Journal of Agricultural and Resource Economics: Preprint ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.358999

Grassland Property Rights and the Size-Productivity Relationship: Evidence from Pastoral China

Mingxue Zhang and Donqing Li

Using household panel data from five major pastoral provinces in China, we illustrate a robust inverse relationship (IR) between grassland size and productivity. Our investigation reveals that the certification of grassland property rights significantly contributes to this IR. The persistence of the IR among households with certified grassland-use rights, contrasted with its absence among those with ambiguous rights, highlights its role. The emergence of grassland misallocation and fragmentation during the property rights certification process appears detrimental to grassland productivity, potentially explaining this phenomenon. Additionally, herders' adaptive strategies, like renting grassland and cooperative management, may help mitigate the IR.

Key words: grassland fragmentation, grassland misallocation, inverse relationship, livestock production, property rights certification

Introduction

Understanding the relationship between farm size and productivity holds significant practical value for both policy makers and researchers. On the policy side, such relationship can inform policymakers on how to enhance agricultural production efficiency, which is essential for achieving high-quality development. Thus, the efficiency comparison between small and large farms has been a persistent topic in agricultural and development economics research (Foster and Rosenzweig, 2022). Extensive literature has consistently highlighted an inverse relationship (IR) between farm size and productivity within the agriculture sector in developing economies, evident at both the household and plot levels (Debrah and Adanu, 2022). Various explanations have been proposed for this IR. One prevalent and intuitive explanation is the imperfect nature of off-farm labor markets (Deininger et al., 2018; Xia et al., 2020), land rental markets (Chernina, Dower, and Markevich, 2014), and credit and insurance markets (Akudugu, 2016). Other explanations include omitted variables related to land quality (Lamb, 2003; Chen, Huffman, and Rozelle, 2011) unobserved household characteristics (Assuncao and Ghatak, 2003), edge effect (Bevis and Barrett, 2020), or measurement errors (Debrah and Adanu, 2022; Ayalew et al., 2024). Recent research has proposed and validated the hypothesis that the economies of scale resulting from transaction costs and mechanical technology adoption lead to a U-shaped relationship between the farm size and productivity (Muyanga and Jayne, 2019; Sheng, Ding, and Huang, 2019; Foster and Rosenzweig, 2022).

Mingxue Zhang (first author) is a PhD student in the China Center for Agricultural Policy, School of Advanced Agricultural Sciences at Peking University. Dongqing Li (corresponding author, dongqing101@foxmail.com) is a lecturer in the School of Economics and Management at Beijing Forestry University.
We declare that we have no conflict of interest. This work acknowledges the financial support from the National Natural Science Foundation of China (Grant no. 72403024, 72322008, and 72173004).

Review coordinated by Vardges Hovhannisyan.

However, existing research has primarily concentrated on crop production, the scant attention given to the IR issues within grassland ecosystems represents a notable oversight. Grasslands, essential components of the global ecosystem, span roughly 40% of the earth's terrestrial area and constitute 69% of the world's agricultural land (Zhao, Liu, and Wu, 2020). Globally, approximately 30% of meat production originates from grasslands (O'Mara, 2012). In China, nearly 18 million herdsmen inhabit pastoral or semi-pastoral regions, relying on grazing livestock as their primary source of income. Considering the pivotal role of grassland ecosystems in production supply, it is imperative to investigate IR issues in pastoral areas, where different natural resource characteristics, economic activities, and land use patterns might present unique challenges and opportunities. Exploration of IR issues in pastoral areas not only offers empirical support for the development strategy of moderate husbandry management, but also sheds light on issues linked to the expanding consumption of high-value agricultural products in China, due to its direct relevance to productivity. Chinese pastoral areas, with its predominantly traditional semi-nomadic pastoralism, provide a valuable context for exploring these issues.

In addition, these mentioned studies addressing the land size-productivity relationship have primarily concentrated on endogenous factors like land economic variables, neglecting the crucial role of the external institutions in shaping this relationship. Recent examinations based on cross-country or household-level data have suggested that the relative inefficiency of agriculture in developing countries could stem from frictions due to property reforms or institutions (Adamopoulos and Restuccia, 2020; Gao, Shi, and Fang, 2021; Adamopoulos et al., 2022; Britos et al., 2022; Zhang, Hu, and Yu, 2023). Can property rights certification elucidate the land size-productivity relationship? Grassland tenure reform in the pastoral areas of China provides us with a unique opportunity to examine how the exogenous institution of property rights influences the IR.

Given this, this paper aims to answer the question of the correlation between grassland size and productivity using a household panel dataset encompassing five major pastoral provinces in China. By using field survey data, this paper observes a significant IR between the grassland size and productivity measured by the livestock number per hectare, even after accounting for land characteristics, grazing inputs, market participation, and a set of control variables. However, we note heterogeneity in the remaining IR based on grassland property rights certification: the inverse relationship (IR) between grassland size and productivity was pronounced among households with clear property rights but disappeared among those with unclear property rights. This suggests that the presence of the inverse relationship, which cannot be explained by inputs, factor markets, etc., may be produced by property rights arrangements. The landscape misallocation and fragmentation resulting from property clarification might elucidate why property rights certification contributes to IR. Additionally, our findings suggest that participating in the grassland rental market or engaging in cooperative management may help herders alleviate IR.

This article makes three contributions to the literature. Firstly, it delves into the grassland size-productivity relationship within pastoral areas, addressing an essential aspect of efficient land use for livestock farming. With the rising demand for high-value animal products and limited arable land in densely populated countries, the efficient utilization of marginal land becomes crucial. Pastoralism, practiced across a significant portion of the world's landmass, exemplifies one of the most prevalent forms of marginal land utilization (McGahey et al., 2014). Despite the importance of this relationship, studies exploring the size-productivity dynamics in grassland farming are scarce. Xia et al. (2020) investigated this relationship using survey data from two northwestern Chinese provinces, revealed an IR between grassland area and livestock production primarily and attributed it to labor input intensity. Expanding upon these findings, our study, based on more comprehensive survey data, provides additional evidence and explanation on the grassland size-productivity relationship.

