Evaluating the Effectiveness of Arable Land Redline in China

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Abstract

As urbanization increasingly threatens food security, the preservation of arable land has become critical, prompting government interventions in land use to ensure food security. However, the effectiveness of these mandatory land-use strategies is often questioned due to the socio-economic complexities. This study utilizes China's ALR policy as a natural experiment to assess the impact of arable land protection on food production. Employing satellite data and Difference-in-Differences with a continuous treatment model, the research examines agricultural outcomes in counties with different cropland restoration requirements before and after the implementation of the ALR policy. The findings suggest that the ALR policy likely reduces crop productivity. Although the sown area remains stable, there is a notable decrease in total grain output. Additionally, the study observes regional disparities. In Northeast China, the ALR policy has led to a notable decline in productivity with an increase in cropland restoration, resulting from substantially increased sown area without affecting grain production levels. This decline is likely due to the conversion of higher-quality farmland into lower-quality land. Conversely, in South China, the policy does not significantly affect crop productivity but results in a notable reduction in both the sown area and grain output. These effects are likely driven by labor shortages, which may lead to farmland abandonment despite restoration efforts.

Keywords: Arable Land Redline; Grain Productivity; Regional Disparities

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1 Introduction

As one of the world's most populated nations, China prioritizes food security as a crucial national strategy (Rosegrant & Cline, 2003). From 1999 to 2008, urban expansion led to a significant reduction of over 20,000 square kilometers in the country's cultivated land (Chen, 2007; Deng, Huang, Rozelle, Zhang, & Li, 2015; Song & Pijanowski, 2014). In response, the Arable Land Redline (ALR) policy was introduced in 2009 to protect cultivated lands by setting a minimum threshold of 1.2 million square kilometers of arable land, a target derived from the second national land survey (Guo et al., 2018).

This policy employs a "balanced farmland requisition and compensation" strategy to maintain this threshold. However, the implementation faces several challenges. For instance, there is a tendency to replace high-quality arable land with lower-quality land, subsequently undermining food production (C. Liu et al., 2023; X. Liu, Zhao, & Song, 2017). Moreover, the enforcement of these protection measures may demotivate the agricultural workforce, influenced by factors such as compensation, changes in farming locations, attitudes towards the policy, and socio-economic conditions (Christensen et al., 2011; Defrancesco, Gatto, Runge, & Trestini, 2008; Dessart, Barreiro-Hurlé, Van Bavel, et al., 2019; C. Liu et al., 2023; Niu, Xiao, & Zhao, 2021; Stupak, Sanders, & Heinrich, 2019).

A further consideration is the potential cost associated with farmland protection policies (Foley et al., 2005; Zabel et al., 2019). On the one hand, such policies may complicate land redistribution and increase urban development costs, thereby stifling local economic growth and reducing overall worker welfare (Yu, 2019). On the other hand, the expansion of cropland may involve converting less productive land, which not only infringed on high-quality habitats but also led to significant ecological costs (Lark, Spawn, Bougie, & Gibbs, 2020). This shift may have implications for climate change, terrestrial carbon storage, and land degradation (Zeng et al., 2018).

This study critically evaluates the effectiveness of the ALR policy, using it as a natural experiment to explore its impact on agricultural output across China. Utilizing precise satellite data and a Difference-in-Differences with a continuous treatment model, this study compares agricultural outcomes in counties subjected to varying cropland restoration requirements before and after the ALR's implementation. The validity of the results relies on the assumption that, absent the policy, trends across these counties would have remained parallel. An absence of divergent pre-2009 trends supports this premise. Additionally, a heterogeneity analysis of differing farmland conversion types is conducted to fully understand the policy's effects.

This study reveals several key findings regarding the impact of the Arable Land Redline (ALR) policy on agricultural outcomes in China. Firstly, the ALR policy is projected to decrease crop productivity in China's primary grain-producing regions. A 1% increase in cropland restoration is associated with a 0.44% reduction in crop productivity. While the sown area remains unaffected, there is a statistically significant decrease in total grain output, ranging from 0.47% to 0.48%.

Secondly, there are anticipated regional disparities observed across the country. In Northeast China, the ALR policy has substantially increased the planted area without affecting grain production levels, resulting in a notable 1.6% decline in productivity with a 1% increase in cropland restoration, likely due to the conversion of high-quality farmland into lower-quality land. Conversely, in South China, the policy has led to a significant reduction in both the sown area (0.4%) and grain output (0.6%), with no significant impact on crop productivity. These outcomes are likely driven by labor shortages stemming from rapid economic development, leading to farmland abandonment despite restoration efforts. Furthermore, this research identifies the effects of various land transactions on local agricultural outcomes, revealing that the transition between cropland and grassland is the predominant factor influencing agricultural production under this policy.

This paper makes the following contributions. First, we contribute to the expanding literature on the effects of land policies on agricultural output. Numerous studies have examined how large-scale land-use policies in China influence crop production, primarily focusing on land rights allocation (De Janvry, Emerick, Gonzalez-Navarro, & Sadoulet, 2015; Holden, Otsuka, & Place, 2010). For example, Chari, Liu, Wang, and Wang (2021) suggests that agricultural productivity can be enhanced by the protection of trading rights. Using household-level data, S. Liu, Ma, Yin, and Zhu (2023) demonstrate that changes in land ownership, mediated through labor shifts, can reduce agricultural productivity. Likewise, Gottlieb and Grobovšek (2019) utilized a general equilibrium selection model in Ethiopia to highlight the positive effects of eliminating public land tenure on agricultural productivity. Our study specifically examines the impact of resource allocation within agricultural land, particularly concerning the compulsory safeguarding of arable land.

Furthermore, our research extends existing studies on cropland protection policies by analyzing their effectiveness based on actual crop yields. The literature has extensively discussed the effects of these policies. On the one hand, scholars are concerned with the direct effects of policy implementation, whether changes in the quantity of arable land can be balanced (L. Liu, Liu, Gong, Wang, & Hu, 2019; Zhou, Li, & Liu, 2021). On the other hand, researchers focus on the indirect effects of policies, such as their ecological consequences and land quality. Tang, Ke, Zhou, Zheng, and Wang (2020) assessed the impact of China's cultivated land expansion on carbon storage and discovered that the expansion led to the conversion of forests and wetlands into farmland, resulting in a loss of carbon storage. Zheng, Li, Ke, Li, and Zhang (2022) found that farmland balancing policies have resulted in significant degradation of habitat quality and a decline in biodiversity. In terms of land quality, Song and Pijanowski (2014) evaluated the effectiveness of China's cultivated land balance policy by utilizing national cultivated land Natural Quality Grade (NQG) data to assess its impact on the potential productivity of cultivated land. Unlike studying the land quality which reflects potential yields of land (C. Liu et al., 2023; Song & Pijanowski, 2014), our article explores the effectiveness of policies through actual yields, which reflect not only the land's potential but also the farmers' incentives to cultivate.

