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Exploring the Heterogeneities in the Impacts of China's Grassland Ecological Compensation Program

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Abstract: The Payments for Ecosystem Services (PES) program is an innovative approach that provides economic incentives directly to natural resource exploiters in order to shape their behavior. Although the implementation of PES programs and the context in which these programs are implemented are often different across space, the spatial heterogeneities in the impacts of PES programs are often neglected in studies. In this study, we demonstrate the spatial and temporal dynamics of the Normalized Differential Vegetation Index (NDVI) in the grassland where China's Grassland Ecological Compensation Program (GECP) has been implemented, and we evaluate the impacts of the GECP on the NDVI. We found that most of the grassland in the GECP area showed small changes in NDVI between 2000 and 2010. On average, the GECP only had a marginal positive effect on the NDVI of grassland. Although the magnitude of impacts of the GECP was relatively small in most places where the program is implemented, we detected substantial heterogeneities in the impacts of the GECP on the NDVI. The impact of the GECP on the NDVI differed substantially, particularly between Inner Mongolia, Sichuan, and other provinces. Our findings suggest that there can be substantial heterogeneities in the impacts of PES programs across space, which can be leveraged to promote the efficacy of the GECP and many other PES programs around the world.

Keywords: matching; normalized differential vegetation index; payments for ecosystem services; vegetation rehabilitation

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1. Introduction

The Payments for Ecosystem Services (PES) program is an innovative tool that provides economic incentives to shape the behavior of natural resource exploiters for the protection of ecosystem services [1–3]. This tool takes into consideration both the conservation of ecosystems and people's livelihoods. PES programs have been implemented in many countries around the world [4–6]. For example, in order to reduce soil erosion caused by agricultural production, improve water quality, and transfer income to farmers, the United States has implemented the Conservation Reserve Program (CRP) [7], which provides many environmental benefits, including an improved water and soil quality and the provision of habitats for wildlife [8]. In the European Union, agri-environmental programs provide financial support for biodiversity conservation and the mitigation of other environmental damages [9]. Costa Rica's Pagos de Servicios Ambientales (PSA) program is one of the most famous PES programs in the developing world [10]. By 2022, the PSA conserved over 247 thousand hectares of forests and forest plantations [11].

With billions of dollars invested in PES programs globally every year, their ecological, economic, and social impacts are of great concern [2,12]. Existing studies have often focused on assessing the overall performance of PES programs [13–16]. However, the impacts of PES programs can be different at different places. For instance, studies on Costa Rica's PSA program have found that the PSA contract significantly increased forest cover in

some regions [17], while no effects were detected in other regions [18]. Studies on China's PES programs for forest restoration have also showed differences in the effectiveness in achieving afforestation goals [19–21]. However, the spatial heterogeneities in the impacts of PES programs are not well understood.

The Grassland Ecological Compensation Program (GECP) of China is probably the world's largest PES program that has been implemented for the conservation of grassland. Since 2003, the GECP has been implemented in eight provinces including Inner Mongolia, Sichuan, Yunnan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang (Figure 1). The Chinese government adopted measures such as the establishment of pasture fences, grazing bans, rotational grazing, feeding grain subsidies, and the improvement in grass seeds in the implementation of the program in order to improve grassland recovery and promote the sustainable development of grassland animal husbandry [22,23]. By 2010, a total of 51.87 million hectares of grassland fences was established, and 12.4 million hectares of grass was replanted in heavily degraded grassland. More than 900,000 farmers and herdsmen in 181 counties have participated in the program. The central government of China has allocated a total of 13.57 billion yuan (currently 1 USD = 6.9 yuan) for the GECP, which accounts for about 75 percent of the country's total investment in grassland protection [24].

