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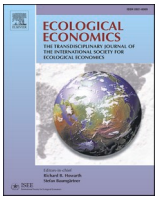

Analysis

Informal institutions and grassland protection: Empirical evidence from pastoral regions in China

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ABSTRACT

Grassland has experienced continuous degradation, resulting in serious ecosystem services loss and unsustainable grazing production. Previous studies have identified the impact of formal environmental institutions or policies on grassland protection. But, little evidence of the effectiveness of informal institutions has been found. Using village grassroots governance as a proxy for informal institutions, this study empirically identifies the effects of informal institutions on grassland quality improvement. Results show that the presence of informal governance leads to improvement in grassland quality. Moreover, these positive effects are found to be more significant when informal governance is in a written form and penalties occur as a consequence of violations. Further investigations reveal that the effectiveness of informal governance is mediated by village size, villager income, household-level compensation from government conservation programs, and grassland property right privatisation. The findings offer new insights into the positive role played by informal institutions in natural resource management and would assist existing policy instruments in grassland protection.

1. Introduction

Continuous degradation of natural resources even with enhanced formal institutions, such as privatised and stabilized property rights (Clark et al., 2010; Gibson et al., 2002; Poteete et al., 2010), motivates us to explore other policy instruments that may encourage conservation of natural resources. Ostrom (2000) emphasizes that collective action at community level is effective to protect nature resources. Informal institutions are expected to play an important regulatory role in collective action. For example, case studies show a strong relationship between informal institutions and resources management, such as forest resource management (Osei-Tutu, 2017; Pacheco et al., 2008), water resource allocation (Sokile et al., 2005) and communal land distribution (Cousins, 1997). However, most case studies failed to establish a robust causal link between informal institutions and resource management or environment conservation by utilizing longitudinal datasets or proper research design and analytical techniques. Therefore more empirical evidence is in need on what is the impact of informal institutions on nature resources protection, especially in developing counties with second-best institutional environments (Macchiavello and Morjaria, 2021).

Quantifying this causal relationship empirically faces two challenges. On one hand, it is not straightforward to measure informal institutions due to its broad concept. As referred to by North (1990), informal institutions are a set of conventions, norms of behavior and self-imposed codes of conduct. Based on this definition, measuring these norms or conventions needs to consider spatial and temporal differences, which is rarely possible with purely cross-sectional or time-series data. On the other hand, without exogenously spatial and temporal variations in informal institutions, it is extremely challenging to identify the causal relationship. Unobserved factors may affect both the formation of informal institutions and environmental outcomes, and reverse causality from environmental outcomes to informal institutions may exist. A quasi-natural experiment in which informal institutions were measured by the presence of village grassroots governance that targets grassland protection in pastoral area helps us address these challenges.

First, village grassroots governance allows us to identify a specific form of informal institutions, which can be regarded as rules and norms, and the extent to which people are punished or sanctioned when they deviate from these rules and norms (Gelfand et al., 2006). It works through villagers' mutual trust and supervision rather than laws and formal regulations. Voigt (2016) delineates informal institutions by

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members of society being responsible for sanctioning when a rule has been reneged upon. So, village grassroots governance can be seen as a measure of informal institutions.

Second, variations in the emergence of grassroots governance among villages allows the use of a two-way fixed effects (within-group) model to examine the impact of informal institutions on grassland quality. In addition, there are other types of village grassroots governance (i.e. hygiene and health), unrelated with grassland protection, serve as instrument variables for grassland grassroots governance (IVs). We further use an instrument variable (IV) approach to test for endogeneity due to a two-way causation between village grassroots governance and grassland quality.

Our main results indicate that village grassroots governance have a positive effect on grassland quality. The improvement of grassland quality can be attributed to livestock reduction at household level, which is the direct target of grassroots governance in most villages. Furthermore, the heterogeneous analysis shows that grassroots governance performs better in villages that are smaller in terms of household numbers and wealthier in terms of per capita income. More interestingly, we found that grassroots mechanisms have a better performance when they interact with formal institutions, i.e. ecosystem compensation and clearly defined grassland use rights, which provides a policy implication that enhancing grassroots governance, seen as informal institutions, is complementary to formal institutions in natural resource management and protection.

This study makes a number of contributions to the literature. First, our identification strategy for the causal relationship between grassroots governance and grassland protection is among the most rigorous, and therefore the findings are robust and reliable. Second, informal institutions are usually outside of government regulations and not part of a written legal framework (Williamson and Kerekes, 2011). In our survey, different types of grassroots governance, such as oral or written, and with or without penalty, make it possible for us to explore the effectiveness of village grassroots governance in different forms. Additionally, we explore how the effect of grassroots governance is mediated by contextual factors and formal natural resource management policies, which may help policymakers take into consideration local conditions and apply different measures for different villages. Third, this is a timely study on informal institutions and grassland protection in China where grassland has been facing degradation for a long time, and our findings offer valuable insights in management of natural resources including grassland, water and native forests in China and other countries with similar background.

