quotas (especially in the eastern CMGPAs), whether the toughness of grain productivity can last long is still an unanswered question.





4. Discussion

4.1. The Strong Toughness of Grain Productivity in CMGPAs

In this study, the ALAI in 31 provinces of China decreased in 2005–2020, proving a weakening arable land allocation intensity. Compared with the non-CMGPAs, the CMG-PAs are experiencing a greater decline of ALAI, but still show a high and robust toughness of grain productivity. From the perspective of toughness [25], the grain productivity in the CMGPAs is much better and stable: during 2008–2018, accompanied by the decreasing ALAI, the grain yield in the CMGPAs increased from 4.05×10^8 t to 5.18×10^8 t, which still contributed greatly to the whole country (75.78% in 2008 and 78.69% in 2018). Facing the general decline of the ALAI among 31 provinces of China, the high grain productivity of the CMGPAs is conducive to guaranteeing the national food security.

It is worth noting that the CMGPAs' strong toughness of grain productivity derived from many unique preponderances. Firstly, the natural endowment advantage guarantees

the robust toughness of GP in CMGPAs. Enjoying better light, temperature, water, and soil conditions, the CMGPAs have been proven to show significantly higher grain production potential [26]. Moreover, most CMGPAs are economically developed areas. Among the CMGPAs, Jiangsu, Shandong, Henan, Sichuan, Hubei, Hunan and Hebei were listed the top 10 provinces that contributed 61.1% to the national GDP in 2018. Booming economic development brought technological advances to the local agricultural production [27]. From the comprehensive input–output analysis on arable land, the agro-production efficiency in CMGPAs also plays a stronger role than it does in the non-CMGPAs [28]. The results of this study and related research have both indicated that during the economic transformation process, the CMGPAs have shown strong abilities to both boom the non-agricultural economy and guarantee traditional grain production.

4.2. The Challenges for Grain Productivity and Arable Land Use

This study highlighted the dislocated motion of the spatial barycenter of ALAI and grain productivity. The spatial barycenter of grain productivity moved northeast, while the ALAI moved northwest. Likewise, previous studies proved a similar spatial bias between arable land distribution and grain production. Wang proposed that when the spatial barycenter of arable land in China moves towards the southwest, and that the spatial barycenter of grain production still moved towards the northeast during 2000–2010 [6]. Based on the relationship of grain supply and demand, Hu put forward that the grain production formed a grain shortage in Southwest China and a surplus in Northeast China [29]. Coincidentally, the economic development in China also transformed from a "high east and low west" pattern to a "high south and low north" pattern [30]. The spatial bias may bring about uncertainties of grain production and the land use pattern in the long future. Specifically, if the urbanization process in the areas with both a developed economy and high grain production continues, the land quota allocation between construction and farming will become a question to be solved.

Secondly, the loss of high-quality arable land needs to be controlled. In China, local governments rely strongly on land finance by recieving revenue from land leasing. The highest land finance risks related with illegal land sales are concentrated in Hebei, Henan, Jiangsu, Anhui, Hubei, Fujian and Guizhou Provinces, five of which are CMG-PAs [31]. What is more, urban land is highly correlated with arable land in spatial distribution, which aggravates the non-agricultural use of arable land [32]. Though local government is devoted to retaining the area of arable land, the quality of arable land is at risk. Most of the reduced arable land is fertile, whereas newly added arable land is barren [28]. What is worse, the "red line" of 0.12 billion hectares of arable land in China may be broken if we maintain the land finance mode in the future [33]. What the loss of fertile arable land may bring to the future grain productivity, especially the CMGPAs, is still full of uncertainty.

Lastly, the planting structure of the CMGPAs is full of changes. The advantage of natural endowment gives the CMGPAs better conditions to produce not only grain but also economic crops, which formed a condition for non-grain production on this land. From the perspective of market returns, planting grain has shown a significant economic disadvantage compared with economic crops, which has led a large number of farmers to transform grain plantation into economic crop plantation [8,9]. In the future arable land use of China, whether the grain productivity could last long in CMGPAs will be a hot issue that needs further study.