Lastly, while existing literature has analyzed changes in China's cropland using various datasets and models, there is a notable gap in empirical research using long-panel high-precision satellite data. Our paper fills this gap by being the first to evaluate the effectiveness of land protection policies using precise datasets that accurately capture each type of land conversion. This approach addresses the obstacle of lack of reliable data in existing studies and makes a significant contribution to the field of cropland evaluation.

The remainder of this paper is structured as follows. Section 2 offers an overview of China's cropland protection policy. Sections 3 and 4 describe the data sources and empirical strategy, including the identification approach for estimating the causal effects of cropland protection on agricultural productivity. Section 5 presents the main findings, discusses spillover effects, and examines the mechanisms behind the observed regional heterogeneity. Finally, Section 6 concludes with a summary of key insights, policy recommendations, and suggestions for future research directions.

2 Policy Background

In fact, as early as 1998, the Land Management Law proposed the "Cultivated land Balance (CLB)" policy (X. Liu et al., 2017). Initially, the CLB aimed to keep the total amount of cultivated land stable. However, due to various factors leading to the loss of cultivated land, particularly policies like returning farmland to forests and adjusting the agricultural structure, this policy soon proved to be challenging to implement realistically. As a result, the focus shifted towards balancing the loss of cultivated land due to construction with the replenishment of equivalent land (Song & Pijanowski, 2014). Although this policy effectively slowed down the decline rate of cultivated land, China's cultivated land area still decreased by approximately 6.11% from 1999 to 2008 (Song & Pijanowski, 2014).

In response, the Ministry of Land and Resources introduced the "Arable Land Redline (ALR)" in 2009, establishing the strictest protection system for cultivated land. This new policy underscored the commitment to preserving a minimum of 1.2 million square kilometers (approximately one-eighth of China's total land area) of cultivated land, directly linking land conservation to national food security [1]. The ALR mandates the replenishment of any cultivated land lost to encroachment, whether from construction, grassland, woodland, or gardens. The alteration in farmland area during the policy period is depicted in Figure 1. The figure illustrates a continued decline in the area of cultivated land prior to 2009, followed by a stabilization after 2009. This chart underscores the role of the ALR in safeguarding farmland. Nonetheless, while the policy serves to protect farmland, it may influence the quality of the restored farmland and alter the agricultural practices of farmers, subsequently impacting the actual yields. Our study is centered on examining the effects of this policy on the yields of cultivated land.

3 Data and Summary Statistics

3.1 Study Area

Our research focuses on China's 13 primary grain-producing provinces (Heilongjiang, Henan, Shandong, Sichuan, Jiangsu, Hebei, Jilin, Anhui, Hunan, Hubei, Inner Mongolia, Jiangxi, and Liaoning). These provinces play a pivotal role in contributing over 80 percent of the nation's aggregate grain production. We further categorized these regions into three geographical zones: Northeast China, North China, and South China, enabling a richer exploration for our analysis.

3.2 Crop Output Data

Primarily, we utilized the county-level Agricultural Database maintained by the Ministry of Agriculture and Rural Affairs of China, encompassing county-specific annual records of total

[1]Source: Ministry of Natural Resources of the People's Republic of China

sowing area and crop yields from 2005 to 2015. Within our analysis, we defined crop productivity (output per mu) as the ratio of total grain output to the sown area.

The data are summarized in Panel A of Table 1, where Column (1) displays the means and standard deviations for the entire period, Column (2) for the period before the implementation of ALR policy, and Column (3) for the period after the implementation of ALR policy. Column (4) contains the t-test results comparing the periods before and after the ALR policy implementation.

3.3 Land-Cover Data

Effective analysis of China's arable land protection policies requires accurate data on the extent and conversion of arable land. However, discrepancies often exist in the arable land area figures reported by different government agencies (X. Liu et al., 2017), hindering the study of land use changes in China. To address this challenge, our study employs precise satellite-derived data to capture long-term land transformations.

The land-cover data used in our analysis were collected from the MCD12Q1.061 MODIS Land Cover Type Yearly Global 500m products from 2005 to 2015. These data allowed us to classify land types into categories such as forestland, shrubland, grassland, wetland, cropland, buildup land, vegetation land, ice land, barren land, and water. Based on the land type raster for each year, we identified two main types of cropland loss [2]: cropland to grassland and cropland to vegetation land. For instance, "cropland to grassland" indicates that the land type in the raster was cropland in the previous year and converted to grassland in the current year. We also classified "cropland loss" as any rasters where cropland was converted to a non-cropland type. Accordingly, we generated corresponding data on new cropland establishment (see Table A1).

For each county, we aggregated raster counts by county code to calculate the acreage of

[2]According to the land area distribution in each region illustrated in Figure 2, the main land types encompass forestland, grassland, vegetation land, and cropland. We exclude forest conversion because of China's Natural Forest Conservation Program.

each type of land conversion from 2005 to 2015. The conversion rate is calculated as the area converted divided by the total land area. Summary statistics for land conversion indicators are presented in Panel B of Table 1.

3.4 Other Related Data

Climate data, encompassing temperature, humidity, and precipitation, were sourced from the China National Meteorological Data Service. Further data were obtained from the county-level census conducted by the National Bureau of Statistics, which included variables such as the added value of the husbandry sector and various socio-demographic indicators. These details are summarized in Panel C of Table 1. Additionally, Gross Primary Productivity (GPP) data were acquired from the annual dataset of terrestrial ecosystems in China, serving as a proxy for land quality.