2. Background

The grassland ecosystem in China is fragile and frequently suffering from severe degradation. As the largest territory in China, it accounts for over 40% of the nation's total land area. Nearly 18 million herdsmen in pastoral or semi-pastoral areas live on grassland with grazing livestock as their major income source (CAHY, 2018). By the mid-2000s, various degrees of degradation had occurred to over 90% of grassland in China (Chen et al., 2016; Waldron et al., 2010), which reduced its provision of ecosystem services. Worse yet, the resulting sandstorms and desertification manifest themselves as major threats to the sustainability of Northern China's environment and ecosystem (Zhang et al., 2013). Economic loss, including direct economic loss (biomass declining) and indirect economic loss (carbon emission, nitrogen loss and plant diversity decrease), due to grassland degradation is also substantial, estimated to be over $20,000/ha per year in the severely degraded Qinghai-Tibetan Plateau (Wen et al., 2013).

Overgrazing has been identified as one of the major human influences that exacerbates grassland degradation (Yan et al., 2013), and in response, the Chinese governments at various levels have promoted a series of formal policies and schemes, such as the Grassland Household Contract System (GHCS) and the Grassland Ecological Compensation Policy (GECP). Following the success of Household Contract System in cropping areas of China and taking note of the economic theory of "tragedy of the commons", the Chinese government started the GHCS in the middle of 1980s, whereby livestock and grassland use rights were privatised to the individual herder household level.[1] The reallocation of livestock and grassland use rights were conducted at village level, which means that if reallocation happened in a village, all households can be allocated livestock and grassland in this village. And reallocation was mostly based on the number of household members. The larger size of households, the more livestock and grassland areas they may be reallocated from a village. The privatisation of livestock was completed quickly in the end of 1980s, while the process for grassland privatisation continued for decades. Until the end of 2018, 27% of grassland use rights still had not been privatised (Liu, 2019).

The GECP, started in 2011, is the largest payment program for grassland ecosystem services that aims to reduce grazing livestock stock numbers and protect grassland in China. The program has funded more than 100 billion yuan for herders' participation, such as keeping forage-livestock balance, at the end of 2020. Although some studies suggest that the GHCS (Liu et al., 2019) and the GECP (Liu et al., 2018) have had positive effects on grassland protection, their overall effectiveness on improving the quality of grassland still remain debatable (Gao et al., 2016; Hu et al., 2019; Li and Huntsinger, 2011; Tan et al., 2018). The GHCS was criticized as it divided grassland into small pieces, which is not efficient in terms of livestock production as it is impossible for individual herders to achieve economies of scale (Li and Gongbuzeren, 2014; Zhaoli et al., 2005). Regarding the GECP, it is also a concern that its huge budget may only have resulted in improved grassland quality by a small magnitude—around 5% (Hou et al., 2020).

In addition to the formal institutions of protecting grassland (i.e. GHCS and GECP), a series of informal institutions are formed spontaneously within local communities. A typical form of informal institutions is village grassroots governance, known as "*cun gui min yue*" in its local language. The village grassroots governance is proposed by village political leaders or prestigious villagers (i.e. senior villagers, spiritual leaders, etc.). It covers a series of grassland protection and management rules: i) setting the maximal grazing capacity and preventing overgrazing; ii) no deforestation without permission from villagers' committee; iii) protecting ecosystem services of grassland, such as conserving wildlife and native vegetation; iv) rewards and punishments (DCA, 2015).

There are two reasons we regard these rules as grassroots level informal governance mechanism. Firstly, these grassland protection and management rules have written or oral forms. For the written form, the grassroots governance is written in words that the villagers can understand and posted on the notice board of the village committee. For the oral form, the villagers learn the grassroots governance's rules through word of mouth. Secondly, villagers may be penalized if they deviate from village grassroots governance. While these penalties are not legally enforceable they may cause reputational damage among the villagers.

Village grassroots governance plays an important role in managing resources in China's rural areas. To the best of our knowledge, existing research mainly focuses on the effect of informal institutions on rural economic and social development (Hu, 2007), and no previous research has empirically documented the effects of village grassroots governance on grassland protection in China. Given the ambiguous effect of formal institutions on grassland protection in China, it is critical to evaluate how informal institutions such as grassroots governance can contribute to grassland protection and under what forms and contexts it may be more effective.

[1] Before the GHCS, both livestock and grassland were managed by communes that employed villagers and paid them wages.

3. Data and descriptive analysis

3.1. Data

We employed a household-level panel dataset collected from a field survey, in the pastoral area of Qinghai and Gansu provinces of China in 2017. Qinghai and Gansu are the two major pastoral provinces in China. A stratified random sampling strategy was used to select households. Four counties in Gansu and six counties in Qinghai were selected according to annual income per capita. Three townships were selected from each county according to per capital grassland area. Similarly, two villages were sampled from one township. In total, six households were randomly selected from each village. Finally, we surveyed 358 households in 60 villages, 30 townships, and 10 counties. For more detailed sampling information, please refer to Xia et al. (2020).

To acquire information on village grassroots governance and grassland utilization, we conducted face-to-face interviews with village leaders and household heads. We used the presence of village grassroots governance targets on grassland protection and utilization in a village as a proxy to measure informal institutions. Specifically, a village leader was asked about whether grassroots governance regarding grassland management was present in his/her village. If the answer was yes, we further asked in which year grassroots governance started in the village and if it ever stopped, the year in which it did. We also asked the forms of communication of grassroots governance (i.e. oral or written) and whether there were any penalties as a result of violations. Besides asking about grassroots governance on grassland management, we collected similar information regarding other types of grassroots governance, such as hygiene and health, community safety, and law-abiding citizens.