Secondly, this paper contributes novel and comprehensive evidence for explanations of the IR concerning exogenous property rights certification policies. Existing literature has predominantly investigated the IR focusing on endogenous factors, including measurement errors

(Debrah and Adanu, 2022; Ayalew et al., 2023) and labor market transaction costs (Foster and Rosenzweig, 2022). While these factors contribute to establishing the relationship between land size and productivity, they may not adequately consider the impact of fragile property rights in developing regions. Establishing secure property rights and determining the optimal utilization of large or small farms are crucial considerations for enhancing production efficiency, especially in marginal lands such as grassland. Other studies have explored how land misallocation resulting from property reforms leads to agricultural inefficiencies in developing nations (Adamopoulos and Restuccia, 2020; Gao, Shi, and Fang, 2021; Adamopoulos et al., 2022; Britos et al., 2022; Zhang, Hu, and Yu, 2023). Building on this literature, our investigation delves into the role of exogenous grassland property rights reforms in explaining the relationship between grassland size and productivity.

Thirdly, our investigation into the adaptive responses of herders to the allocation of grassland property extends the existing body of literature by providing a comprehensive analysis. By examining market-based practices—specifically, involvement in the grassland rental market, cooperative management, and participation in the labor market—we contribute to a deeper understanding of the effectiveness of these strategies in addressing inefficiencies observed in grassland resource environments. Unlike previous studies, such as Zhang, Hu, and Yu (2023), which emphasized the positive impact of farmland leasing on total factor productivity by reducing misallocation, our research broadens the scope by evaluating another strategy, cooperative management, and its effects in grassland resource settings.

The rest of the article is structured as follows: The subsequent section introduces the institution background. The next section introduces our sample and details our data collection methods. Following this, we establish the existence of the observed IR in grassland farming, expound upon the IR attributed to property rights certification, delineate the channels from grassland misallocation and fragmentation, and evaluate the effects of herders' adaptations. Finally, we conclude by discussing the empirical results and their policy implications.

Background

Following the success of Household Contract System in cropping areas of China, the Chinese government started the Grassland Household Contract System (GHCS) in the middle of 1980s, aiming to assign both livestock property rights as well as grassland use rights, which previously owned by the communities, to household level. In practice, such reform followed two stages. That is, first, livestock property rights began to be allocated to individual herders mostly based on population in the early 1980s and the grasslands were still collectively owned. Then, grassland was segmented and assigned to individual households since mid-1980s. To bolster the stability of grassland property rights and accelerate the grassland tenure reform process, in the mid-1990s, each province initiated the issuance of certifications to individuals to provide legal protection to property rights. The content of certifications encompassed the rights and obligations of both parties, delineation of boundaries and area, duration, with specified start and end dates and so on. Each household allocated private grassland use rights were under obligation to obey a carrying capacity, that is, the maximum number of livestock that households can graze in their entitled private grassland area (Li, Gong, and Li, 2014).

Through policy interventions, grassland tenure reform had made significant progress. Our survey indicates that the proportion of households that privatized grassland use rights steadily increased. By 2018, 87% of villages had delineated the location of each household's pasture and issued corresponding contract certificates (Hou, Liu, and Tian, 2023). The secure property rights had also spurred the marketization of grassland leasing, gradually standardizing and institutionalizing the process. For instance, formal agreements through written contracts were required to establish agreements. Nevertheless, within pastoral regions, there are still many communities (villages or joint households) that maintain a model of grassland sharing, particularly in summer grasslands (Qi and Li, 2021). Consequently, two distinct forms of grassland property rights have emerged in pastoral areas. One is clear property right, which involves the full implementation of the grassland tenure system, enabling single household operation by contracting specific plots of grassland to individual households. The other is ambiguous property right, which maintains the practice of grassland joint management within the community. Such form involves clarifying household grazing rights by allocating grazing quotas to herders, allowing households to graze a certain number of livestock on communal grasslands (Qi and Li, 2021).

The allocation system described above had reduced the gap between rich and poor herders due to the more equitable use of grassland resources (Li, Gong, and Li, 2014). However, in the process of implementing this system, there were inevitably some problems. On the one hand, the assignments were based mostly on the household population but ignored those individuals' ability. As the household size increases, more livestock and grassland areas were typically assigned to them from the village. As a result, there was a mismatch between grassland area and household production capacity. High-productivity households might not obtain their desired area, but low-ability households might obtain excess area. On the other hand, the assignments were intended to be fair for each household in terms of grassland quality, which induced fragmentation of the grassland ecosystems. The assignments might have divided high (low) quality grassland into several fragmented plots according to the total number of households in the village. For example, if the highest-quality grassland in a village covered 100 hectares and there were 50 households in total, then under the assignment process, these 100 hectares were divided into 50 plots. These unexpected problems, the misallocation of grassland resources and the fragmentation of the grassland ecosystem, may hinder the livestock productivity of herders.

Data

We construct a household-level panel dataset using an extensive, multiyear field survey to investigate the relationship between grassland size and livestock productivity. The dataset covers five key pastoral provinces in China: Qinghai, Gansu, Xinjiang, Inner Mongolia, and Tibet. The survey was carried out sequentially in Qinghai and Gansu in 2017, followed by Inner Mongolia and Xinjiang in 2018, and Tibet in 2019 (refer to Table S1). These provinces collectively represent the primary pastoral regions in China, accounting for approximately 70 percent of the nation's total grassland area.