4 Empirical Framework

4.1 Baseline Analysis

Since the impact of cropland policy may vary depending on the intensity of treatment received by different units, this paper employed a difference-in-difference model with continuous treatment intensity (Iyigun, Nunn, & Qian, 2017), introducing the ratio of cropland loss before policy implementation as an additional independent variable. This approach enables us to compare agricultural outcomes in areas that required more restoration of cropland to agricultural outcomes in areas that restored less cropland before and after ALR implementation, operating under the assumption that counties with higher cropland loss may receive greater regulatory scrutiny and consequently exhibit stronger incentives to restore farmland. Figure 3 confirms the evident positive correlation between the ratio of cultivated land loss before the policy implementation and the ratio of newly added cultivated land after the policy implementation. The regression is shown as follows:

$$Y_{ct} = \alpha + \delta(CroplandLossRatio_c * After_t) + \beta Control_{ct} + \mu_t + \gamma_c + \sigma_{i,t} + \epsilon_{ct} \tag{1}$$

where Y_{ct} represents the outcome variable in county c and year t. Those properties are regressed on a did estimator $CroplandLossRatio_c * After_t$ which is an interaction term of the land loss ratio and policy implementation dummy variable, the continuous variable $CroplandLossRatio_c$ was the proportion of cropland loss before the policy implementation; the time dummy variable $After_t$ was assigned the value 1 after year 2009.

To address potential confounding issues, our analysis incorporates a set of county-by-year climate indicators $Control_{ct}$ (including temperature, humidity, and precipitation), along with time-fixed effects μ_t and county-fixed effects γ_c. These controls help mitigate the impact of external factors that could distort the estimated effects. Moreover, to account for any unobserved policy shocks that may not be adequately captured by the aforementioned controls, we include a city-by-year fixed effect $\sigma_{i,t}$. Finally, standard errors are clustered at the county level to appropriately account for potential correlation within counties (Abadie, Athey, Imbens, & Wooldridge, 2023).

4.2 Event Study

The validity of our baseline analysis relies on the assumption that no differential trend exists across counties with different farmland restoration requirements throughout the period of study had the policy never been implemented. To evaluate the parallel trend assumption, we employ an event study assessing the response of agricultural indicators over time.

$$Y_{ct} = \alpha + \sum_{j=-4}^{6} \delta_j (CroplandLossRatio_c * T_{t+j}) + \beta Control_{ct} + \mu_t + \gamma_c + \sigma_{i,t} + \epsilon_{ct} \quad (2)$$

where the dummy variables T_{t+j} represent the timing of reform implementation. For example, T_{t-4} refers to the four years before the policy implementation, we omitted the year prior to the policy implementation T_{t-1} as a reference group.

4.3 Heterogeneity Analysis

To investigate the heterogeneous impacts of the policy across different types of land conversion, the fixed effects model was re-estimated using various categories of land conversion as measures of intensity. The heterogeneity of these effects is captured in the regression model outlined below:

$$\begin{gathered} Y_{ct} = \alpha + \delta 1 (CroptoGrassRatio_c * After_t) + \\ \delta 2 (CroptoVegeRatio_c * After_t) + \beta Control_{ct} + \mu_t + \gamma_c + \sigma_{i,t} + \epsilon_{ct} \end{gathered} \quad (3)$$

In this model, Y_{ct} denotes the outcome variable for county c in year t. The continuous variables $CroptoGrassRatio_c$ and $CroptoVegeRatio_c$ represent the proportions of cropland converted to grassland and vegetation land, respectively, prior to the implementation of the policy. All other variables remain consistent with those used in the previous analysis.

5 Result and Discussion

5.1 The Effect of ALR on Crop Productivity

Figure 4 depicts an event study graph tracing treatment effects over time. Findings indicate that the treatment effects for both overall and sub-regions remained close to zero prior to policy implementation, supporting the presence of parallel trends and thus affirming the validity of the DID approach.

Table 2 summarizes the results from estimating Equation (1) with crop productivity as outcome variables. The results are organized into four panels: Panel A examines the overall effects on total crop area, Panel B focuses on the Northeast region, Panel C on the Northern region, and Panel D on the Southern region. Each panel includes county, year, and city-by-year fixed effects, with Columns (2), (4), and (6) incorporating temperature, humidity, and precipitation as control variables.

Under the DID model with continuous treatment, we find that ALR significantly affects agricultural production. Subsequent to the implementation of ALR, areas with 1% more restoration of cropland will experience about 0.44% less crop productivity. Specifically, the sown area will not be significantly affected, but there was a statistically significant decrease in total grain output, ranging from 0.47% to 0.48%. This is a sizable, and plausibly moderate magnitude. It shows that mandatory cropland restoration had a quantitatively negative impact on reducing crop productivity.

Our analysis further reveals that the impacts of policies vary across different regions. Notably, the productivity in the Northeast region has experienced a significant decline. Specifically, regions witnessing a 1% increase in cropland restoration are associated with a decrease in crop productivity by approximately 1.6% after the policy. This decline can primarily be attributed to a substantial increase in the sown area (roughly 1%) without a corresponding significant enhancement in the total output value. Regarding the Southern region, while its productivity has not faced a significant impact, both its sown area and total output value have witnessed considerable reductions. Specifically, following the implementation of the policy, regions undergoing a

1% increase in cropland restoration are expected to see a decrease of about 0.4% in the sown area and a 0.6% reduction in the total output value.

In summary, the implementation of the Arable Land Redline (ALR) is projected to have a negative effect on land productivity, exhibiting variations in impact across different regions. Specifically, the policy's effect on the cultivated area was not statistically significant overall, with the positive impact in the Northeast region counteracted by the negative impact in the South. Furthermore, there was a statistically significant decrease in total grain output after the policy, this decline was predominantly observed in the Southern region while remaining unaffected in other regions.

5.2 Event Study

Figure 4 presents an event study plot over time, analyzing the crop productivity, planted area, and total grain output to assess the dynamic effects of the ALR. Considering the long-term impact of policy implementation, the coefficient related to overall productivity is significantly negative and exhibits a continuous decline. Specifically, the impact coefficient for the entire crop productivity has decreased from -0.25 to -0.65 over the seven years following the implementation of the policy. In the Northeast, this coefficient has dropped from -0.75 to -2.5. Similarly, this enduring impact is observable in the cultivated land area in both the Northeast and the South. In the Northeast, the policy has consistently increased the cultivated area from 0.35% to 1.5%, whereas in the South, it has persistently reduced the sown area from -0.1% to -0.5%. However, the policy's influence on total output does not demonstrate a clear persistence.

5.3 Heterogeneity Analysis

Table 3 explores the heterogeneity of treatment effects based on different types of land conversion, including transitions between cropland and grassland, as well as between cropland and vegetated land.