We used household farm level Normalized Difference Vegetation Index (NDVI) as an indicator for grassland quality. The original NDVI data were from MOD13A3 product from NASA Earth data for the period of 2007–2017, combined with GPS coordinate of farms to create farm-level NDVI. More detailed information about the data set can be found in Didan (2015). We used household level grazing intensity as an indicator for grassland utilization. In the survey, we recorded the number of each type of livestock on a grazing farm for each of the years from 2008 to 2010 and from 2015 to 2017,[2] and grassland area for each of the years from 2007 to 2017. Grazing intensity was calculated by dividing the sum of all animals in sheep equivalent units by total grazing grassland area.

In addition, a range of characteristics at the household-level and village-level were also collected. The household-level control variables include: household size—the number of people in a household; proportion of pastoral labor—the percent of people engaged in grazing in a household; participation in the non-pastoral job market—a dummy variable with 1 indicating that a household has someone engaged in other jobs (e.g. construction and services) besides grazing; operated grassland size per capita—the total operated grassland area divided by the number of households; participation in the land market—a dummy variable with 1 indicating a household has participated in the rental market of grassland; and the GECP subsidy intensity—the total GECP subsidy per household divided by their total operated grassland area.

The village-level control variables include economic and climate characteristics. Village size is indicated by the number of households in a village. Farm-gate livestock price is a village-level farm-gate price for livestock, calculated as total revenue from different livestock divided by total number of sheep equivalent livestock. Villager income is average income per capita per year in a village. The presence of paved road in a village is used to indicate market access. Whether the village implemented the GHCS indicated the grassland property allocated. The climate characteristics include mean daily temperature from May to September and cumulative rainfall from May to September.[3] The daily weather data are originally obtained from the National Meteorological Information Centre of China. For counties without a national station, a spatial interpolation method proposed by Thornton et al. (1997) was used to extrapolate the daily temperature and precipitation (Zhang et al., 2013).

3.2. Descriptive analysis

Village grassroots governance had increased its presence from 2007 to 2017 (Fig. 1). The percentage of villages with grassroots governance in our sample increased from 15% in 2007 to 67% in 2017. However, there were still 20 (33%) villages without grassroots governance by the end of 2017.

In addition, village grassroots governance has different types (Table 1). Most of them are in written forms (over 90%), while less than 10% are in oral forms. Nearly half of villages reported that their grassroots governance applies penalties if a household violates the rules, such as a fine.

With the increasing presence of village grassroots governance, Fig. 2a shows that grassland quality measured by NDVI varies between 2007 and 2017. NDVI was 0.646 in 2017, 2% higher than 2007. At the same time, Fig. 2b shows gazing intensity decreased nearly 15% from 2008 (4.10) to 2017 (3.47).

4. Empirical models

To identify the effects of village grassroots governance on grassland quality and management, we specify a fixed effects model as follows:

$$Q_{ijt} = \alpha_0 + \alpha_1 G_{jt} + \boldsymbol{\gamma} \boldsymbol{X}_{ijt} + \boldsymbol{\varphi} \boldsymbol{Z}_{jt} + u_{ij} + \tau_t + \varepsilon_{ijt} \quad (1)$$

where Q_{ijt} is the NDVI in household i, village j, year t to indicate grassland quality or grazing intensity in log form to indicate grassland management. G_{jt} is a dummy variable, indicating whether village j has grassroots governance on grassland, which takes three forms: first, a general form of grassroots governance on grassland (specifically, on grazing intensity and production); second, a written form of grassroots governance on grassland; and third a penalty form. The purpose of testing grassroots governance in different forms is to investigate whether certain conditions would make grassroots governance more effective in grassland protection and management in the study context. $\boldsymbol{X}_{ijt}$ is vector of household-level control variables, including household size, proportion of pastoral labor, participation in the non-pastoral job market, operated grassland size per capita in log form, participation in the rental land market and GECP subsides intensity. $\boldsymbol{Z}_{jt}$ is a vector of village-level control variables, including village size, farm-gate livestock price in log form, villager income level in log form, market access, whether the village implemented the GHCS, mean temperature from May to September and cumulative rainfall from May to September. The descriptive statistics of variables are shown in Table A1 (Panel a and b). u_{ij} captures household fixed effects that do not vary with year. τ_t captures year fixed effect that are similar to all households. ε_{ijt} is a random error term. The coefficient α_1 is of our primary interest.

Fixed effects eliminate time-invariant unobserved variables that cause grassroots governance to be endogenous. However, there is still the possibility that time-variant unobserved variables causing the endogeneity problem. Therefore, an instrument variable (IV) estimation approach was firstly employed in order to test whether grassroots governance is endogenous to grassland quality or grazing intensity. If the endogeneity test suggested grassroots governance is exogenous, an OLS panel fixed effects model was estimated. Otherwise, a panel effects model using IVs was needed. This approach ensured a real causal effect

[2] Livestock number usually do not change dramatically. Therefore, we chose two periods for the panel livestock number. The first period 2008–2010, which was before the GECP, can eliminate the effects of the policy.

[3] In the study area, the growing season of grass is from May to September.