A stratified random sampling strategy was adopted to choose the samples from these provinces. Initially, we chose 4-6 pastoral counties in each province based on their grassland type and annual net per capita income. Subsequently, within each county, townships were categorized into two or three quantiles according to their grassland area per capita, and one township was randomly selected from each tertile. Similarly, 2-3 villages were randomly picked from each township, and ultimately, 6-8 households were selected randomly from each village. Our resulting sample comprised 1027 households from 164 villages, spanning 81 townships and 27 counties. The sample distribution for each province is outlined in Table S1. We designed structured survey questionnaires for conducting face-to-face interviews with household members and village leaders during our survey. This approach allowed us to gather data covering a three-year period (2015-2017) in Qinghai and Gansu Provinces, as well as another three-year span (2016-2018) in Inner Mongolia, Xinjiang, and Tibet.

Household-level variables. First, we use livestock number per hectare as a proxy of grassland productivity, which is a relatively universal indicator for measuring grassland productivity, such as Xia et.al. (2020) and Feng et al. (2021). During the field survey, household members were asked about the year-end total headcount of each livestock type (e.g., cattle, sheep, and horses). To facilitate comparisons, we standardized the headcounts of various animals into sheep units based on the Agricultural Industry Standards 2015. The livestock number per hectare was calculated by dividing the total animal headcount by the grassland size. There are two reasons to employ stocking rate as a measurement tool. Firstly, the information on the number of livestock over time is easily accessible from the households, which makes it more accurate and reliable. Secondly, while other measurements such as income/revenue per hectare could serve as an alternative proxy, it contains various factors such as market prices that might introduce noise into our results. Capturing all relevant income information accurately could also prove challenging.

One potential issue with this measurement is the nonlinear relationship between the number of animals and livestock output. Output may decline if there are too many livestock on the grassland. To address this concern, following Xia et al. (2020), we restricted the sample to households raising no more than nine livestock per hectare, which was the lowest number in our sample among jointly operated households grazing on the same land. Our results indicate that the number of livestock per hectare in these households does not have a negative impact on the livestock production of other households sharing the grassland. Thus, it can be reasonably assumed that own production does not decrease with excessive herd size below nine livestock per hectare.

Second, to gather information about the area of grassland under each household's operation, we first inquired with herders about the area, operational form (single or cooperative), and rental status (renting in or out) of each plot they managed in every survey year. Utilizing this plot data, we computed the grassland size at the household level by aggregating the area of plots operated by the interviewed household[1] and deducting the area of rented-out plots. operated by the interviewed household and subtracting the area of those plots that were rented out.

Third, to gather property information, we inquired about the year households obtained their grassland-use rights certificate. The binary variable property rights certification was assigned a value of 1 if the household possessed a grassland property rights certificate; otherwise, it was set to 0. We consider obtaining a grassland-use rights certificate as an indication of clearer property rights, superior to a household grassland contract, even if the household signed such a contract. This distinction arises from the initial distribution of grassland use rights to individual households during the GHCS, where borders between households were poorly defined. Upon the subsequent distribution of physical privatization certificates to individual households and clarification of grassland borders between neighboring households, households received an official certification of grassland-use rights, significantly enhancing the clarity of their property rights.

Fourth, we gathered diverse household-level characteristics to serve as control variables in addition to the previously mentioned information via the household survey. Land characteristics included the number of plots, the share of joint ownership grassland, the share of rotational grazing grassland, and the average distance between each plot and the dwelling. Grazing inputs factors comprised grazing labor input per hectare, labor hiring costs per hectare, supplementary forage grass and fodder expenditure per hectare, and production facility area per hectare. To capture market participation, we documented herders' activities such as renting grassland, participating in cooperative management, purchasing livestock insurance or loans for livestock production, and participation in off-farm job market. Additional socioeconomic variables included household size, share of labor force (16-65 years old), share of grazing member, share of off-farm member, grassland ecological compensation policy (GECP) subsidy per capita, and the proportion of cattle in the livestock herd.

Village- and township-level variables. We conducted interviews with village leaders to gather village- and township-level socioeconomic data. To corroborate property rights certification, village leaders reported the year when households received grassland property rights certifications and the year of reallocation of grassland within their village. Additionally, we documented various control variables at these levels, including the presence of policies like suspended grazing, grass

[1] In instances where a grassland plot was jointly owned by multiple households within a village, we requested information regarding the total area, the portion operated by the interviewed household, and the number of households utilizing the plot. In cases where the interviewed herders were unable to distinguish the area they operated from those managed by others, we evenly divided the plot among the households based on the number of households sharing the same grassland.

and livestock balance, grassland rental records, paved roads, 4G connectivity, and natural disasters in the response year. Market prices for cattle, sheep, forage grass, and grassland rentals, along with off-farm wages, were collected at the township level. Climate data, including village-level annual average precipitation and temperature, was derived by merging original climate data obtained from the National Meteorological Information Center of China with geographical coordinates for each village. Furthermore, we utilized NDVI data at the village level to account for grassland quality, following Hou et al. (2021).

Given that small grassland plots under operation are primarily used for planting rather than grazing, these plots might bias our results. Consequently, we removed observations with operated grassland areas under 2 hectares. After eliminating observations lacking information on household-level grassland area and livestock numbers, the final dataset comprised 976 households, totaling 2886 observations. Descriptive statistics concerning grassland productivity, area, and other control variables mentioned earlier are detailed in Table S2.