4.3. Expectation for the Top-Down Quota-Oriented Land Use Planning Policy

The top-down quota-oriented land use planning in China is a product of China's characteristic socialist public ownership system, which has helped to manage vast national land resources in China since 1993 [34]. Until today, few pieces of research have discussed the performance of land use planning, and opinions vary. For instance, the regulations during the second national land use planning process were thought to be significantly

effective in preserving arable land [35]. Adversely, Zhong indicated that 1,657,868.82 hm² of arable land is lost additionally due to construction purposes in the second land use planning, which makes the second national land use planning a failure in arable land protection [36].

Now, China has experienced two rounds of the national land use planning process. The first plan was not implemented effectively, which was replaced by the revised planning in 1999. The second one ended by the end of 2020. Facing the upcoming round of land quota allocation, this study proposes some important issues:

- i. It is urgent to tighten the quota of arable land transformed into construction land, especially in the CMGPAs. The loss of arable land should be controlled by limiting the arable land being transferred to construction land quotas in order to stop the ALAI from falling from this source.
- ii. The improvement of the per-unit grain yield should be further emphasized in order to improve the effectiveness of the land use planning. This study finds that a high toughness of grain productivity exists in some of the non-CMGPAs (especially Xinjiang). Though the arable land area in Xinjiang is not high, the performance of the per-unit grain yield and the toughness of grain productivity was ideal. In order to maintain national food security, more support of arable land quotas should be given to the areas with a higher potential of grain yield according to their per-unit area.
- iii. The accuracy of remote sensing technology and field surveys should be improved widely in the arable land use survey, which will help to better monitor the local governments' performance of arable land protection. The concealment of the actual local arable land area transformed to other land use types should be identified more easily, which is beneficial for the monitoring of the actual implementation effect of the overall land use planning.

5. Conclusions

In order to discuss the performance of grain productivity in China's unique top-down quota-oriented land use planning system, this study measured the arable land allocation intensity (ALAI), the grain productivity, and the response of grain productivity to the ALAI in 31 provinces in China. The conclusions are:

- (1) The ALAI in 31 provinces of China showed a downward trend while the grain productivity went upward. Compared with the other areas, China's Major Grain Producing Areas (CMGPAs) showed a lower ALAI but higher grain productivity, which indicated a spatial mismatch of policy and productivity.
- (2) The spatial barycenter of ALAI moved towards the northwest (specifically, the construction land indicator moved towards the southwest, but the arable land indicator moved northeast), but the spatial barycenter of grain productivity moved towards the northeast, much faster and further than that of ALAI, indicating the far-reaching influence of the arable land use in northeastern China.
- (3) The responses of the grain productivity to arable land allocation intensity are multiple. The CMGPAs have a better toughness of grain productivity to the inferior arable land allocation intensity, whereas most non-CMGPAs showed no positive toughness. Though the per-unit grain yield in 30 of the 31 provinces showed a positive toughness, the grain-sown area of nine provinces showed no toughness, which highlighted the importance of increasing the grain-sown area by improving the cropping system. Facing the low gains of grain production by comparison with economic crops, non-grain plantation should be controlled by suitable subsidies and guidance in grain production, especially in southern provinces like Guangxi, Guangdong, Fujian, Zhejiang and Guizhou.

This study confirmed both the advantages of grain productivity and the disadvantages of arable land allocation intensity in China's major grain producing areas. In the future, possible uncertainties of grain productivity in these areas may appear because of the changes of the plantation structure and economic development. In the top-down quotaoriented land use planning system, a larger arable land area, a higher permanent basic farmland area, and a better economic construction–agricultural production balance should be promoted in order to improve the arable land use efficiency, especially in the CMGPAs.

Author Contributions: Conceptualization, G.Y.; methodology, G.Y.; software, Y.L.; validation, S.X.; formal analysis, W.W.; data curation, G.Y.; writing—original draft preparation, G.Y.; writing—review and editing, G.Y.; visualization, S.X.; supervision, G.Y.; project administration, G.Y.; funding acquisition, G.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (Project No. 42171253), the Humanities and Social Science project of Shandong Province (2021-JCGL-08), the Social Science Planning Special Project of Shandong Province (21CCXJ15), and the Research Project of Teaching Reform of Shandong Normal University (2019XM42).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available from a publicly accessible repository that does not issue DOIs. Publicly available datasets were analyzed in this study. This data can be found here: http://www.gov.cn/jrzg/2008-10/24/content_1129693_4.htm (accessed on 24 October 2008).

Acknowledgments: The authors extend great gratitude to the anonymous reviewers and editors for their helpful review and critical comments.