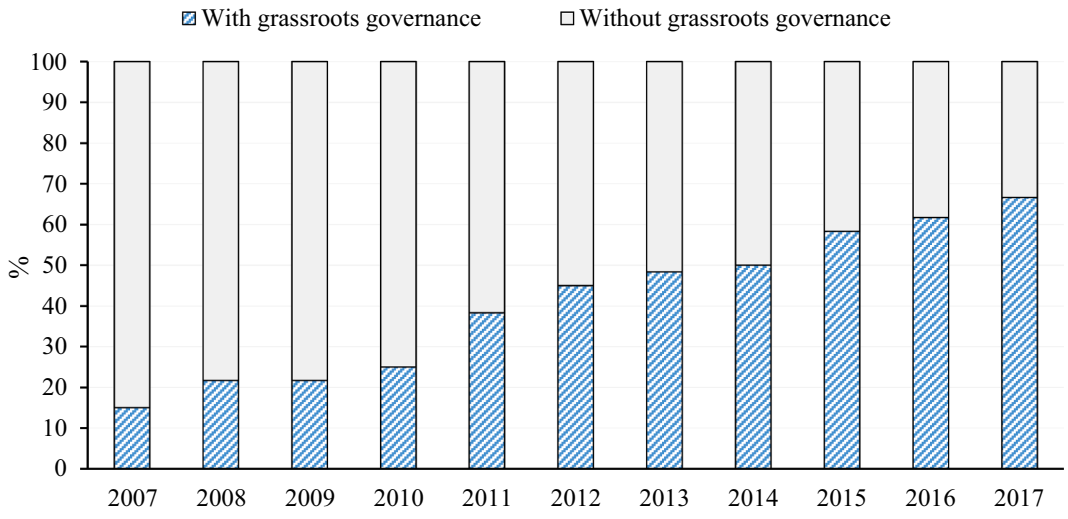

Fig. 1. Emergence of village grassroots governance ($n = 60$).

Table 1
Number of villages with grassroots governance in 2017 by different types.

Grassroots governance types	Village number	Percent in villages with grassroots
All with grassroots governance on grazing intensity or production	40	100
Types of communication		
Oral	3	7.5
Written	37	92.5
Having penalties		
Yes	18	45
No	22	55

of grassroots governance can be obtained. Appropriate IVs are critical to the performance of IV models. We used other type of village grassroots governance including hygiene and health, community safety, and law-abiding citizens (Table A1, panel c), which are correlated with grassroots governance on grassland, as IVs. They are intuitively exogenous to grassland quality or grazing intensity because grassroots governance in these areas does not have a direct effect on grassland management or protection, and therefore, are considered as appropriate IVs for grassroots governance (Bertrand et al., 2004). Weak-identification tests and over-identification tests were performed to ensure the instruments were not weak and valid. If weak-identification tests failed, the limited-information maximum likelihood estimator (LIML) was used, which is more robust to weak instruments (Stock et al., 2002).

To explore the heterogeneous effects of grassroots governance on grassland quality, we added an interaction term of village grassroots governance and an indicator for heterogeneity in eq. (1). The model is as follows:

$$Q_{ijt} = \alpha_0 + \alpha_1 G_{jt} + \alpha_2 G_{jt} \cdot H_{(i)jt} + \boldsymbol{\gamma} \boldsymbol{X}_{ijt} + \boldsymbol{\varphi} \boldsymbol{Z}_{jt} + u_{ij} + \tau_t + \varepsilon_{ijt} \quad (2)$$

where $H_{(i)jt}$ are several village or household characteristics selected from control variables, such as village size indicates large or small villages, and villager income level that indicates rich or poor villages. In addition, we include the GECP subsides at household level and whether the village implemented the GHCS, which represent two important formal institutions in Chinese pastoral area.

5. Results

Table 2 reports the basic results for Eq.1, with estimates of the full set of independent variables presented in Table A2 in the appendix. Endogeneity tests suggested that grassroots governance (and its various forms) was not endogenous to NDVI or grazing intensity, except for one model in which grassroots governance with penalty is endogenous to NDVI. Therefore, models (1), (2), (4), (5) and (6) were estimated by OLS panel fixed effects while model (3) was estimated by panel fixed effects LIML estimator.

Results suggest that village grassroots governance improves grassland quality, especially for grassroots governance that has a written form or penalties because of violations. Compared to the counterparts, the establishment of grassroots governance improves grassland NDVI index by 1.0% (Col.1, Table 2), although it is not significant at the 10% level. When grassroots governance takes a written form, grassland quality increases by 1.5% and the coefficient is statistically significant (10% level). The penalty form of grassroots governance is much more effective as the coefficient indicates an increase in grassland quality by 13.3% (5% level). The written form may provide clearer information about grassroots governance for villagers, and the penalty form may be more restrictive. The above empirical results confirmed that clear and binding grassroots governance can bring more significant environment improvement. Table A3 adds a first lag of NDVI, and the results are still robust except for a slight decrease in the main coefficient.

One possible channel through which grassroots governance improves grassland quality is reducing gazing intensity. Results show that villages grassroots governance reduces grazing intensity by about 10–11% (Cols. 4–6, Table 2). Less grazing intensity means less production pressure and faster ecological restoration on grassland. Higher NDVI is also found to be statistically significantly associated with smaller household size, higher GECP subsidy, lower farm-gate livestock price, absence of market access, higher growing season mean temperature and higher growing season cumulative rainfall. Other possible channels, such as nudging herders investing in grassland protection, may exist. But we cannot

Fig. 2. Change of grassland quality and grazing intensity in household level.

empirically identify those channels due to unavailability of the variables.