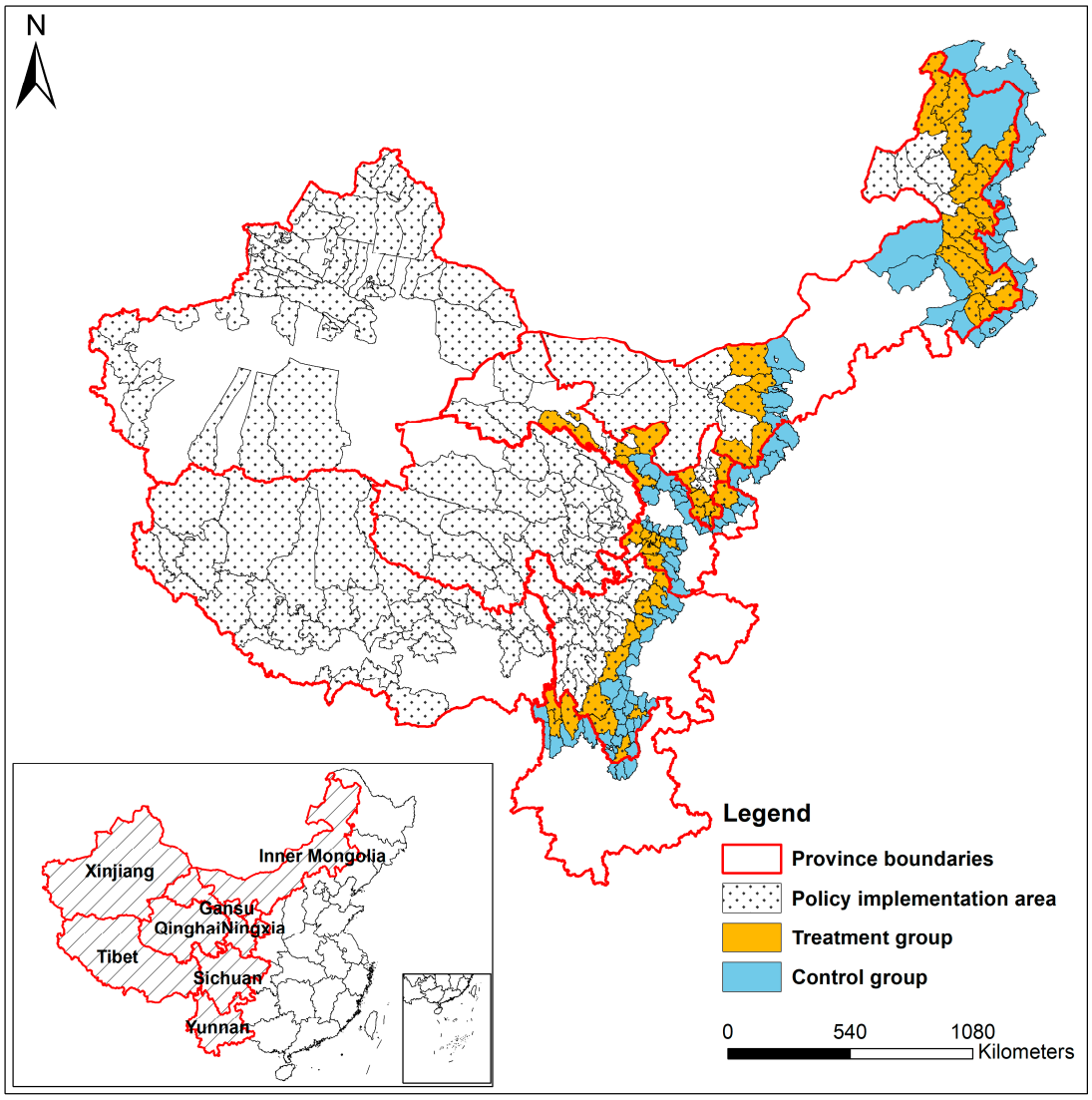


Figure 1. Regions where the GECP has been implemented and the distribution of treatment and control groups.

Given the scale of the GECP, its impact on grassland conservation and management has been of great concern. Studies on the GECP have mostly focused on the impacts of the program on the spatial and temporal dynamics of grasslands, and on the socioeconomic status of the participants. These studies measured grassland status using metrics such as grassland area, grass yield, net primary productivity (NPP), and Normalized Differential Vegetation Index (NDVI) [25,26]. A few studies that evaluated the socioeconomic impact of the GECP measured the income of people in the area where the program has been implemented [27,28]. Most of these studies have found a recovery in the grassland [29,30] and an improvement in the livelihoods [28,31] since the implementation of the GECP. However, studies have found a continued degradation of grassland in the northern Tibetan Plateau; on the western side of Inner Mongolia, Gansu, and Ningxia provinces; and in Xinjiang province [26]. Past studies have evaluated the impacts of the GECP in different regions across China, while the evaluation of the overall impacts of the program is rare [32]. To the best of our knowledge, the spatial heterogeneities in the impacts of the GECP on the grassland have not been evaluated yet.