Empirical method

Upon preliminary examination via local polynomial regression, we observed an IR between the number of livestock per hectare and grassland size at the household level (refer to Figure S1). To further elucidate the association between grassland size and productivity, we adopt an empirical approach. Our assumption posits that the production function of a representative pasture takes the Cobb-Douglas form (Sheng, Ding, and Huang, 2019). The livestock output is influenced by a blend of factor inputs, such as grassland, labor, capital and various socio-economic factors.

$$Y = P \cdot G^{\theta} \cdot L^{\varphi} \,.\, K^{\gamma} \cdot M^{\delta} \tag{1}$$

Where Y represents the standardized livestock output. P denotes production technology. G, L, K and M are grassland, labor, capital (e.g. grazing facilities), and intermediate inputs (e.g. supplementary feeding). θ, φ , γ and δ are the output elasticity of each input. Dividing G on both sides of equation (1) and taking the logarithm, we can derive grassland productivity as the function of grassland size and other inputs.

$$\ln(Y/G) = (\theta + \varphi + \gamma + \delta - 1)\ln G \; + \varphi \ln(L/G) + \gamma \ln(K/G) + \delta \ln(M/G) \tag{2}$$

Equation (2) shows that grassland productivity should be either positively, negatively or not related to the grassland size if the production function demonstrates increasing ($\theta + \varphi + \gamma + \delta - 1 > 0$), decreasing ($\theta + \varphi + \gamma + \delta - 1 < 0$) or constant returns to scale ($\theta + \varphi + \gamma + \delta - 1 = 0$). We use a two-way fixed-effects model to identify the grassland size-productivity relationship:

$$y_{ijt} = \beta_1 g_{ijt} \; + \beta_2 \boldsymbol{x}_{ijt} + \mu_i + \tau_t + \varepsilon_{ijt} \tag{3}$$

where $y_{ijt} = \ln(Y/G)$ represents the number of livestock per hectare for household i in village j and year t. $g_{ijt} = \ln G$ represents the area of the grassland operated by the household. The coefficient of interest, β_1, measures the correlation between the grassland size and productivity. If β_1 is negative and statistically significant, an IR exists. $\boldsymbol{x}_{ijt}$ is a vector of household-, village- and township-level characteristics including land characteristics, grazing inputs, market participation, climate condition, and other control variables list in Table S2. u_i indicates a vector of household fixed effects that control for unobserved, time-invariant household characteristics. τ_t represents a vector of year fixed effects. ε_{ijt} is the error term clustered at the village level.

Despite employing two-way fixed effects and controlling for various relevant variables, there exists a potential endogeneity issue or reverse causality concerning the correlation between unobserved factors and grassland size. To address this concern, we employ an instrumental variable (IV) method. Our instruments to identify grassland size consist of two factors: contract grassland areas allocated by GHCS and a dummy variable representing grassland reallocation within the village. Firstly, the contract grassland areas are unlikely to be correlated with grassland productivity as they were primarily allocated based on household population rather than individuals' abilities (Li, Gong, and Li, 2014). Secondly, the grassland area acquired through reallocation depends solely on local grassland availability and property policies, unrelated to herders' grassland productivity. Consequently, these instrumental variables are anticipated to exhibit a positive correlation with grassland size while satisfying unrelated to omitted unobserved variables.

To empirically discern the factors explaining the remaining IR (after accounting for land characteristics, grazing inputs, market participation and climate conditions), we examine how an exogenous variable, property rights certification, influences the IR. In equation (3), we introduce the interaction of property rights certification and grassland size:

$$y_{ijt} = \alpha_0 g_{ijt} + \alpha_1 g_{ijt} \cdot P_{ijt} + \alpha_2 P_{ijt} + \alpha_3 \boldsymbol{x}_{ijt} + \mu_i + \tau_t + \varepsilon_{ijt} \quad (4)$$

where P_{ijt} represents the dummy variable indicating the certification of grassland-use rights at the household level, signifying the presence or absence of property rights certification. All other variables are defined as in equation (3). α_1 is our coefficient of interest. A negative and significant α_1 would imply that property rights certification intensifies the IR, whereas a positive α_1 would suggest a reduction in the IR due to property rights certification.

Next, we explore the potential mechanism through which property rights strengthen the IR. To this end, we establish grassland misallocation index from the inverse efficient allocation indicator, refer to Britos et al. (2022). Grassland misallocation index equals:

$$\text{Grassland misallocation index} = -\frac{1}{N}\sum_{i=1}^{N}(tfp_{i,t} - \overline{tfp_{J,t}}) * (G_{i,t} - \overline{G_{J,t}}) \quad (5)$$

where $tfp_{i,t}$ represents total factor productivity as measured by the estimated residue from equation (1) for household i in year t. $G_{i,t}$ denotes grassland size by household i in year t. $\overline{tfp_{J,t}}$ and $\overline{G_{J,t}}$ indicate the village-level arithmetic means of the herders' total factor productivity and grassland size, respectively. N denotes the number of households in the village. A higher value of the grassland misallocation index suggests a greater misallocation of grassland, indicating that more productive herders possess smaller land areas.

We derive the grassland fragmentation index using the proportion of plots smaller than the average plot size within the village. Plot size represents a fundamental spatial attribute and a crucial indicator of value (Ritter et al., 2020; Schaak, Meissner, and Musshoff, 2023). Herders experiencing a higher number of smaller plots than their peers might encounter increased grassland fragmentation. Unlike Simpson's diversification index, our grassland fragmentation index focuses on small-sized land patch density, providing more detailed insights into grassland size. In this case, P_{ijt} represents grassland misallocation index and grassland fragmentation index.

We also explore the role of the market-based adaptive behaviors in mitigating IR. For this purpose, we replace P_{ijt} with different market-based strategies: whether to rent grassland, engage in cooperative management, or participate in the off-farm market.