Besides distinguishing the forms of grassroots governance, we further examine its heterogeneous effects, i.e. under what external conditions grassroots governance could be more effective in improving grassland quality. We use the written form of grassroots governance to create the interaction terms as this form was estimated as statistically significant (10% level) for NDVI.

Full regression results are presented in Table A4 in the appendix while the effects of grassroots governance conditional on village or household characteristics are displayed in Fig. 3. First, grassroots governance has a larger impact on NDVI in villages with fewer households. One possible reason is that herders can monitor and supervise each other easily in small villages. Another possible explanation is that grassroots governance is formed by a larger share of village households in smaller villages, making it more likely to be adhered to. Specifically, when village size is less than 270 households, grassroots governance has a significantly positive impacts in grassland quality. In our sample, 70% of villages have less than 270 households. When village size is greater than 270 households, grassroots governance has no significant impacts on grassland quality.

Second, grassroots governance is more effective in villages with higher per capita income. More specifically, when village per capita income is less than 3600 yuan/year (approximately 550 USD), grassroots governance has no significant impact. However, after village per capita income is larger than 3600 yuan/year, the positive impact becomes statistically significant and larger as income increases. For example, when village per capita income is equal to 8500 yuan/year (75% quantile) and 20,000 yuan/year (95% quantile), the marginal effect of grassroots governance on NDVI is 2.6% and 3.8%, respectively. Grazing livestock is the major income source, especially for the lower income areas. When herder income is too low to support their living expenses, they have no choice but to graze grassland more intensively, which makes grassroots governance on grassland less effective.

Third, the effect of grassroots governance on grassland quality depends on formal governance as well. In our case, we found both ecosystem compensation and privatised grassland property rights enhance the effectiveness of grassroots governance. When the ecosystem compensation received by a household is less than 6000 yuan/year, grassroots governance has insignificant impact on grassland quality. As the ecosystem compensation increases from 6000 yuan/year, the positive impact of grassroots governance becomes larger and larger. For example, when ecosystem compensation is 10,000 yuan/year (75% quantile) and 69,000 yuan/year (95% quantile), the marginal effect of grassroots governance on grassland quality is estimated as 1.5% and 6.3%, respectively. We also found that when the village has no clearly defined grassland use rights, grassroots governance has little impact on grassland quality, while it has a positive and statistically significant effect when grassland use rights are clearly defined. In our survey area, 95% village have clearly defined grassland use rights. The positive impact of grassroots governance may be offset by the common tragedy issue in publicly used grassland, which leads to insignificant impact in villages without clearly defined grassland use rights.

To summarize, these heterogeneity effects of grassroots governance on grassland protection may offer valuable insights in the protection and utilization of other common pool resources. For example, a small group may cost less effort to reach agreements and supervise each other under informal institutions. An appropriate income level, sufficient compensation for ecological protection and a clearly defined resource allocation regime also act as mediators for grassroots governance to influence grassland quality outcomes. These findings offer insights in the optimal design and implementation of grassroots governance, which should take considerations of the local context and existing formal governance, some of which may be preconditions for successful grassroots governance and some may be criteria to be considered in choosing the most appropriate form of grassroots governance.

Table 2
The effects of village grassroots governance on NDVI and grazing intensity.

Variables	Y = log(NDVI)			Y = log(Grazing intensity)		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel a. Regression results						
Regression method	OLS	OLS	IV-LIML	OLS	OLS	OLS
G-governance for grazing intensity and production	0.010			−0.114***		
	(0.008)			(0.043)		
G-governance (**written** versus others)		0.015*			−0.096**	
		(0.008)			(0.046)	
G-governance (**with penalty** versus others)			0.133**			−0.108*
			(0.068)			(0.063)
Panel fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Number of households	358	358	358	354	354	354
Number of years	11	11	11	6	6	6
Observations	3938	3938	3938	1935	1935	1935
Within R-squared	0.121	0.122	–	0.162	0.159	0.158
Panel b. Endogeneity and model test with IV						
Weak identification test (K-P Wald F statistic)[a]	56.91	46.97	9.48	40.82	37.81	28.22
Over-identification test (Hansen J statistic)[b]	3.43	3.60	1.32	4.42	4.43	0.96
Endogeneity test (Chi-squared statistic)[c]	0.97	0.42	3.66*	0.73	0.32	1.54

Clustered robust standard errors adjusted for household clusters were estimated. For all the weak identification, over-identification and endogeneity tests, the excluded instruments are other forms of governance in villages, namely three dummies representing whether a village had governance in the area of hygiene and health, community safety, and law-abiding, respectively.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

[a] Weak identification refers to the excluded instruments being correlated with the endogenous regressors, but only weakly. A test statistic that above the 10% critical value (6.46) suggests that the maximal IV bias size is 10%.

[b] The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation.

[c] The null hypothesis is that the specified endogenous regressors can actually be treated as exogenous. Failing to reject the null hypothesis in models (1), (2), (4), (5), and (6) suggested that the village grassroots governance in the models was exogenous to the dependent variable—NDVI and grazing intensity, respectively.

6. Conclusion and discussion

Although a large amount of financial budget and efforts have been invested in formal governance policies for grassland management in China, the positive effect of formal institutions on grassland quality is still ambiguous in the literature and much of grassland still experienced severe degradation. This motivates us to assess the effectiveness of informal institutions such as grassroots governance in grassland protection. Village grassroots governance, known as "*cun gui min yue*" in local language, in pastoral areas of China provides a natural experiment for us to evaluate its impacts.