Studies that evaluate the impacts of conservation programs often compare changes in ecological or socioeconomic indicators before and after the implementation of the programs [33,34]. For instance, changes in forest cover and NPP before and after the implementation of China's Natural Forest Conservation Program have been used to evaluate the effectiveness of the program [26]. A comparison of the grassland quality and socioeconomic status before and after the implementation of the GECP has often been used to evaluate the impacts of the program [35]. Although these approaches have produced important insights in the understanding of the impacts of PES programs, the conclusions from these approaches can be biased due to the self-selection of participants into the programs [3,16]. Recently, a growing number of studies have begun to evaluate the impacts of PES programs using quasi-experimental design methods such as matching [6,36]. The quasi-experimental design methods can be used to correct the biases due to self-selection processes and attenuate the effect of omitted variables [37]. However, quasi-experimental design methods have rarely been used in the evaluation of the impacts of the GECP.

This study aims to explore the heterogeneities in the impacts of China's GECP program. We first described the spatial and temporal dynamics in the NDVI of grassland within the area where the GECP has been implemented. We then established a treatment group and a control group for the implementation of the GECP, and we estimated the average effect of the GECP on the NDVI of grassland. Further, we evaluated the spatial heterogeneities in the effect of the GECP on the grassland NDVI across different counties.

2. Methods

2.1. Data

We identified the distribution of grassland in 2003 from the China annual land cover dataset [38]. Based on the Landsat/LT05 data [39], we calculated the yearly median of grassland NDVI (a spatial resolution of 300 m was used to compromise for the computational cost) for each year between 1993 and 2010 in order to reduce the effect of outliers [40]. We also calculated the trend of yearly median NDVI before the implementation of the GECP (i.e., between 1993 and 2002). In addition, we obtained precipitation, temperature, elevation, slope, and socioeconomic data that have been identified as the key drivers of grassland quality [41]. Precipitation and temperature were obtained from the WorldClim2 dataset [42]. Elevation and slope were extracted from Aster Global Digital Elevation Map [43]. Socioeconomic data, including the beef and mutton productions, were obtained from the statistical yearbooks of Inner Mongolia, Ningxia, Gansu, Sichuan, and Yunnan provinces [44–48].

2.2. Analytical Approach

To illustrate the spatiotemporal dynamics in the NDVI of grassland within the area where the GECP has been implemented, we calculated the average annual NDVI for each

county in 2002 and 2010 to detect changes after the implementation of the program. We also calculated the changes in the average NDVI for each county between 2002 and 2010.

We used the Propensity Score Matching (PSM) method to estimate the effect of the GECP on the NDVI of grassland. This method compares the differences between the samples in a control group and the samples in a treatment group that have similar characteristics so that the impacts of the non-policy factors are largely eliminated [49]. First, we identified a group of counties where the policy has been implemented and a group of counties where the policy has not been implemented on the boundary of the policy implementation (Figure 1). We selected these counties based on the first law of geography that near things are more related to each other than distant things [50], so the counties where the policy has been implemented tend to be similar to the counties where the policy has not been implemented. A total of 54 counties and 99 counties were identified from the counties where the policy has been implemented and the counties where the policy has not been implemented, respectively. As a result, all the grassland pixels in the 54 counties where the policy has been implemented formed the treatment group, while all the grassland pixels in the 99 counties where the policy has not been implemented formed the control group (see Supplementary Material for selected characteristics of the counties in the treatment group). The spatial resolution of the pixels was 300 m.

Second, we selected pixels from the treatment group and pixels from the control group that have similar characteristics. To identify the pixels from the treatment and control groups that are similar in each of the characteristics, a propensity score was calculated for each pixel using a logit regression of the policy implementation on one of the characteristics of pixels, as shown in the following equation:

$$\mathrm{PS}(\mathrm{X}_i) = \Pr(D_i = 1|X_i) = \frac{\exp\,(\beta X_i)}{1 + \exp\,(\beta X_i)} \tag{1}$$

where $\mathrm{PS}(\mathrm{X}_i)$ represents the propensity score for the ith pixel to implement the policy, D indicates whether the policy has been implemented (implementation = 1; non-implementation = 0), X denotes a characteristic that influences the implementation of the policy, and β is a parameter to be estimated based on the observed data. Then, caliper matching [51] was conducted to identify pixels from the treatment group and pixels from the control group that have similar values of the characteristic. The characteristics that were used to select pixels from the treatment and the control groups included the grassland NDVI of 2002, the trend of NDVI between 1993 and 2002, elevation, slope, precipitation, and temperature. Through this process, all the pixels from the treatment and the control groups that have similar characteristics were selected as samples for the estimation of the effect of the GECP on the NDVI of grassland.