Results

5.1 Existence of IR

Empirical results from Table 1 show that an IR exists between grassland size and livestock number per hectare. Column 1 indicates that with only fixed effects taken into account, livestock number per hectare decreases by 0.648 percent for each one percent increase in grassland size, which is statistically significant at the 1% level. After adding the control variables, including land characteristics, the grazing inputs, market participation and climate, IR is weakened in magnitude. The result in Column 2 presents that a one percent increase in grassland size is associated with

Table 1. Regression of livestock number per hectare on grassland size

	TWFE		TWFE−IV	
Variables	**(1)**	**(2)**	**(3)**	**(4)**
Grassland size (log form)	-0.648***	-0.489***	-0.526***	-0.459***
	(0.041)	(0.088)	(0.145)	(0.142)
Controls	No	Yes	No	Yes
Two-way fixed effects	Yes	Yes	Yes	Yes
R-squared	0.250	0.415	0.254	0.421
First-stage F test of IV	—	—	35.09	36.56
Observations	2,886	2,886	2,886	2,886
Number of households	976	976	976	976

Note: This table represents the regression of livestock number per hectare on grassland size using two-way fixed effects (TWFE) and two-way fixed effects instrumental variables (TWFE-IV) models. Column 1 employs TWFE models without adding control variables, and Column 2 employs TWFE models with adding control variables. Columns 3-4 show the corresponding results by using TWFE-IV models. Dependent variable is livestock number per hectare in log form. The IVs include grassland contracted area and dummy of grassland reallocation. Robust standard errors in parentheses are clustered by village. *** p<0.01, ** p<0.05, * p<0.1. Regressions for the first stage of TWFE-IV are reported in the Table S4.

a reduction of 0.489 percent in livestock number per hectare. Despite the control variables accounting for approximately one-third of the observed IR, a negative association between grassland size and livestock productivity persists.

The estimation results derived from the TWFE-IV regression are consistent with these previously mentioned findings (Columns 3-4, Table 1), although there is a reduction in the intensity of the IR. This discrepancy may stem from the TWFE-IV's ability to control for time-variant unobserved variables. Moreover, similar IR results are observed when utilizing two additional productivity measures: livestock sales per hectare (Columns 1-2, Table S3) and livestock income per hectare (Columns 3-4, Table S3). As a result, we assert that an IR between grassland size and livestock productivity prevails among the majority of herders in pastoral regions.

Several studies found a U-shaped relationship between grain yield and farmland area in cropping areas in China (Muyanga and Jayne, 2019; Sheng, Ding, and Huang, 2019; Foster and Rosenzweig, 2022). To identify such a relationship, we add the square term of the log of grassland size into equation (3). This result corresponds to a U-shaped relationship after controlling for a series of variables, which suggests that the number of livestock per ha first decreases and then increases as the area of the grassland under operation increases (Table S5). Only approximately 1 percent of households exceeded the turning point in our sample. Thus, we believe that an IR between grassland size and productivity exists for the majority of herders in pastoral regions. This situation arises primarily due to the low level of mechanization in pastoral areas characterized by rugged terrain, sparse population density, and extensive grazing lands, which hampers the ability of pastoralists to achieve economies of scale.

5.2 Explanation of remaining IR from property rights certification

The empirical findings presented in Table 2 demonstrate that the interaction item between grassland size and whether certificate grassland-use rights or not at household level is negative

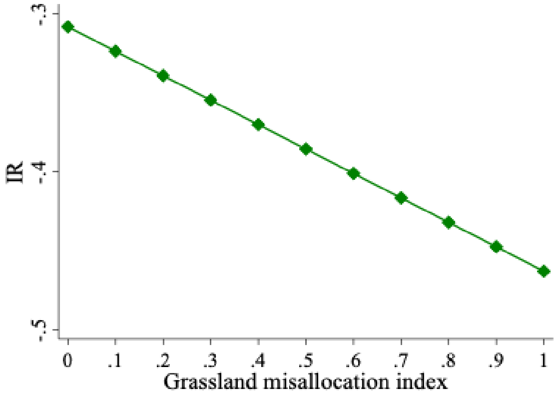
Table 2. Explanation of IR from property rights certification

Variables	Interaction terms include:			
	Dummy of certificating grassland-use rights at household level	Dummy of certificating grassland-use rights at village level	Grassland misallocation index	Grassland fragmentation index
	(1)	(2)	(3)	(4)
Grassland size (log form)	0.292	0.478	-0.308***	-0.435***
	(0.303)	(0.432)	(0.083)	(0.086)
Grassland size*Interaction terms	-0.757***	-0.927**	-0.155***	-0.059**
	(0.289)	(0.413)	(0.036)	(0.029)
Controls	Yes	Yes	Yes	Yes
Two-way fixed effects	Yes	Yes	Yes	Yes
R-squared	0.420	0.420	0.439	0.413
Observations	2,886	2,886	2,886	2,886
Number of households	976	976	976	976

Note: This table presents the results of the regression examining how property rights certification explains IR by adding interaction terms. Columns 1 and 2 add interaction items of grassland size in log form and dummy variable of whether to have certificating grassland-use rights at household level and at village level, respectively. Columns 3-4 show the potential channels from grassland misallocation and grassland fragmentation, which add interaction items of grassland size in log form and grassland misallocation index and grassland fragmentation index, respectively. Dependent variable is livestock number per hectare in log form. Robust standard errors in parentheses are clustered by village. *** p<0.01, ** p<0.05, * p<0.1.

and significant (Column 1, Table 2). Such result indicates that there is a significant negative relationship between grassland area and productivity among herders with grassland use rights certifications. Conversely, this IR becomes non-existent among households without grassland use rights certifications. We also employ property rights certification at the village level to conduct robustness test (Column 2, Table 2). Specifically, we apply the same set of models and variables as in Column 1, except that the grouping basis is replaced by villages with or without certificates of grassland-use rights to households. The results are consistent with those estimators in Column 1. These findings indicate that the remaining IR can be elucidated by property rights certification. Having established that the remaining IR may be elucidated by property rights certification, we delve into exploring two potential channels underlying this relationship: grassland misallocation and fragmentation. Before examining these mechanisms, it’s essential to clarify the connection between property rights certification and both grassland misallocation and fragmentation. The property rights certification of GHCS aimed to equitably distribute grassland size and quality among households, yet this process inadvertently led to misallocation and fragmentation. On the one hand, the allocation process primarily considered the family size, rather than the capabilities of these individuals, leading to a misallocation between grassland area and household production capacity. On the other hand, high-quality grassland was divided into smaller plots proportional to the total number of households in a village, contributing to fragmentation. The findings from data indicate a positive association between granting households a grassland-use rights certificate and both the grassland misallocation index and grassland fragmentation index (refer to Table S6). This suggests that clear property rights have contributed to misallocation of grassland resource among herders (Adamopoulos and Restuccia, 2020) and increased fragmentation of grassland plots.