Using 11-year household level panel data from a field survey in pastoral area of Qinghai and Gansu provinces of China, this paper examines the effectiveness of village grassroots governance on grassland quality and utilization. Our empirical results provide robust evidence that village grassroots governance is effective in improving grassland quality. One important channel of village grassroots governance is that it changes herder grazing behavior, i.e. reducing grazing intensity. In particular, the written form of village grassroots governance and those with penalties are effective, which suggests that when implementing grassroots governance, villages should consider having it written down and not only relying on oral communications. The design of village grassroots governance should also include a penalty mechanism that would effectively encourage compliance.

Heterogeneity analysis shows grassroots governance in smaller and richer villages are more effective. This suggests that large villages with more households and the villages with lower per capita income should pay particular attention to the effectiveness of grassroots governance. It is likely that such communities need more effective types of village grassroots governance, or formal institutions such as economic incentives may be more effective. In addition, we find that village grassroots governance's effect is conditional on formal institutions, such as clearly defined property using right and the level of government incentives to conserve grassland. This suggests that while the effect of formal institutions on grassland quality may be mixed in the literature, it is nevertheless an important element that strengthens the effectiveness of village grassroots governance. Therefore, formal and informal institutions should be complementary rather than substitutable.

Findings of this study offer important policy implications on the ecological protection and sustainability development of China's pastoral region. As mentioned previously, overgrazing is one of the main causes of continual grassland degradation. Formal institutions has its own limitations such as huge costs in implementation and monitoring. Informal institutions, bounded by village grassroots governance that focuses on livestock stock controlling and gazing efficiency may provide an attractive alternative to grassland ecological restoration because it is flexible, adaptable and has low transaction costs. In particular, the advancement of information and communication technology could further promote the effectiveness of village grassroots governance in the vast and population sparse pastoral areas, such as the use of social media, remote sensing and artificial intelligence. In addition, village grassroots governance regarding grassland protection may serve as an example for the protection and utilization of other common pool resources that as well face over-exploitation in China, such as water and

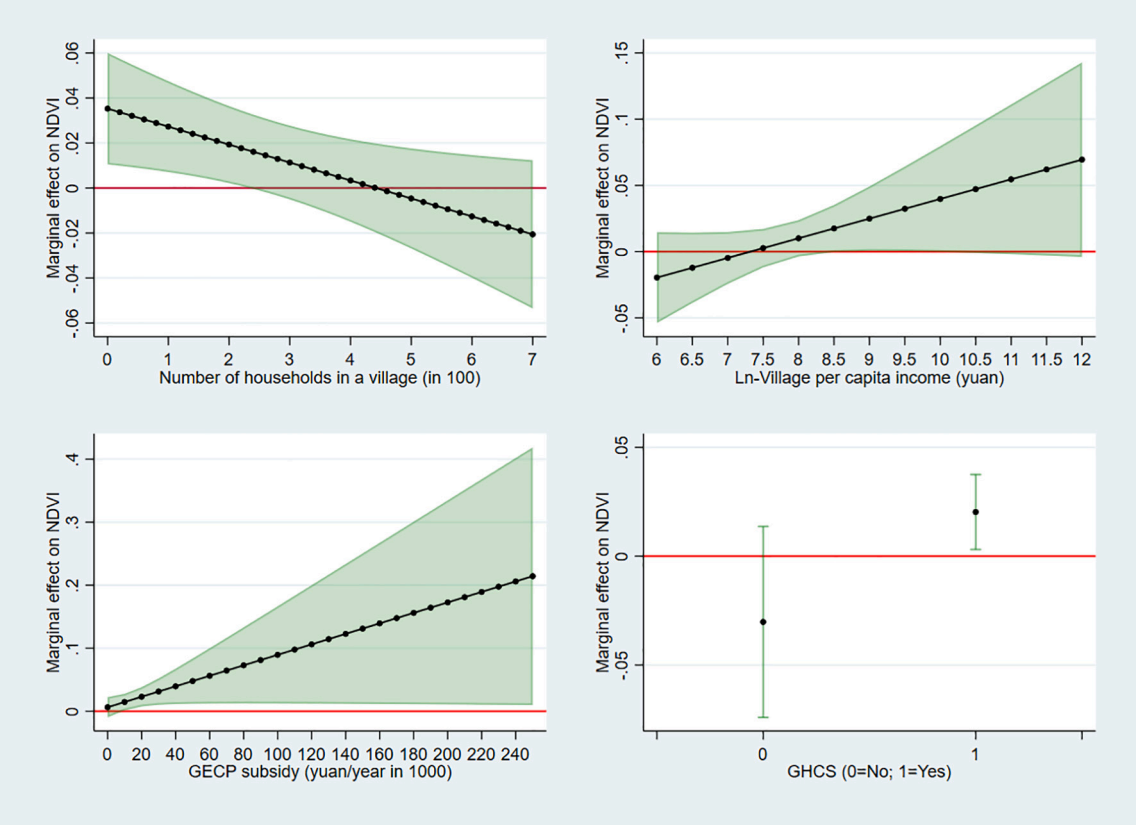

Fig. 3. Conditional marginal effects and associated 95% confidence intervals of grassroots governance (written form) on NDVI.

native forests.