The analysis, divided into four panels representing different geographic areas, suggests that the conversion between cropland and grassland predominantly underlies the impact of farmland protection on agricultural outcomes. After the policy implementation, areas with 1% more restoration of cropland from grassland will experience 0.52% less crop productivity and 0.61% less total output. Specifically, in the Northeast, this conversion results in a 1.7% decrease in crop productivity and an increase of approximately 0.9% in sown area for every 1% increase in cropland restoration. In the South, each 1% increase in cropland restoration from grassland results in a 0.56% decrease in sown area and a 0.8% reduction in total grain output. The magnitude is similar to the results of the baseline analysis, both in terms of total area, and sub-regions.

Notably, the conversion of cropland to vegetation has augmented total grain output in Northeast China (about 5.8% to 6.6%), although this effect is not fully captured in the overall regional policy impact assessment.

5.4 Mechanism Analysis

This section explores the underlying mechanisms affecting agricultural productivity in the northeast and south regions. While both regions have experienced substantial policy interventions aimed at restoring cropland, the outcomes differ markedly due to distinct channels.

In the Northeast, policy interventions have succeeded in expanding the sown area. However, this increase has not translated into higher grain yields. A plausible explanation for this discrepancy lies in land quality: the expansion may involve converting previously uncultivated or marginal land into cropland, replacing high-quality farmland with lower-quality alternatives (C. Liu et al., 2023; X. Liu et al., 2017). Such degradation in land composition can neutralize the productivity gains typically associated with an increase in cultivated area.

To examine this mechanism, we employ gross primary productivity (GPP) as a proxy for land quality. Table 4 reports the heterogeneous effects of cropland restoration across counties with varying GPP levels in the Northeast. The results show that in counties with low or medium GPP, an increase in restored arable land leads to a significant expansion of the sown area. In contrast, no significant effect is observed in counties with high GPP. This suggests a tendency among farmers to convert to lower-quality farmland. Moreover, in counties characterized by low soil quality, the increase in sown area does not correspond to higher grain output, indicating that the marginal land being brought into production likely has limited productivity. In counties with medium-quality land, increases in sown area are associated with modest gains in grain output, although these results are statistically insignificant. Collectively, these findings indicate that without concurrent improvements in land quality, expanding cultivated area alone may be insufficient to enhance agricultural productivity in the region.

In contrast, the southern region has experienced simultaneous declines in both the sown area and total grain production, suggesting a different underlying mechanism. Here, labor shortages appear to be a critical limiting factor. Rapid industrialization in the South has likely accelerated the structural transformation of the rural economy, drawing labor away from agriculture into higher-wage non-agricultural sectors (Cao & Birchenall, 2013; Foster & Rosenzweig, 2007). Consequently, the agricultural sector may face increasing constraints due to insufficient labor input, limiting its capacity to expand cultivation and output levels.

This hypothesis is tested using regional farming population data from the National Bureau of Statistics, with results presented in Table 5. The analysis reveals that in areas with low agricultural labor availability, an increase in cropland restoration actually leads to a reduction in both sown area and grain production. Conversely, in regions with relatively abundant agricultural labor, cropland restoration yields positive effects on both outcomes. These findings highlight the significant role of labor availability in mediating the effectiveness of agricultural policy interventions. Even with efforts to restore cropland, labor scarcity has led to farmland abandonment in the South, further reducing cultivated area and output.

5.5 Spillover Effect

The implementation of strict farmland protection policies may incur costs in other sectors, as explored in the added value of the animal husbandry sector (see Table 6). The results indicate adverse effects on the livestock industry, particularly in Northeast and North China, where South areas have not decreased. Specifically, the estimates show that counties with a 1% increase in the area of restored cropland after ALR will experience an overall decrease of 0.53% in the value added of the livestock sector. Furthermore, the conversion between cultivated land and grassland has been identified as a major factor negatively impacting the livestock industry, suggesting that the policy may lead to inefficient land resource distribution and adverse spillover effects.

5.6 Robustness Check

Variations in grain planting area and yield may result from changes in grain composition. There is a concern that the outcomes of the primary analysis might be influenced by the counterbalancing effects among various crops due to these structural adjustments. To enhance the reliability of our findings, we conducted additional analyses by replacing the outcome variables with agricultural indicators specific to different grains.

Table 7 presents the impacts of the ALR on diverse crops including rice, wheat, maize, and soybean. Overall, the implemented policies have resulted in reductions in both the productivity and total output across these crops, with maize exhibiting a marked decrease in productivity (6.7%) and rice showing a notable reduction in total output (0.5%). Within the Northeast region, the policy generally led to a decline in the productivity of these crops, alongside a significant expansion in their sown area, rice being the exception. Similarly, the policy engendered a decrease in both the sown area and total production of the crops in the Southern region. Those trends are in alignment with the baseline results. The results indicate no significant structural changes among these different crops, thereby confirming the robustness of our initial analysis.

6 Conclusion and Policy Suggestions

This study utilizes a difference-in-differences estimator with continuous treatment intensity to evaluate the impact of the Arable Land Redline (ALR) on agricultural outcomes in China. We analyzed land cover using MODIS Land Cover Type Yearly Global 500m data and assessed agricultural output at the county level from the Ministry of Agriculture and Rural Affairs of China for the years 2005 to 2015.

Our findings indicate that the ALR policy, while aimed at protecting farmland, has not enhanced land output efficiency and has led to a decrease in crop production in China's major grain-producing areas. The results also show significant regional variations. In the Northeast, the policy has successfully expanded the sown area but did not increase grain production. It is hypothesized that this phenomenon is due to the poorer quality of farmland that farmers have converted. The substitution of high-quality farmland with land of inferior quality is believed to be responsible for the decline in agricultural productivity. Conversely, the Southern region has experienced a notable setback in agricultural advancement, both in terms of sown area and grain production. This decline may be attributed to labor shortages, exacerbated by the South region's rapid economic growth. Additionally, strict farmland protection policies may result in inefficient land use and adverse spillover effects on husbandry sector.

Based on the empirical results of this study, several recommendations can be drawn for policymakers. Firstly, these findings underscore the varied effects of policy interventions that prioritize the protection of farmland, necessitating region-specific implementation strategies. Secondly, in the examination of land policies, discrepancies in China's arable land area data provided by different governmental departments pose challenges. Incorporating satellite data into the analysis can help mitigate possible errors and enhance the reliability of the findings. Finally, it is crucial to consider the potential spillovers of farmland protection policies on other sectors, which may arise from inefficient land use.