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

References

- 1. The United Nations. United Nations Millennium Development Goals. 2000. Available online: https://maintenance.un.org/ (accessed on 31 August 2020).
- 2. The United Nations. The State of Food Security and Nutrition in the World. 2021, pp. 35–36. Available online: https://www.fao.org/3/cb4474en/cb4474en.pdf (accessed on 31 August 2020).
- 3. Li, B.; Yang, W.; Zhu, X. Multilevel correlation analysis of influencing factors on grain total factor productivity in main grain producing provinces of china. *Open J. Appl. Sci.* **2018**, *8*, 12–24. [CrossRef]
- Tao, R.; Su, F.; Liu, M.; Cao, G. Land Leasing and Local Public Finance in China's Regional Development: Evidence from Prefecture-level Cities. Urban Stud. 2010, 47, 2217–2236. [CrossRef]
- Fan, X.; Qiu, S.; Sun, Y. Land finance dependence and urban land marketization in China: The perspective of strategic choice of local governments on land transfer. *Land Use Policy* 2020, *99*, 105023. [CrossRef]
- 6. Wang, J.; Xin, L. Spatial-temporal variations of cultivated land and grain production in China based on GlobeLand30. *Trans-Actions Chin. Soc. Agric. Eng.* **2017**, *33*, 1–8. [CrossRef]
- Kuang, W.; Liu, J.; Dong, J.; Chi, W.; Zhang, C. The rapid and massive urban and industrial land expansions in China between 1990 and 2010: A CLUD-based analysis of their trajectories, patterns, and drivers. *Landsc. Urban Plan.* 2016, 145, 21–33. [CrossRef]
- Liu, Y.; Song, W.; Mu, F. Changes in ecosystem services associated with planting structures of cropland: A case study in Minle County in China. *Phys. Chem. Earth Parts A B C* 2017, 102, 10–20. [CrossRef]
- 9. Zhang, S.; Hou, X.; Wu, C.; Zhang, C. Impacts of climate and planting structure changes on watershed runoff and nitrogen and phosphorus loss. *Sci. Total Environ.* **2019**, *706*, 134489. [CrossRef]
- 10. Li, F.; Qin, Z.; Liu, X.; Chen, Z.; Wei, X.; Zhang, Q.; Lei, M. Grain production space reconstruction and land system function tradeoffs in China. *Geogr. Sustain.* **2021**, *1*, 22–30. [CrossRef]
- 11. Sun, D.F.; Li, H.; Dawson, R.; Tang, C.J.; Li, X.W. Characteristics of steep cultivated land and the impact of the grain-for-green policy in China. *Pedosphere* **2006**, *2*, 215–223. [CrossRef]
- 12. Yang, Q.; Zhang, D. The influence of agricultural industrial policy on non-grain production of cultivated land: A case study of the "one village, one product" strategy implemented in Guanzhong plain of China. *Land Use Policy* **2021**, *108*, 105579. [CrossRef]
- 13. Su, Y.; Qian, K.; Lin, L.; Wang, K.; Guan, T.; Gan, M. Identifying the driving forces of non-grain production expansion in rural China and its implications for policies on cultivated land protection. *Land Use Policy* **2020**, *92*, 104435. [CrossRef]
- 14. China State Council. Outline of National Overall Land Use Planning in China (1997–2010). 1999. Available online: http://www.gov.cn/xxgk/pub/govpublic/mrlm/201011/t20101115_62801.html (accessed on 31 August 2020).
- 15. China State Council. Outline of National Overall Land Use Planning in China (2006–2020). 2008. Available online: http://www.gov.cn/zxft/ft149/content_1144625.htm (accessed on 31 August 2020).
- Zhong, T.; Mitchell, B.; Scott, S.; Huang, X.; Li, Y.; Lu, X. Growing centralization in China's farmland protection policy in response to policy failure and related upward-extending unwillingness to protect farmland since 1978. *Environ. Plan. C Polit. Space* 2017, 35, 1075–1097. [CrossRef]