Penal A. IR under different grassland misallocation level



Penal B. IR under different grassland fragmentation level

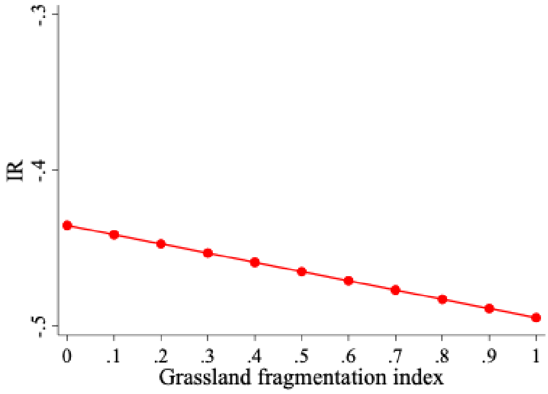


Figure 1. The role of grassland misallocation and fragmentation in shaping IR
Note: Figure 1 plots the IR (inverse relationship between grassland size and livestock number per ha) coefficient under different situation. Penal A and B plots the IR coefficient under different grassland misallocation level and fragmentation level, respectively.

To empirically explore whether disparities in grassland misallocation or fragmentation contribute to the observed differences in the remaining IR, we firstly introduce an interaction term between grassland size and grassland misallocation index as in equation (4). The results in Penal A, Figure 1 (refer to average results in Column 3, Table 2) indicate a gradual increase in the IR with an escalation in grassland misallocation. Specifically, when the grassland misallocation index is around 0 (25th percentile), the IR measures at -0.31; when the grassland misallocation index rises to approximately 1 (95th percentile), the IR increases to -0.46. Grassland misallocation leads to inefficiencies in both grassland and labor resource allocation. Some herder households with substantial grasslands may possess idle land due to an inadequate workforce or a lack of skilled workers, resulting in the wastage of land resources and reducing productivity. Conversely, herders with smaller grassland sizes might have surplus workers or members possessing higher production skills, leading to enhanced grazing productivity and thus intensifying IR. This misallocation of resources further exacerbates the IR.

Secondly, we incorporate equation (4) and introduce an interaction term between grassland size and fragmentation index. The significantly negative interaction between grassland area and grassland fragmentation index indicates that increased grassland fragmentation exacerbates the IR (Penal B, Figure 1, refer to average results in Column 4, Table 2). For instance, as the grassland fragmentation index increases from 0 to 1, the IR intensifies from -0.43 to -0.49. Essentially, in households experiencing greater grassland fragmentation, the livestock carrying capacity per hectare diminishes, even when households operate the same grassland size.

This finding implies that the grassland fragmentation resulting from the certification of grassland property rights can intensify the observed IR. One possible explanation is that fragmentation, especially among large-scale households, increases management difficulty and reduces resource-use efficiency. Compared to a single contiguous plot, fragmented parcels require more labor and inputs due to heterogeneity across parcels. In addition, irregularly shaped plots, often separated by fences and boundaries, can also hinder livestock access to high-quality forage, water, and safe migration routes, further limiting productivity (Kreutzmann, 2013). In contrast, small-scale operations tend to be more efficient due to lower fragmentation. As a result, grassland fragmentation emerges as a key driver of the IR.

It is worth noting that while smaller grasslands often exhibit higher productivity, small-scale grazing is not necessarily a recommended practice. Firstly, small-scale herders may face challenges related to surplus labor, hindering their ability to obtain higher benefits. Additionally, small-scale farming may lead to grazing intensity exceeding the carrying capacity of grasslands, which is detrimental to grassland conservation efforts. The top priority is to develop comprehensive strategies in pastoral areas to overcome barriers to mechanization, which can unlock opportunities for increased productivity, resilience, and sustainable development in these landscapes.

We further extend our analysis of the overall relationship between property rights and stocking rate and examine how property rights certification shapes changes in grazing management practices. Our findings, presented in Panel A, Column 1 of Table S7[2], indicate that household-level certification of grassland-use rights significantly reduces livestock number per hectare at the 10% level, and village-level certification has a negative but statistically insignificant coefficient. These results declare that property rights contribute to a reduction in stocking rate, although the effect is modest. Regarding grazing practices, certification at both household and village levels significantly increases average grazing days per plot (Panel A and B, Column 2) and household labor input, including both household pastoral months and the likelihood of hiring a shepherd (Panel A and B, Column 3 and Column 4). This implies that herders with certified grassland-use rights are more likely to adjust grazing schedules to better allocate livestock across pastures, improving grassland use and reducing localized overgrazing. Increased labor input also enables more precise herd management, such as route planning, livestock monitoring, and structured feeding. Furthermore, property rights certification not only affect short-term practices but also encourage long-term investment. Specifically, certification increases the likelihood of adopting new livestock breeds (Panel A and B, Column 5), which improves productivity and disease resistance, reflecting a shift toward more efficient, resilient production systems.