Third, to estimate the effect of the GECP on the NDVI of grassland, we calculated the average treatment effect for the treated (ATT) using the method [52] that is shown in the following equation:

$$\begin{aligned} \mathrm{ATT} &= \mathrm{E}(Y_{1i} - Y_{0i}|D_i = 1) = \mathrm{E}\{E[Y_{1i} - Y_{0i}|D_i = 1, PS(X_i)]\} \\ &= E\{E[Y_{1i}|D_i = 1, PS(X_i)] - E[Y_{0i}|D_i = 0, PS(X_i)|D_i = 1]\} \end{aligned} \tag{2}$$

where Y is the NDVI in 2010. Y_{1i} and Y_{0i} denote the NDVI in 2010 of the same pixel under the conditions where the policy has been implemented and where the policy has not been implemented, respectively.

Fourth, we also evaluated the spatial heterogeneities in the effect of the GECP on the NDVI of grassland across different counties by estimating the ATT for each of the 54 counties identified above where the policy has been implemented. For this purpose, we followed the same procedure as presented above except for the formation of the treatment and the control groups. When we estimate the ATT of a county, all the grassland pixels in the county formed the treatment group, while all the grassland pixels in its neighboring counties where the policy has not been implemented formed the control group.

3. Results

The spatial distribution of grassland NDVI across the counties where the GECP has been implemented is presented in Figure 2. The average annual NDVI of grassland showed similar patterns between 2002 (i.e., a year before the implementation of the GECP) and 2010. Most of the counties in the Tibetan Plateau and some counties in western Inner Mongolia and the Eastern Xinjiang Autonomous Region showed relatively low values of the average annual NDVI of grassland. Moderate NDVI values were detected in the counties in the eastern Tibetan Plateau, northern Xinjiang, and the northeast of Inner Mongolia (Figure 2). Relatively high NDVI values were detected in the counties on the southeast border of the Tibetan Plateau, northern Xinjiang, and northern Inner Mongolia. Between 2002 and 2010, the average annual grassland NDVI in most of the counties where the GECP has been implemented had increased. Counties where the NDVI decreased are located in the eastern Tibetan Plateau, western Inner Mongolia, and northern Xinjiang.