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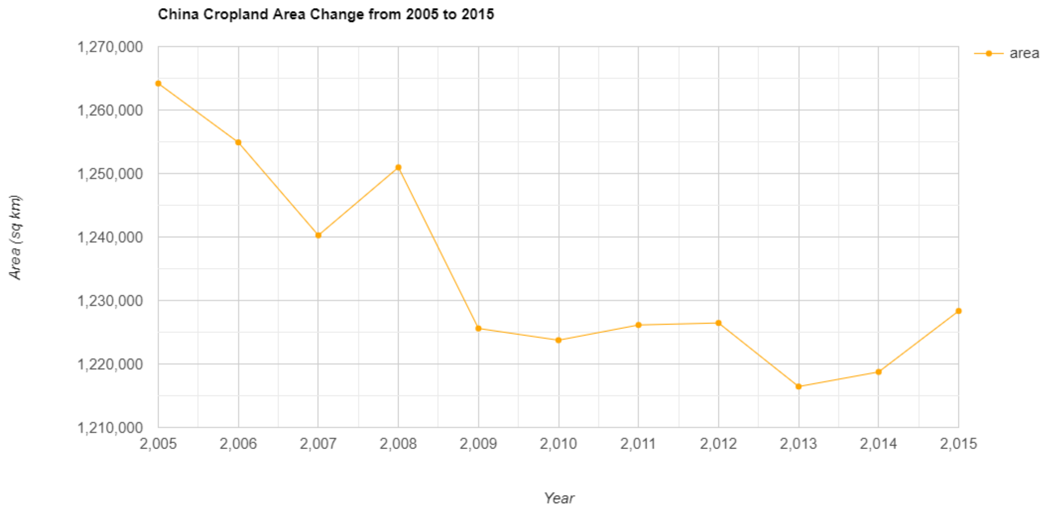
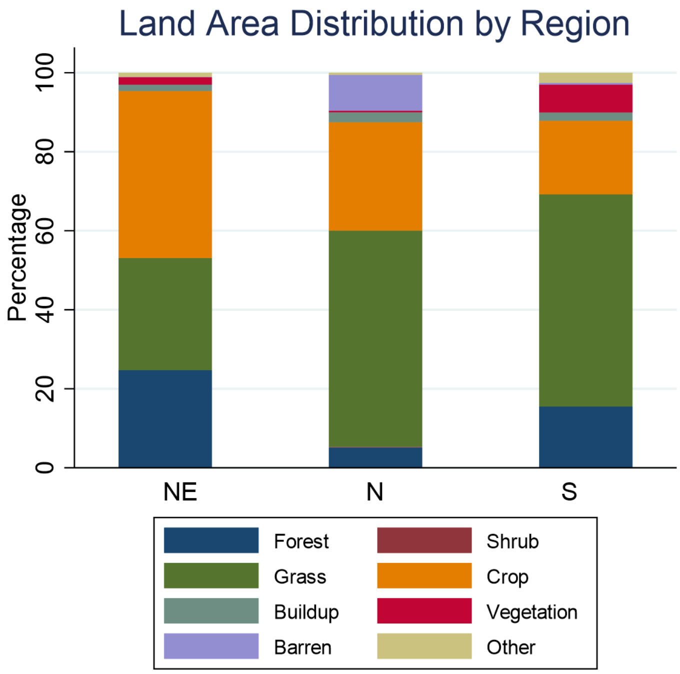
Tables and Figures

Figure 1: Cropland Alteration



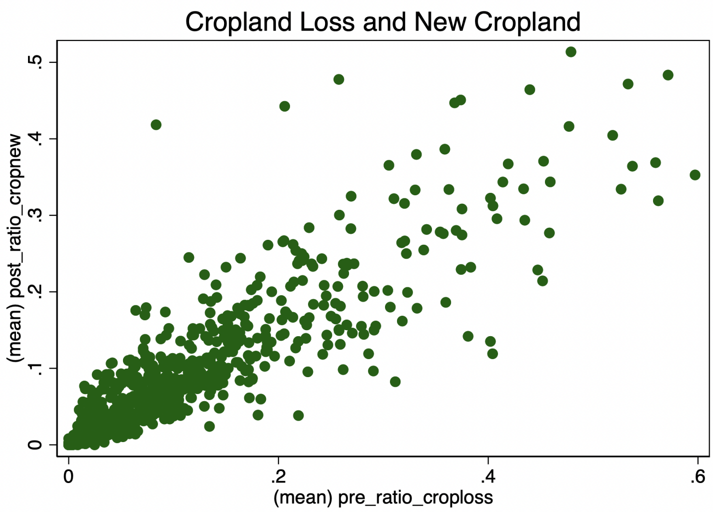
Note: This figure presents the cropland alteration in China during 2005-2015. The figure was generated from Google Earth Engine (Source: https://earthengine.google.com/).

Figure 2: Land Distribution



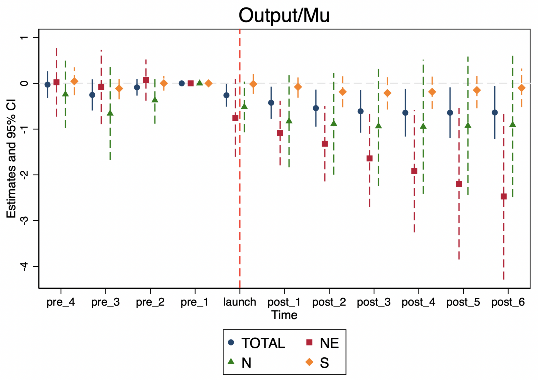
Note: This figure presents the land area distribution by Northeast China, North China, and South China. It is observed that the primary components of the total land area include forestland, grassland, vegetation land, and cropland.

Figure 3: Cropland Loss and New Cropland

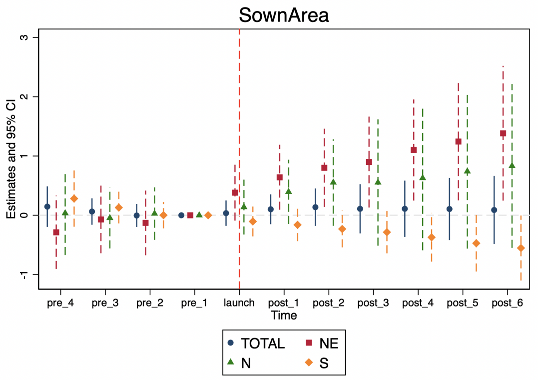


Note: This figure presents the relation between the cropland loss ratio before policy implementation and the new cropland ratio after policy implementation.