- 17. Ping, Y.C. Explaining Land Use Change in a Guangdong County: The Supply Side of the Story. *China Q.* **2011**, 207, 626–648. [CrossRef]
- 18. Li, H.; Wu, Y.; Huang, X.; Sloan, M.; Skitmore, M. Spatial-temporal evolution and classification of marginalization of cultivated land in the process of urbanization. *Habitat Int.* **2017**, *61*, 1–8. [CrossRef]
- 19. Lichtenberg, E.; Ding, C. Assessing farmland protection policy in China. Land Use Policy 2008, 25, 59–68. [CrossRef]
- 20. Lv, X.; Huang, X.J.; Chen, Z.G. Evaluation on the grain production performance of the cultivated land protection policy in China. *Resour. Sci.* **2010**, *32*, 2343–2348. (In Chinese) [CrossRef]
- 21. Li, X.; Zhang, W.; Peng, Y. Grain Output and Cultivated Land Preservation: Assessment of the Rewarded Land Conversion Quotas Trading Policy in China's Zhejiang Province. *Sustainability* **2016**, *8*, 821. [CrossRef]
- 22. Chen, J.; Cheng, S.; Song, M. Estimating policy pressure for China's cultivated land use protection based on an extended index. *Phys. Chem. Earth Parts A B C* 2017, 101, 21–34. [CrossRef]
- Kuang, B.; Han, J.; Lu, X.; Zhang, X.; Fan, X. Quantitative evaluation of China's cultivated land protection policies based on the PMC-Index model. *Land Use Policy* 2020, 99, 105062. [CrossRef]
- 24. Su, Y.; Qian, K.; Lin, L.; Wang, K.; Guan, T.; Gan, M. Identifying the driving forces of non-grain production and its implications for policies on cultivated land protection. *Land Use Policy* **2020**, *95*, 104435. [CrossRef]
- Hassink, R.; Gong, H. Regional Resilience. In International Encyclopedia of Human Geography, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 351–355. [CrossRef]
- 26. Ye, S.; Song, C.; Shen, S.; Gao, P.; Cheng, C.; Cheng, F.; Wan, C.; Zhu, D. Spatial pattern of arable land-use intensity in China. *Land Use Policy* **2020**, *99*, 104845. [CrossRef]
- 27. China's Bureau of Statistics. China Statistical Yearbook; China's Bureau of Statistics: Beijing, China, 2019; p. 200.
- 28. Guo, B.; He, D.; Zhao, X.; Zhang, Z.; Dong, Y. Analysis on the spatiotemporal patterns and driving mechanisms of China's agricultural production efficiency from 2000 to 2015. *Phys. Chem. Earth Parts A B C* 2020, 120, 102909. [CrossRef]
- 29. Hu, T.; Ju, Z.; Wei, Z. Regional pattern of grain supply and demand in China. *Acta Geogr. Sin.* 2016, *71*, 1372–1383. (In Chinese) [CrossRef]
- Fan, Y.; Fang, C.; Zhang, Q. Coupling coordinated development between social economy and ecological environment in Chinese provincial capital cities-assessment and policy implications. J. Clean. Prod. 2019, 229, 289–298. [CrossRef]
- 31. Zhang, B.; Li, J.; Tian, W.; Chen, H.; Kong, X.; Chen, W.; Zhao, M.; Xia, X. Spatio-temporal variances and risk evaluation of land finance in China at the provincial level from 1998 to 2017. *Land Use Policy* **2020**, *99*, 104804. [CrossRef]
- 32. Tan, M.; Li, X.; Xie, H.; Lu, C. Urban land expansion and arable land loss in China—A case study of Beijing–Tianjin–Hebei region. *Land Use Policy* **2005**, *3*, 187–196. [CrossRef]
- Zhong, T.; Huang, X.; Zhang, X.; Scott, S.; Wang, K. The effects of basic arable land protection planning in fuyang county, Zhejiang province, China. *Appl. Geogr.* 2012, 35, 422–438. [CrossRef]
- Wang, Y.; Li, X.; Lu, D.; Yan, J. Evaluating the impact of land fragmentation on the cost of agricultural operation in the southwest mountainous areas of China. *Land Use Policy* 2020, *99*, 105099. [CrossRef]
- Zhong, T.; Mitchell, B.; Huang, X. Success or failure: Evaluating the implementation of China's national general land use plan (1997–2010). *Habitat Int.* 2014, 44, 93–101. [CrossRef]
- 36. Cai, Y.; Zhang, W.; Zhao, Y. Discussion on evolution of land-use planning in China. China City Plan. Rev. 2009, 18, 32–37.