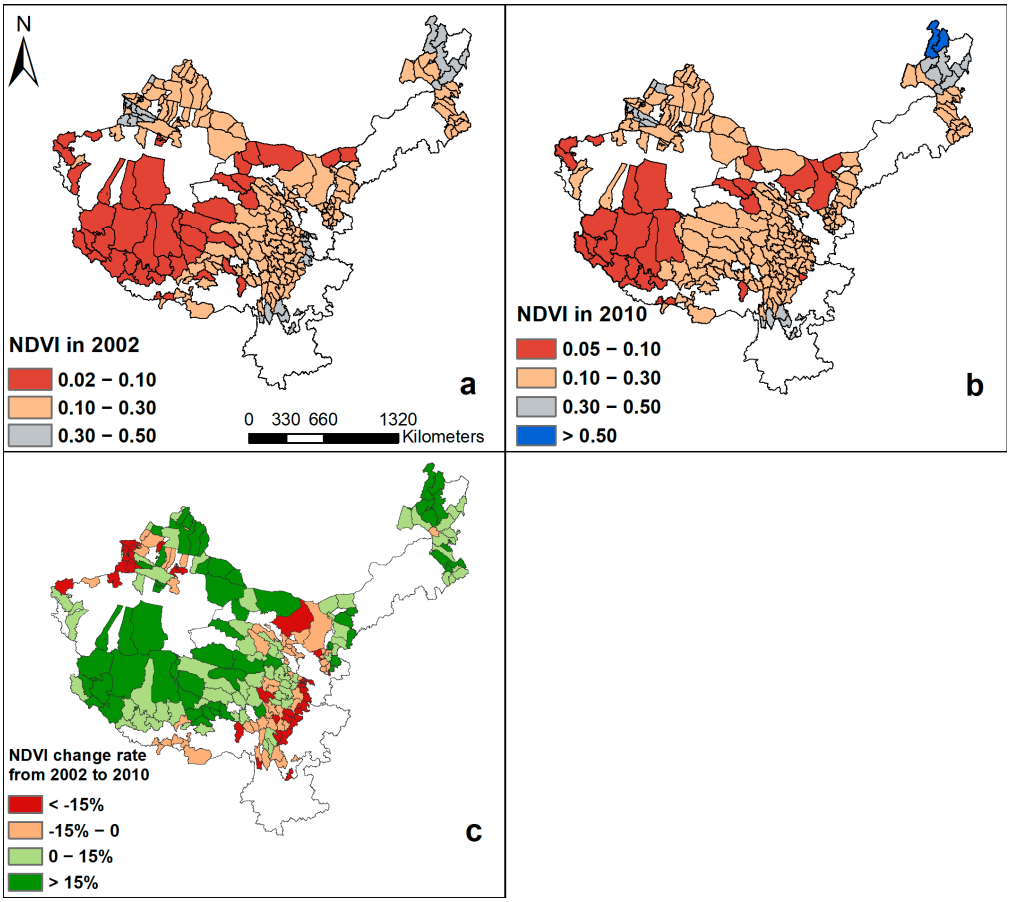


Figure 2. Spatial and temporal changes in the average grassland NDVI of counties. (**a**) Average NDVI of each county in 2002; (**b**) average NDVI of each county in 2010; (**c**) rate of changes in NDVI between 2002 and 2010).

Based on the data from the selected counties on the boundary of the policy implementation (Figure 1), it was estimated that the GECP had increased the NDVI of grassland. The ATT across the selected counties was 0.02 ($p < 0.01$), which showed a positive correlation between the implementation of the GECP and the change in the NDVI of grassland. However, the magnitude of the ATT was relatively small, which accounted for about 7% of the average annual NDVI of 2002 in the 54 selected counties where the GECP has been implemented.

The evaluation of the spatial heterogeneities in the effect of the GECP on the NDVI of grassland showed substantial differences in the ATT of individual counties. We detected

a positive ATT ($p < 0.1$) in 19 counties, a negative ATT ($p < 0.1$) in 27 counties, and a non-significant ATT in two counties (Figure 3). Pixels in six of the selected counties where the policy has been implemented failed to match with the pixels of the selected counties where the policy has not been implemented. These results suggest that the implementation of the GECP was correlated to an increase in the NDVI of grassland in 19 counties, and a decrease in the NDVI of grassland in 27 counties. Most of the counties that had a positive ATT are located in Gansu, Inner Mongolia, and Ningxia provinces, while the counties that had a negative ATT are mostly located in Inner Mongolia, Sichuan, and Ningxia provinces (Figure 3). Based on the evaluation of the ATT in the selected counties where the GECP has been implemented (Figure 1), most of the counties in Inner Mongolia and Sichuan provinces exhibited a negative ATT, while most of the counties in Gansu province exhibited a positive ATT. The number of counties that exhibited a positive ATT is similar to the number of counties that exhibited a negative ATT in Ningxia and Yunnan provinces (Figure 3).