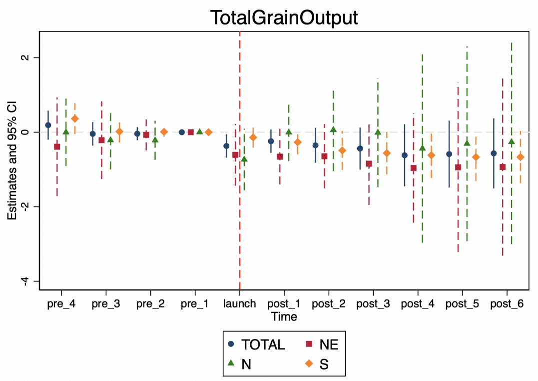
Figure 4: Event Study on Grain Productivity



(a) Output/Mu



(b) Sown Area



(c) Total Grain Output

Note: This figure presents the dynamic effect of treatment by year. Panel A represents the event study of output per mu, defined as the ratio of total grain output to sown area; Panel B represents the event study of sown area; Panel C represents the event study of total grain output. The year prior to the policy implementation pre_1 is omitted as a reference group.

Table 1: Summary Statistics

	(1)	(2)	(3)	(4)
	Entire Sample	Before 2005-2008	After 2009-2015	t-test (3)-(2)
Panel A: agricultural production indicators				
ln(Output per Mu)	1.865	1.831	1.884	0.053***
	(0.359)	(0.291)	(0.391)	
ln(Sown Area)	10.393	10.336	10.426	0.090***
	(1.359)	(1.342)	(1.368)	
ln(Total Grain Output)	12.064	11.979	12.113	0.135***
	(1.500)	(1.444)	(1.529)	
Panel B: land indicators				
countysum(cropland) (500m*500m)	3824.812	3899.302	3782.246	-117.056
	(5191.770)	(5342.286)	(5103.605)	
countysum(new cropland) (500m*500m)	82.709	84.196	81.858	-2.338
	(230.523)	(227.154)	(232.435)	
countysum(cropland loss) (500m*500m)	97.611	102.332	94.913	-7.42
	(284.076)	(303.712)	(272.202)	
Panel C: control variables and other variables				
ln(temperature)	2.734	2.730	2.736	0.006
	(0.296)	(0.307)	(0.289)	
ln(humidity)	4.214	4.211	4.216	0.004*
	(0.093)	(0.093)	(0.093)	
ln(precipitation)	0.003	0.003	0.003	0.000
	(0.001)	(0.001)	(0.001)	
ln(added value of husbandary)	10.806	10.611	10.917	0.306***
	(0.916)	(0.962)	(0.869)	
Observations	13,101	4,764	8,337	

Note: This table presents summary statistics for key indicators, classified into three panels. Panel A comprises agricultural production indicators, Panel B includes land conversion indicators, and Panel C includes control variables and other variables. Column (1) displays the means and standard deviations for the period spanning from 2005 to 2015. Column (2) presents the means and standard deviations before the implementation of the Arable Land Redline (ALR). Column (3) showcases the means and standard deviations after the implementation of ALR. Column (4) represents the t-test results between column (2) and column (3). *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 2: Baseline Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln(Output per Mu)		ln(Sown Area)		ln(Total Grain Output)	
Panel A: Total						
after#ln(cropland loss ratio)	-0.443**	-0.445**	0.046	0.047	-0.478*	-0.480*
	(0.173)	(0.174)	(0.202)	(0.201)	(0.268)	(0.268)
ln(temperature)		0.317		-0.150		0.290
		(0.212)		(0.229)		(0.290)
ln(humidity)		0.445		0.505		0.581
		(0.490)		(0.409)		(0.495)
ln(precipitation)		1.702		-1.124		7.997
		(10.826)		(17.480)		(21.437)
Observations	13,101	13,101	13,101	13,101	13,101	13,101
R-squared	0.782	0.782	0.981	0.981	0.975	0.975
Panel B: Northeast Area						
after#ln(cropland loss ratio)	-1.677***	-1.635***	1.014**	1.046**	-0.724	-0.631
	(0.487)	(0.488)	(0.484)	(0.468)	(0.679)	(0.654)
ln(temperature)		0.193		-0.037		0.210
		(0.274)		(0.250)		(0.345)
ln(humidity)		1.085		1.540**		2.895**
		(1.011)		(0.767)		(1.134)
ln(precipitation)		52.739		-14.555		92.367
		(48.881)		(32.117)		(66.044)
Observations	2,541	2,541	2,541	2,541	2,541	2,541
R-squared	0.714	0.714	0.988	0.988	0.975	0.975
Panel C: North Area						
after#ln(cropland loss ratio)	-0.522	-0.531	0.529	0.543	-0.132	-0.134
	(0.462)	(0.463)	(0.489)	(0.482)	(0.672)	(0.675)
ln(temperature)		0.530		-0.332		0.585
		(0.456)		(0.565)		(0.679)
ln(humidity)		0.468		0.794		0.383
		(0.928)		(0.691)		(0.784)
ln(precipitation)		-13.362		-66.070		-81.652
		(25.140)		(56.380)		(67.182)
Observations	5,401	5,401	5,401	5,401	5,401	5,401
R-squared	0.792	0.793	0.972	0.972	0.969	0.969
Panel D: South Area						
after#ln(cropland loss ratio)	-0.113	-0.115	-0.422**	-0.414**	-0.592**	-0.585**
	(0.132)	(0.132)	(0.185)	(0.183)	(0.274)	(0.271)
ln(temperature)		0.303		-0.324		-0.106
		(0.352)		(0.629)		(0.772)
ln(humidity)		-0.063		-0.537		-0.685
		(0.313)		(0.643)		(0.743)
ln(precipitation)		2.864		27.231*		33.019*
		(11.384)		(14.897)		(17.523)
Observations	5,159	5,159	5,159	5,159	5,159	5,159
R-squared	0.874	0.874	0.984	0.984	0.983	0.983
Control	N	Y	N	Y	N	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
City by Year FE	Y	Y	Y	Y	Y	Y