It is encouraging to conclude that village grassroots governance contributes positively to grassland ecological restoration in the pastoral areas in China. There are still many aspects of village grassroots governance left unanswered. For example, who are eligible for drafting and amending village grassroots governance, and why herders abide by the rules of village grassroots governance? These questions may be examined within the framework of grassroots management system and joint decision-making in pastoral areas. Finally, an important future research agenda could focus on herders' preferences for formal and informal institutions, and how the two can be designed optimally to maximize their synergic effect on grassland quality improvement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Descriptive statistics of control variables.[a]

	Obs.	Mean	Sd.	Min	Max
Panel a. Household level control variables					
Household size (the number of people in a household)	3938	4.89	1.91	1	15
Proportion of pastoral labor (%)	3938	39.7	25.3	0	100
Participating in the non-pastoral job market (1 = yes; 0 = no)	3938	0.335	0.472	0	1
Operated grassland size per capita (ha)	3938	135	418	0	3198
Participating in the land market (1 = yes; 0 = no)	3938	0.165	0.372	0	1
GECP subsidy intensity (yuan/ha/year)	3938	71.8	150.7	0	2514
Panel b. Village level control variables					
Village size (the number of households in a village)	660	221	138	35	709
Farm-gate livestock price [b] (yuan/kg)	660	72.6	15.4	34	115
Villager income level (1000yuan)	660	6.19	7.39	1	60
Market access (1 = yes; 0 = no)	660	0.439	0.496	0	1
Whether the village have conducted GHCS (1 = yes; 0 = no)	660	0.948	0.222	0	1
Mean temperature from May to September (°C)	660	9.09	2.97	3.32	16.52
Cumulative rainfall from May to September (mm)	660	317	164	2.3	607

(*continued on next page*)

Table A1 (*continued*)

	Obs.	Mean	Sd.	Min	Max
Panel c. Other type of grassroots governance					
Hygiene and health grassroots governance (1 = yes; 0 = no)	660	0.503	0.500	0	1
Community safety grassroots governance (1 = yes; 0 = no)	660	0.544	0.498	0	1
Law-abiding citizens grassroots governance (1 = yes; 0 = no)	660	0.220	0.414	0	1
Panel d. Key Y and key X					
NDVI in household level	3938	0.631	0.170	0.072	1
Grazing intensity in household level (sheep unit/ha)	1935	3.812	5.903	0.01	57.8
Grassroots governance in village level (1 = yes; 0 = no)	660	0.411	0.492	0	1

[a] All variables have 11 sample years data from 2007 to 2017, except Village size and Grazing intensity. Village size has 4 years data, 2008, 2010, 2015 and 2017, and values for other years were filled using the interpolation method. Grazing intensity has 6 years data, 2008, 2009, 2010, 2015, 2016 and 2017.

[b] The price is weighted by livestock number, the livestock contain cattle, sheep, goat and other big animals.

Table A2
Full regression results for models in Table 2.

Variables	**Y = log(NDVI)**			**Y = log(Grazing intensity)**		
	(1)	(2)	(3)	(4)	(5)	(6)
	(OLS)	(OLS)	(IV-LIML)	(OLS)	(OLS)	(OLS)
G-governance for grazing intensity and production	0.010			−0.114***		
	(0.008)			(0.043)		
G-governance (**written** versus others)		0.015*			−0.096**	
		(0.008)			(0.046)	
G-governance (**with penalty** versus others)			0.133**			−0.108*
			(0.068)			(0.063)
Household size	−0.005**	−0.005**	−0.007***	−0.065***	−0.065***	−0.067***
	(0.002)	(0.002)	(0.002)	(0.019)	(0.019)	(0.019)
Proportion of pastoral labour/100 (%)	−0.012	−0.013	−0.033	0.290**	0.289**	0.302**
	(0.018)	(0.018)	(0.022)	(0.118)	(0.118)	(0.118)
Participating in the non-pastoral job market (1 = yes; 0 = no)	−0.005	−0.005	−0.010	0.030	0.029	0.033
	(0.009)	(0.009)	(0.010)	(0.044)	(0.045)	(0.045)
Ln-Operated grassland size per capita log(ha)	−0.003	−0.003	−0.004	−0.532***	−0.529***	−0.536***
	(0.004)	(0.004)	(0.004)	(0.080)	(0.080)	(0.078)
Participating in the land market (1 = yes; 0 = no)	0.008	0.008	0.007	−0.030	−0.031	−0.028
	(0.010)	(0.010)	(0.011)	(0.055)	(0.056)	(0.055)
GECP subsidy intensity/100 (yuan/ha/year)	0.003***	0.003**	0.002	0.009	0.009	0.008
	(0.001)	(0.001)	(0.002)	(0.007)	(0.007)	(0.007)
Village size (the number of households in a village)	−0.011	−0.010	−0.014*	−0.070**	−0.068**	−0.050*
	(0.008)	(0.008)	(0.008)	(0.029)	(0.029)	(0.029)
Ln-Farm-gate livestock price (yuan/kg)	−0.036*	−0.034*	−0.038*	−0.203*	−0.199	−0.185
	(0.019)	(0.019)	(0.022)	(0.121)	(0.123)	(0.122)
Ln-Villager income level (yuan)	−0.013	−0.014	−0.010	0.056*	0.055*	0.048
	(0.009)	(0.009)	(0.009)	(0.031)	(0.032)	(0.032)
Market access (1 = yes; 0 = no)	−0.015	−0.016*	−0.026**	0.109**	0.112**	0.113**
	(0.009)	(0.009)	(0.013)	(0.049)	(0.049)	(0.050)
Whether the village have conducted GHCS (1 = yes; 0 = no)	−0.035***	−0.034***	−0.014	–	–	–
	(0.012)	(0.012)	(0.016)			
Mean temperature from May to September (°C)	0.026***	0.026***	0.027***	0.047**	0.045**	0.038*
	(0.009)	(0.009)	(0.009)	(0.022)	(0.022)	(0.022)
Cumulative rainfall from May to September/100 (mm)	0.025***	0.025***	0.021***	0.014	0.014	0.014
	(0.005)	(0.005)	(0.005)	(0.013)	(0.013)	(0.013)
Constant	−0.518***	−0.521***		3.457***	3.451***	3.494***
	(0.130)	(0.130)		(0.568)	(0.569)	(0.574)
Two-way fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3938	3938	3938	1935	1935	1935
Within R-squared	0.121	0.122	–	0.162	0.159	0.158