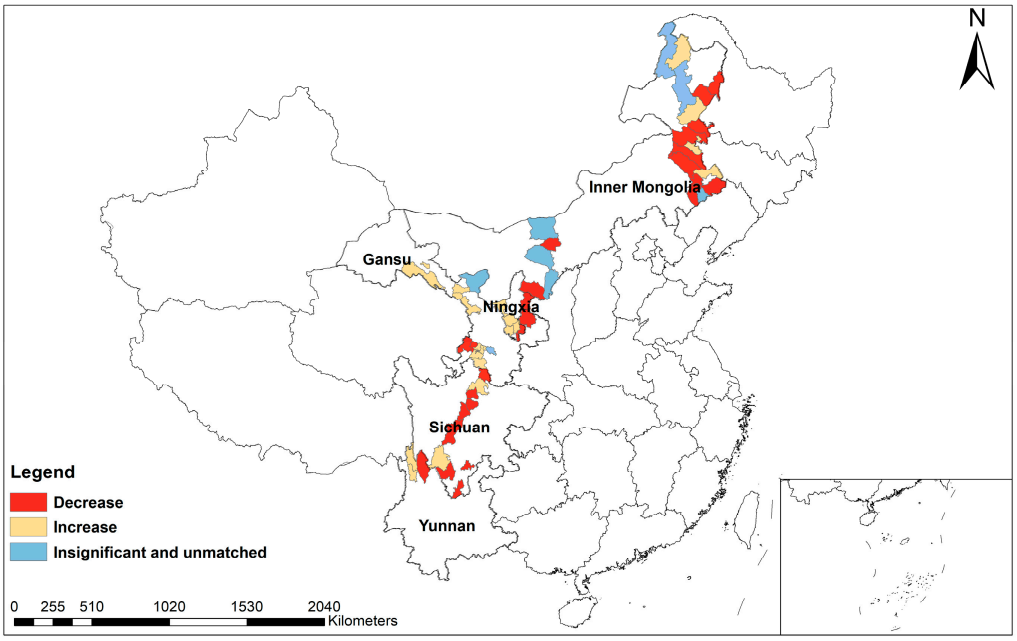


Figure 3. Spatial distribution of the effects of GECP from caliper matching.

4. Discussion

In this study, we evaluated the impacts of the GECP program on the NDVI of grassland across different counties in China. We found that the average annual NDVI of grassland in most of the counties where the GECP has been implemented had increased between 2002 and 2010. In order to obtain a robust estimation of the impacts of the GECP program on the NDVI of grassland, we identified a group of counties where the policy has been implemented and a group of counties where the policy has not been implemented on the boundary of the policy implementation to form the treatment and control groups for the estimation of the effect of the GECP. We found that, overall, the GECP had increased the NDVI of grassland, although the magnitude of the impact was relatively small. In addition, we found substantial heterogeneities in the effect of the GECP on the NDVI of grassland. We detected a positive ATT in 19 counties and a negative ATT in 27 counties (Table 1).

Table 1. Mean grassland NDVI in 2002 and 2010 and ATT for each county in the treatment group.

Province	County	NDVI in 2002	NDVI in 2010	ATT
Gansu	Yugur Autonomous County of Sunan	0.180	0.174	0.031
Gansu	Zhang County	0.381	0.236	0.000
Gansu	Diebu County	0.403	0.287	0.044
Gansu	Hezuo City	0.278	0.248	−0.019
Gansu	Zhuoni County	0.359	0.291	0.051
Gansu	Huan County	0.165	0.206	−0.017
Gansu	Lintan County	0.355	0.233	0.002
Gansu	Xiahe County	0.258	0.258	−0.023
Gansu	Yongchang County	0.156	0.148	0.012
Gansu	Minqin County	0.116	0.108	0.000
Gansu	Tianzhu Zangzu Autonomous County	0.253	0.234	0.101
Inner Mongolia	Arun Banner	0.367	0.382	−0.130
Inner Mongolia	Genhe City	0.384	0.562	0.058
Inner Mongolia	Daur Autonomous Banner of Morin Dawa	0.368	0.419	−0.084
Inner Mongolia	Yakeshi City	0.333	0.467	0.000
Inner Mongolia	Zhalantun City	0.343	0.388	0.014
Inner Mongolia	Holingola	0.209	0.222	−0.007
Inner Mongolia	Kailu County	0.168	0.203	−0.016
Inner Mongolia	Horqin Northeast County	0.177	0.195	−0.032
Inner Mongolia	Horqin East Middle County	0.165	0.201	0.006
Inner Mongolia	Kulun Banner	0.169	0.191	0.000
Inner Mongolia	Naiman Banner	0.175	0.198	−0.006
Inner Mongolia	Jarud Banner	0.211	0.251	−0.007
Inner Mongolia	Horqin Right Wing Front Banner	0.242	0.268	−0.014
Inner Mongolia	Horqin Right Wing Middle Banner	0.200	0.226	−0.011
Inner Mongolia	Tuquan County	0.189	0.262	0.034
Inner Mongolia	Ulan Hot City	0.218	0.260	0.027
Inner Mongolia	Jalaid Banner	0.228	0.262	−0.024
Inner Mongolia	Eerguna City	0.334	0.500	0.000
Inner Mongolia	Urad Front Banner	0.120	0.143	−0.008
Inner Mongolia	Urad Middle Banner	0.098	0.103	0.000
Inner Mongolia	Otog Front Banner	0.142	0.154	−0.008
Inner Mongolia	Hangjin Banner	0.107	0.125	0.000
Inner Mongolia	Uxin Banner	0.124	0.155	0.000
Ningxia	Pengyang County	0.195	0.229	−0.033
Ningxia	Xiji County	0.191	0.190	0.004
Ningxia	Yuanzhou District	0.212	0.200	0.011
Ningxia	Jingyuan County	0.383	0.275	−0.008
Ningxia	Yanchi County	0.136	0.148	−0.026
Ningxia	Haiyuan County	0.162	0.154	0.013
Ningxia	Shapotou District	0.142	0.104	0.006
Sichuan	Huili City	0.373	0.302	−0.031
Sichuan	Tibetan Autonomous County of Muli	0.353	0.321	0.017
Sichuan	Yanyuan County	0.347	0.333	−0.010
Sichuan	Jiuzhaigou County	0.420	0.237	−0.004
Sichuan	Kangding City	0.207	0.171	−0.048
Sichuan	Zhaojue County	0.327	0.302	−0.017
Sichuan	Heishui County	0.233	0.174	−0.031
Sichuan	Li County	0.173	0.087	−0.075
Sichuan	Songpan County	0.342	0.218	0.017
Sichuan	Xiaojin County	0.199	0.161	−0.051
Yunnan	Deqin County	0.240	0.232	0.114
Yunnan	Weixi Lisu Autonomous County	0.409	0.319	0.035
Yunnan	Shangri-la City	0.330	0.311	−0.029