---

[2] Table S7 displays the estimates of the relationships of property rights and stocking rate as well as grazing management practices, measured by the annual average grazing days per plot, the total annual household pastoral months, and dummy variables for hiring a shepherd and adopting new livestock breeds. The regression model is specified as: $y_{ijt} = \delta_0 P_{ijt} + \delta_1 \boldsymbol{x}_{ijt} + \tau_t + \varepsilon_{ijt}$, where y_{ijt} represents the number of livestock per hectare in log form and grazing management practices outcomes for household i in village j and year t. P_{ijt} is a dummy for household-level certification of grassland-use rights. We also perform the analysis using village-level grassland-use rights by replacing P_{ijt} with P_{jt}, which repsents village level certification. All other specifications remain the same as in equation (3). Due to collinearity, only year fixed effects are included. Standard errors are clustered at the village level.

Table 3. Efficiency of adaptive behaviors from herders

	Interaction terms include dummy of:		
	Renting grassland	**Cooperative management**	**Participation in off-farm job market**
Variables	**(1)**	**(2)**	**(3)**
Grassland size (log form)	-0.494***	-0.499***	-0.488***
	(0.095)	(0.086)	(0.091)
Grassland size*Interaction terms	0.059***	0.049**	-0.003
	(0.020)	(0.021)	(0.012)
Controls	Yes	Yes	Yes
Two-way fixed effects	Yes	Yes	Yes
R-squared	0.415	0.414	0.411
Observations	2,886	2,886	2,886
Number of households	976	976	976

Note: This table represents the relationship of different adaptive behaviors and IR for different property rights certification groups. Columns 1-3 add interaction items of grassland size and a dummy variable of whether renting grassland, whether practicing cooperative management, and whether participating in off-farm job market, respectively. Dependent variable is livestock number per hectare in log form. Robust standard errors in parentheses are clustered by village. *** p<0.01, ** p<0.05, * p<0.1.

5.3 Adaptive behaviors from herders

As previous section discussed, the certification of grassland rights has inadvertently led to an unanticipated misallocation of grassland resources and landscape fragmentation, potentially contributing to certain aspects of the observed IR. Given that herders act as rational economic agents, the underutilization of grassland may not be sustainable in the long term. It is expected that they will likely engage in market-based practices, such as participation in the grassland rent market, cooperative management with others and participation in the off-farm labor market, to maximize the utilization of their grassland resources and labor forces.

To investigate the diverse impact of these market-based adaptive behaviors among herders, we utilize equation (4) for a heterogeneity analysis. We utilize different dummy variables – renting grassland, cooperative management, and participation in the off-farm market – to indicate various market-based strategies employed by herders. Table 3 presents the empirical estimates of these market-based strategies aimed at mitigating the IR.

Firstly, participation in the grassland rental market contributes to reducing the IR. Compared to households who do not rent land, the IR significantly decreases 12% (Column 1, Table 3) for households engaged in the grassland rental market. This decline may stem from these households better managing the area of grassland according to their capabilities. However, it's essential to note that the IR persists among households renting grassland. One reason for this persistence is the imperfections within the grassland rental market, which incur institutional costs for herders attempting to rent sufficient grassland. Additionally, the rental market offers limited solutions to address the issue of grassland fragmentation. Our field survey reveals that only 25% of rented grassland plots are contiguous to the renting households' own plots.

Secondly, cooperative management serves as another means of reducing IR by enhancing grassland scale and minimizing fragmentation. In comparison to independently operated households, the IR significantly decreases by 10% (Column 2, Table 3) for households engaging in cooperative grassland management. The reason could be the individual resource limitations, prompting greater benefits from cooperative management in optimizing resource use. Such benefits foster an easier organization and implementation of cooperative management strategies among shareholders.

Thirdly, entering into the off-farm labor market appears to have no significant impact on the observed IR (Column 3, Table 3). This might be due to the underdevelopment of the labor market, failing to address misallocation in grassland resources within Chinese pastoral regions. Only 43% of household members engage in off-farm work in our sample, significantly lower than the framing areas' rate, which stood at 85% (Li et al., 2021). Additionally, the limited effect could be attributed to herders' part-time engagement in the off-farm market, leading to minimal migration to urban areas. Our field survey indicates that 65% of off-farm laborers participate part-time work.

Conclusion and discussion

Empirical observations in developing regions have long indicated the presence of IR in the context of cropland farming. However, the relationship between grassland size and productivity in the context of grassland farming remains uncertain in the literature. Using extensive panel data from a field survey in China, our study aims to (i) determine the robustness of the observed IR in grassland farming; (ii) elucidate this IR concerning property rights and how grassland misallocation and fragmentation impact it; and (iii) assess the effects of herders' adaptations.

Our empirical findings strongly support the existence of an IR between grassland size and productivity, specifically a decrease of 0.49 percent in livestock number per hectare for each 1 percent increase in the operational grassland area. Such an IR remains statistically significant even after controlling for various factors and employing the IV method, which may contrast with the conclusions drawn by Xia et al. (2020). Additionally, upon introducing the interaction of property rights certification, we observed that the IR persists significantly in regions with clearly defined grassland property rights but loses its significance in areas with ambiguous property rights. This suggests that the certification of grassland-use rights might have adversely affected livestock productivity, potentially explaining the remaining portion of the observed IR. Property rights certification influences the observed IR primarily through grassland misallocation and fragmentation. Our findings demonstrate that grassland misallocation exacerbates the IR, consistent with existing literature illustrating how mismatches in land resources can impede production (Adamopoulos and Restuccia, 2020; Ayerst, Brandt, and Restuccia, 2020; Chari et al., 2021). Similarly, our results also indicate that grassland fragmentation notably contributes to the IR, aligning with previous studies highlighting the adverse impact of land fragmentation on productivity (Jia and Petrick, 2014; Looga et al., 2018).