Clustered robust standard errors adjusted for household clusters were estimated.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

Table A3
The effects of village grassroots governance on NDVI.

Variables	**Y = log(NDVI)**		
	(1)	(2)	(3)
Panel a. Regression results			
Regression method	OLS	OLS	IV-LIML
G-governance for grazing intensity and production	0.009		
	(0.007)		
G-governance (**written** versus others)		0.014*	
		(0.007)	
G-governance (**with penalty** versus others)			0.109*
			(0.058)
NDVI first lag	0.170***	0.170***	0.178***
	(0.031)	(0.031)	(0.030)
Panel fixed effects	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Control variables	Yes	Yes	Yes
Number of households	358	358	358
Number of years	11	11	11
Observations	3938	3938	3938
Within R-squared	0.121	0.122	–
Panel b. Endogeneity and model test with IV			
Weak identification test (K-P Wald F statistic)	56.67	46.78	9.50
Over-identification test (Hansen J statistic)	3.45	3.63	1.76
Endogeneity test (Chi-squared statistic)	0.69	0.21	2.64*

Clustered robust standard errors adjusted for household clusters were estimated. In this regression, we add NDVI first lag.
*** $p < 0.01$.

* $p < 0.1$.

Table A4
Heterogeneity effects of village grassroots governance on NDVI.

Variables	(1)	(2)	(3)	(4)
G-governance for grazing intensity and production	0.035***	−0.109	0.006	−0.030
	(0.013)	(0.069)	(0.008)	(0.022)
G-governance*Village size	−0.008**			
	(0.003)			
G-governance*Net income per villager		0.015*		
		(0.009)		
G-governance*GECP subsides			0.001*	
			(0.000)	
G-governance*GHCS dummy				0.050**
				(0.023)
Household size	−0.005**	−0.005**	−0.004*	−0.005**
	(0.002)	(0.002)	(0.002)	(0.002)
Proportion of pastoral labour/100 (%)	−0.012	−0.011	0.004	−0.014
	(0.018)	(0.018)	(0.016)	(0.018)
Participating in the non-pastoral job market (1 = yes; 0 = no)	−0.005	−0.005	−0.007	−0.007
	(0.009)	(0.009)	(0.008)	(0.009)
Ln-Operated grassland size per capita log(ha)	−0.003	−0.003	−0.002	−0.003
	(0.004)	(0.004)	(0.004)	(0.004)
Participating in the land market (1 = yes; 0 = no)	0.008	0.008	0.004	0.007
	(0.010)	(0.010)	(0.008)	(0.010)
GECP subsidy intensity/100 (yuan/ha/year)	0.003**	0.003**	0.003**	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Village size (the number of households in a village)	−0.007	−0.010	−0.003	−0.015*
	(0.008)	(0.008)	(0.006)	(0.009)
Ln-Farm-gate livestock price (yuan/kg)	−0.038**	−0.024	−0.062***	−0.037**
	(0.018)	(0.020)	(0.018)	(0.018)
Ln-Villager income level (yuan)	−0.013	−0.026**	−0.015**	−0.012
	(0.008)	(0.012)	(0.008)	(0.009)
Market access (1 = yes; 0 = no)	−0.016*	−0.014	−0.013	−0.015
	(0.009)	(0.009)	(0.008)	(0.009)
Whether the village have conducted GHCS (1 = yes; 0 = no)	−0.035***	−0.034***	−0.024**	−0.032***
	(0.012)	(0.012)	(0.012)	(0.012)
Mean temperature from May to September (°C)	0.025***	0.026***	0.014*	0.025***
	(0.009)	(0.009)	(0.008)	(0.009)
Cumulative rainfall from May to September/100 (mm)	0.025***	0.023***	0.017***	0.025***
	(0.005)	(0.005)	(0.004)	(0.005)
Constant	Yes	Yes	Yes	Yes

(*continued on next page*)

Table A4 (*continued*)

Variables	(1)	(2)	(3)	(4)
Two-way fixed effects	Yes	Yes	Yes	Yes
Observations	3938	3938	3938	3938
Within R-squared	0.124	0.124	0.200	0.125

Clustered robust standard errors adjusted for household clusters were estimated.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

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