Our finding that the average annual NDVI of grassland in most of the counties where the GECP has been implemented had increased since the implementation of the policy (Figure 2) is consistent with the findings in the literature [25,30,53]. The average annual

NDVI of grassland had decreased on the eastern border of the Tibetan Plateau, in western Inner Mongolia, and in northern Xinjiang, where human activities tend to be relatively intensive [26,54]. These results suggest that the effectiveness of the GECP tends to be higher in the regions where there is less human influence. Due to this counterfactual issue, however, we cannot observe the changes in the NDVI of grassland after the implementation of the GECP under the condition that the policy had not been implemented. As a result, the effect of the policy cannot be estimated accurately [55].

The relatively small average effect of the GECP on the NDVI of grassland across the selected counties on the boundary of the policy implementation is also consistent with studies in the literature [56]. Given the dual goals of the GECP in the restoration of the degraded grassland and poverty alleviation, as well as the size of the investment through this policy, our results suggest that the policy is probably more effective in poverty alleviation than in the restoration of the degraded grassland [28,31]. However, our analyses focused on the counties along the boundary of the implementation of the GECP (Figure 1) in order to identify the grassland that had similar characteristics between the area where the policy has been implemented and the area where the policy has not been implemented. As a result, much of the grassland that was selected in this study falls into the area where the average annual NDVI grassland decreased between 2002 and 2010. Therefore, there is a possibility that our estimation of the effect of the GECP on the NDVI of grassland for the selected counties can underestimate the overall effect of the policy at the national level.

Substantial spatial heterogeneities in the effect of the GECP on the NDVI of grassland reflected the differences in human influence on the grassland. Among the provinces where the GECP has been implemented in our analyses (Figure 1), Inner Mongolia and Sichuan provinces produced more beef and mutton than other provinces in 2002 (Figure 4). Between 2002 and 2009, the beef and mutton production in Inner Mongolia had more than doubled. Although the beef and mutton production in Sichuan province remained roughly the same between 2002 and 2009, they were much greater than those in other provinces such as Gansu (Figure 4). This at least partly explained the fact that most of the counties in Inner Mongolia and Sichuan provinces exhibited a negative effect of the GECP on the grassland NDVI, while most of the counties in Gansu province exhibited a positive effect of the GECP on the grassland NDVI. We did not detect a correlation between the effect of the GECP on other factors such as population density and agricultural production. The heterogeneities in the impacts of the GECP provide important policy implications and can be leveraged to target regions for improving the efficacy of the program.