Note: This table reports the DID analysis with cropland loss ratio as a variation of treatment. Panel A represents the results in total crop area, Panel B represents the results in Northeast area, Panel C represents the results in North area, and Panel D represents the results in South area. Columns (1)-(2) report the effect on output per mu, defined as the ratio of total grain output to sown area; Columns (3)-(4) report the effect on sown area; Columns (5)-(6) report the effect on total grain output. All columns add county, year, and city-by-year fixed effects. Columns (2), (4), and (6) add log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 3: Heterogeneity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln_Output/Mu		ln_SownArea		ln_TotalGrainOutput	
Panel A: Total						
after#ln(cropland to grass ratio)	-0.518***	-0.519***	0.008	0.010	-0.610**	-0.610**
	(0.195)	(0.195)	(0.231)	(0.230)	(0.308)	(0.308)
after#ln(cropland to vege ratio)	-0.002	-0.007	0.135	0.134	0.154	0.147
	(0.148)	(0.149)	(0.198)	(0.198)	(0.240)	(0.240)
Observations	13,101	13,101	13,101	13,101	13,101	13,101
R-squared	0.782	0.783	0.981	0.981	0.975	0.975
Panel B: NorthEast Area						
after#ln(cropland to grass ratio)	-1.723***	-1.685***	0.879*	0.902*	-0.930	-0.849
	(0.486)	(0.488)	(0.485)	(0.467)	(0.685)	(0.657)
after#ln(cropland to vege ratio)	1.804	2.092	4.139*	4.613**	5.829**	6.640**
	(2.838)	(2.901)	(2.121)	(2.140)	(2.740)	(2.792)
Observations	2,541	2,541	2,541	2,541	2,541	2,541
R-squared	0.714	0.715	0.988	0.988	0.975	0.976
Panel C: North Area						
after#ln(cropland to grass ratio)	-0.520	-0.530	0.505	0.518	-0.143	-0.147
	(0.465)	(0.466)	(0.496)	(0.489)	(0.685)	(0.688)
after#ln(cropland to vege ratio)	1.135	1.263	-2.760	-2.566	-0.151	0.300
	(1.364)	(1.385)	(3.145)	(3.184)	(3.427)	(3.465)
Observations	5,401	5,401	5,401	5,401	5,401	5,401
R-squared	0.792	0.793	0.972	0.972	0.969	0.969
Panel D: South Area						
after#ln(cropland to grass ratio)	-0.162	-0.164	-0.560**	-0.552**	-0.804**	-0.797**
	(0.162)	(0.163)	(0.230)	(0.227)	(0.343)	(0.340)
after#ln(cropland to vege ratio)	0.022	0.020	-0.021	-0.016	0.010	0.014
	(0.137)	(0.138)	(0.193)	(0.193)	(0.237)	(0.235)
Observations	5,159	5,159	5,159	5,159	5,159	5,159
R-squared	0.874	0.874	0.984	0.984	0.983	0.983
Control	N	Y	N	Y	N	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
City by Year FE	Y	Y	Y	Y	Y	Y

Note: This table reports the DID analysis with heterogeneous cropland loss ratio as a variation of treatment, including conversion between cropland and grassland, as well as cropland and vegetation land. Panel A represents the results in total crop area, Panel B represents the results in Northeast area, Panel C represents the results in North area, and Panel D represents the results in South area. Columns (1)-(2) report the effect on output per mu, defined as the ratio of total grain output to sown area; Columns (3)-(4) report the effect on sown area; Columns (5)-(6) report the effect on total grain output. All columns add county, year, and city-by-year fixed effects. Columns (2), (4), and (6) add log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 4: Mechanism Analysis for Northeast Area

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln(Output per Mu)		ln(Sown Area)		ln(Total Grain Output)	
Panel A: Low GPP						
after#ln(cropland loss ratio)	-2.169**	-2.180**	1.668**	1.654**	-0.345	-0.356
	(0.843)	(0.851)	(0.674)	(0.660)	(0.544)	(0.526)
Observations	759	759	759	759	759	759
R-squared	0.635	0.637	0.993	0.993	0.985	0.986
Panel B: Medium GPP						
after#ln(cropland loss ratio)	1.297	1.381	1.585*	1.570*	3.613	3.709
	(1.329)	(1.342)	(0.802)	(0.807)	(2.278)	(2.346)
Observations	792	792	792	792	792	792
R-squared	0.780	0.781	0.990	0.990	0.968	0.968
Panel C: High GPP						
after#ln(cropland loss ratio)	-2.244***	-2.242***	1.084	1.146	-1.872**	-1.781**
	(0.694)	(0.709)	(1.034)	(1.000)	(0.773)	(0.709)
Observations	814	814	814	814	814	814
R-squared	0.817	0.818	0.981	0.982	0.982	0.982
Control	N	Y	N	Y	N	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
City by Year FE	Y	Y	Y	Y	Y	Y

Note: This table presents the results of the mechanism analysis for the Northeast region. Panel A reports estimates for areas characterized by low Gross Primary Productivity (GPP), Panel B for areas with medium GPP, and Panel C for areas with high GPP. Columns (1)-(2) report the effect on output per mu, defined as the ratio of total grain output to sown area; Columns (3)-(4) report the effect on sown area; Columns (5)-(6) report the effect on total grain output. All columns add county, year, and city-by-year fixed effects. Columns (2), (4), and (6) add log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 5: Mechanism Analysis for South Area

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln(Output per Mu)		ln(Sown Area)		ln(Total Grain Output)	
Panel A: Low Farming Population Ratio						
after#ln(cropland loss ratio)	-0.318	-0.313	-0.868***	-0.868***	-1.218***	-1.213***
	(0.206)	(0.207)	(0.224)	(0.219)	(0.314)	(0.308)
Observations	1,518	1,518	1,518	1,518	1,518	1,518
R-squared	0.846	0.846	0.979	0.979	0.977	0.977
Panel B: Medium Farming Population Ratio						
after#ln(cropland loss ratio)	0.015	-0.025	-0.678**	-0.701**	-0.662	-0.742
	(0.296)	(0.286)	(0.286)	(0.272)	(0.532)	(0.498)
Observations	1,441	1,441	1,441	1,441	1,441	1,441
R-squared	0.859	0.860	0.993	0.993	0.984	0.985
Panel C: High Farming Population Ratio						
after#ln(cropland loss ratio)	0.056	0.035	0.209	0.199	0.250	0.212
	(0.139)	(0.133)	(0.233)	(0.230)	(0.228)	(0.213)
Observations	1,617	1,617	1,617	1,617	1,617	1,617
R-squared	0.934	0.934	0.993	0.993	0.992	0.992
Control	N	Y	N	Y	N	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
City by Year FE	Y	Y	Y	Y	Y	Y