Since 2011, the Chinese government has continued to implement the GECP. During the second phase of the GECP, the standard of the compensation has increased [26]. The fodder and grain subsidies have also been replaced with subsidies and rewards for grassland conservation. Further, the implementation of the GECP has been expanded to include a total of 13 provinces [57]. Because the area where the GECP has been implemented in the second phase is not consistent with that in the first phase, it is difficult to identify a set of treatment groups that have received the same length of policy implementation with a comparable control group. Therefore, we focused on the first phase of the program in this study in order to simplify the study by dealing with only one phase of the program and to make the identification of the treatment and control groups straightforward. The spatial heterogeneities in the impacts of the second phase of the GECP involve complex relations with the impacts of the first phase, which deserve further studies. Future studies may also try to explain the driving forces of the heterogeneities in the effects of the GECP when sound data become available.

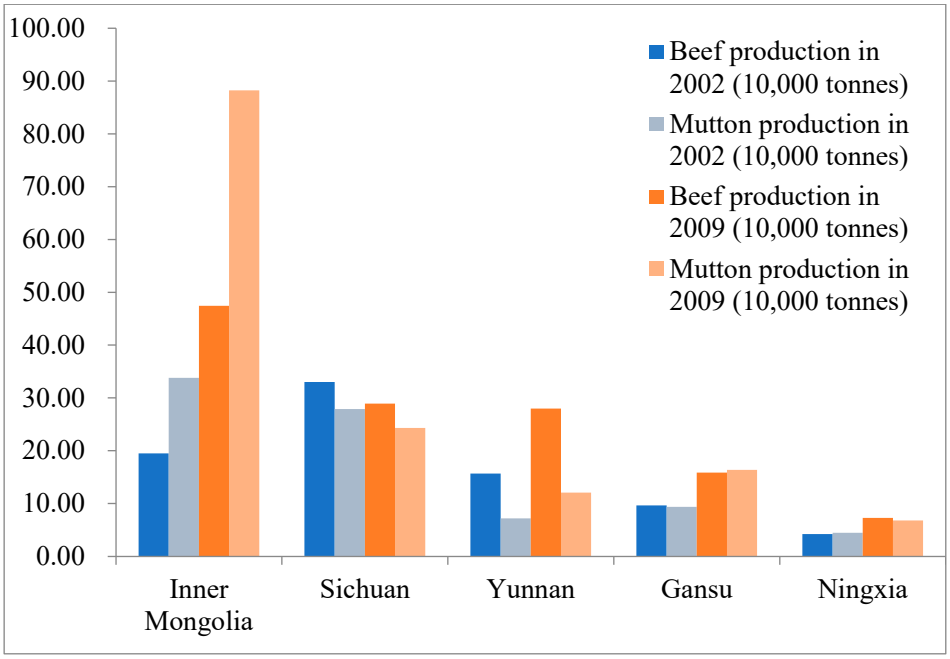


Figure 4. Beef and mutton production in 2002 and 2009 among different provinces.

5. Conclusions

This study explored the heterogeneities in the impacts of China's Grassland Ecological Compensation Program (GECP) on the Normalized Differential Vegetation Index (NDVI) in the grassland. We found an overall positive correlation between the implementation of the GECP and the change in the NDVI of grassland. Although the GECP had increased the NDVI of grassland, the magnitude of the estimated effect is relatively small, suggesting that the policy is probably more effective in poverty alleviation than in the restoration of the degraded grassland. We identified substantial heterogeneities in the effect of the GECP on the NDVI of grassland. Among the 54 counites that were included in this study where the GECP has been implemented, a positive effect of the GECP was detected in 19 counties and a negative effect of the GECP was detected in 27 counties. Most of the counties that exhibited a positive effect of the GECP are located in Gansu, Inner Mongolia, and Ningxia provinces, while the counties that exhibited a negative effect of the GECP are mostly located in Inner Mongolia, Sichuan, and Ningxia provinces. In addition, relatively high levels of beef and mutton production at least partially explained the negative effect of the GECP in most of the counties in Inner Mongolia and Sichuan provinces. The identified heterogeneities in the impacts of the GECP in this study can be used to target regions for improving the efficacy of the GECP.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13020132/s1, Table S1: Characteristics of counties in the study where the Grassland Ecological Compensation Program has been implemented [58].

Author Contributions: Conceptualization, X.C.; Methodology, S.S., J.N., H.Y. and X.C.; Software, S.S., J.N., Y.W. and H.Y.; Formal Analysis, S.S. and J.N.; Investigation, S.S., J.N., Y.W., H.Y. and X.C.; Writing, S.S., J.N. and X.C. All authors have read and agreed to the published version of the manuscript.

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

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