This table presents the results of the mechanism analysis for the South region. Panel A reports estimates for areas characterized by low farming population, Panel B for areas with medium farming population, and Panel C for areas with high farming population. Columns (1)-(2) report the effect on output per mu, defined as the ratio of total grain output to sown area; Columns (3)-(4) report the effect on sown area; Columns (5)-(6) report the effect on total grain output. All columns add county, year, and city-by-year fixed effects. Columns (2), (4), and (6) add log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 6: Spillover Effect

	(1)	(2)
VARIABLES	ln_husbandry	
Panel A: Total		
after#ln(cropland loss ratio)	-0.528***	-0.527***
	(0.172)	(0.172)
Observations	13,101	13,101
R-squared	0.933	0.933
Panel B: NorthEast Area		
after#ln(cropland loss ratio)	-1.081***	-1.042***
	(0.381)	(0.374)
Observations	2,541	2,541
R-squared	0.937	0.938
Panel C: North Area		
after#ln(cropland loss ratio)	-1.373***	-1.352***
	(0.377)	(0.373)
Observations	5,401	5,401
R-squared	0.892	0.893
Panel D: South Area		
after#ln(cropland loss ratio)	0.022	0.021
	(0.198)	(0.196)
Observations	5,159	5,159
R-squared	0.955	0.955
Panel E: Croploss by Categories		
after#ln(cropland to grass ratio)	-0.563***	-0.563***
	(0.186)	(0.186)
after#ln(cropland to vege ratio)	-0.148	-0.147
	(0.265)	(0.266)
Observations	13,101	13,101
R-squared	0.933	0.933
Control	N	Y
County FE	Y	Y
Year FE	Y	Y
City by Year FE	Y	Y

Note: This table reports the spillover effects of the Arable Land Redline. Panel A represents the results in total crop area, Panel B represents the results in Northeast area, Panel C represents the results in North area, Panel D represents the results in South area, and Panel E represents the results with heterogeneous cropland loss ratio as a variation of treatment, including conversion between cropland and grassland, as well as cropland and vegetation land. All columns add county, year, and city-by-year fixed effects. Column (2) adds log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Table 7: Robustness Check

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	ln(Output per Mu)				ln(Sown Area)				ln(Total Grain Output)			
VARIABLES	Rice	Wheat	Maize	Soybean	Rice	Wheat	Maize	Soybean	Rice	Wheat	Maize	Soybean
Panel A: Total												
after#ln(cropland loss ratio)	-7.356	-19.50	-6.697*	-2.426	-0.160	0.208	0.538*	0.237	-0.505*	-0.457	-0.129	-0.337
	(5.772)	(47.25)	(3.587)	(2.076)	(0.264)	(0.407)	(0.280)	(0.275)	(0.302)	(0.497)	(0.317)	(0.340)
Observations	13,101	13,101	13,101	13,101	13,101	13,101	13,101	13,101	13,101	13,101	13,101	13,101
R-squared	0.988	0.913	0.972	0.607	0.988	0.980	0.985	0.959	0.988	0.983	0.984	0.957
Panel B: Northeast Area												
after#ln(cropland loss ratio)	5.431	-243.1	-28.47	-3.157	-0.631	2.877***	1.180**	1.518*	-0.526	0.631	-0.0545	1.644
	(7.020)	(173.1)	(23.71)	(3.028)	(0.591)	(0.784)	(0.482)	(0.886)	(0.699)	(0.736)	(0.631)	(1.228)
Observations	2,541	2,541	2,541	2,541	2,541	2,541	2,541	2,541	2,541	2,541	2,541	2,541
R-squared	0.985	0.837	0.979	0.768	0.987	0.970	0.986	0.968	0.983	0.975	0.978	0.969
Panel C: North Area												
after#ln(cropland loss ratio)	-21.49	-77.30	-7.738	-6.690	0.638	1.123	1.049	0.615	-0.613	0.715	-0.246	-1.023
	(15.08)	(93.31)	(5.527)	(6.653)	(0.690)	(0.743)	(0.655)	(0.492)	(0.860)	(1.002)	(0.665)	(0.660)
Observations	5,401	5,401	5,401	5,401	5,401	5,401	5,401	5,401	5,401	5,401	5,401	5,401
R-squared	0.947	0.993	0.908	0.591	0.983	0.976	0.981	0.945	0.980	0.977	0.981	0.945
Panel D: South Area												
after#ln(cropland loss ratio)	-2.864	63.59	-2.029	-0.350	-0.440**	-0.866*	0.154	-0.254	-0.430*	-1.298**	-0.0885	-0.495
	(6.261)	(54.94)	(2.432)	(1.149)	(0.214)	(0.514)	(0.323)	(0.357)	(0.249)	(0.634)	(0.414)	(0.405)
Observations	5,159	5,159	5,159	5,159	5,159	5,159	5,159	5,159	5,159	5,159	5,159	5,159
R-squared	0.999	0.726	0.494	0.613	0.990	0.980	0.977	0.963	0.992	0.981	0.978	0.954
Control	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City by Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Note: This table reports the effects of the Arable Land Redline on different crops including rice, wheat, maize, and soybean. Panel A represents the results in total crop area, Panel B represents the results in Northeast area, Panel C represents the results in North area, and Panel D represents the results in South area. Columns (1)-(4) report the effect on output per mu, defined as the ratio of total grain output to sown area; Columns (5)-(8) report the effect on sown area; Columns (9)-(12) report the effect on total grain output. All columns add county, year, and city-by-year fixed effects. We add log values of temperature, humidity, and precipitation as control variables. The standard errors are clustered at the county level. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Appendix A Appendix Figures and Tables

Table A1: Data Generation

	(1)
EXPLANATIONS	Land Conversion Data Generation
Panel A: cropland loss	
cropland to grass	cropland to grass'i' = sum (cropland'i-1' = 1 & grass'i' = 1)
cropland to vegetation	cropland to vegetation'i' = sum (cropland'i-1' = 1 & vegetation'i' = 1)
cropland loss	cropland loss'i' = sum (cropland'i-1' = 1 & cropland'i' ≠ 1)
Panel B: new cropland	
grass to cropland	grass to cropland'i' = sum (grass'i-1' = 1 & cropland'i' = 1)
vegetation to cropland	vegetation to cropland'i' = sum (vegetation'i-1' = 1 & cropland'i' = 1)
new cropland	new cropland'i' = sum (cropland'i-1' ≠ 1 & cropland'i' = 1)

Note: This table reports data generation process. Panel A presents the creation of variables related to cropland loss in year 'i'; Panel B displays the creation of variables related to new cropland in year 'i'.