We also extend our analysis of the relationship between property rights and livestock management. Our findings suggest that property rights certification contributes to a reduction in livestock number per hectare to some extent. However, this adjustment is not merely about reducing grazing pressure but rather reflects a strategic shift toward more refined and efficient resource management, as herders gain greater security and long-term control over their land. This security enables herders to adopt forward-looking production strategies, balancing immediate income with long-term pasture sustainability to maximize overall economic returns. Specifically, our results indicate that property rights certification significantly increases average grazing days, household labor input, and the likelihood of adopting higher-quality livestock breeds. Through these changes, herders can improve pasture utilization, implement more precise daily herd management, and enhance production efficiency. These findings highlight the role of property rights in promoting sustainable and efficient grazing, serving as a valuable supplement to the literature on the ecological and economic impacts of property rights (Li et al., 2018; Liu et al., 2019; Liu et al., 2020; Hou, Liu, and Tian, 2023).

We further investigate three market-based strategies adopted by herders to enhance productivity: participation in the grassland rental market, cooperative management of grassland with others, and involvement in the labor market. Our empirical results indicate that participation in the grassland rental market or cooperative management significantly mitigates the IR. However, the impact of entering the labor market on addressing the misallocation in grassland resources in underdeveloped pastoral regions appears to be insignificant. This highlights the imperative need to customize strategies aimed at mitigating institutional costs resulting from property rights privatization—such as promoting the grassland rental market or cooperative management—to align with local conditions.

The study findings offer crucial insights for policymaking aimed at the sustainable utilization of grasslands in developing regions. The privatization of grassland use rights could potentially hinder productivity, particularly in large-scale operations, posing challenges for policymakers in choosing effective remedial measures to counteract the institutional costs resulting from this exogenous property rights reform. Implementing market-based solutions, such as land rental markets or cooperative management, holds promise in addressing land fragmentation and misallocation, potentially mitigating the observed productivity reduction. It's also vital to acknowledge that while reducing grazing intensity may yield short-term productivity reductions, it could yield long-term benefits for ecological conservation. Moreover, exploring the enduring effects of property rights privatization on grassland productivity necessitates further future research.

One limitation of our study is the use of livestock stocking rate as a measure of grassland productivity. Our research focuses on the herders' grassland management practices, where livestock stocking rate, relative to the above-ground net primary production (ANPP) commonly used by ecologists as a measure of grassland productivity, provides a more immediate reflection of how grassland resources are utilized and managed (Craine et al., 2012; Brookshire and Weaver, 2015; Fay et al., 2015). While stocking rate can indicate the carrying capacity of the grassland, which is closely correlated with productivity, it does not directly measure productivity especially in the long-term. It is influenced by various factors such as grazing management choices, grazing practices and ecological conditions. Therefore, while livestock stocking rate may serve as a useful proxy in some contexts, it cannot fully capture the dynamic changes in productivity. Future surveys could incorporate more precise measures to better reflect the actual, dynamic productivity of grassland.

[First submitted November 2024; accepted for publication June 2025.]

References

Adamopoulos, T., L. Brandt, J. Leight, and D. Restuccia. 2022. "Misallocation, selection, and productivity: A quantitative analysis with panel data from China." *Econometrica* 90(3), 1261-1282. doi: 10.3982/ECTA16598.

Adamopoulos, T., and D. Restuccia. 2020. "Land reform and productivity: A quantitative. analysis with micro data." *American Economic Journal: Macroeconomics* 12(3), 1-39. doi: 10.1257/mac.20150222.

Akudugu, M. A. 2016. "Agricultural productivity, credit and farm size nexus in Africa: a case study of Ghana." *Agricultural Finance Review* 76(2), 288-308. doi: 10.1108/AFR-12-2015-0058.

Assuncao, J. J., and M. Ghatak. 2003. "Can unobserved heterogeneity in farmer ability explain the inverse relationship between farm size and productivity." *Economics Letters* 80(2), 189-194. doi: 10.1016/S0165-1765(03)00091-0.

Ayalew, H., J. Chamberlin, C. Newman, K. A. Abay, F. Kosmowski, and T. Sida. 2024. "Revisiting the size–productivity relationship with imperfect measures of production and plot size." *American Journal of Agricultural Economics* 106(2), 595-619. doi: 10.1111/ajae.12417.

Ayerst, S., L. Brandt, and D. Restuccia. 2020. "Market constraints, misallocation, and productivity in Vietnam agriculture." *Food Policy* 94, 101840.

Bevis, L. E., and C. B. Barrett. 2020. "Close to the edge: High productivity at plot peripheries. and the inverse size-productivity relationship." *Journal of Development Economics* 143, 102377. doi: 10.1016/j.jdeveco.2019.102377.

Britos, B., M. A. Hernandez, M. Robles, and D. R. Trupkin. 2022. "Land market distortions and aggregate agricultural productivity: Evidence from Guatemala." *Journal of Development Economics* 155, 102787. doi: 10.1016/j.jdeveco.2021.102787.

Brookshire, E. N. J., and T. Weaver. 2015. "Long-term decline in grassland productivity driven by increasing dryness." *Nature Communications* 6(1), 7148. doi: 10.1038/ncomms8148.

Chari, A., E. M. Liu, S. Y. Wang, and Y. Wang. 2021. "Property rights, land misallocation, and agricultural efficiency in China." *The Review of Economic Studies* 88(4), 1831-1862. doi: 10.1093/restud/rdab067.

Chen, Z., W. E. Huffman, and S. Rozelle. 2011. "Inverse relationship between productivity and farm size: the case of China." *Contemporary Economic Policy* 29(4), 580-592. doi: 10.1111/j.1465-7287.2010.00236.x.

Chernina, E., P. C. Dower, and A. Markevich. 2014. "Property rights, land liquidity, and internal migration." *Journal of Development Economics* 110, 191-215. doi: 10.1016/j.jdeveco.2013.03.010.

Craine, J. M., J. B. Nippert, A. J. Elmore, A. M. Skibbe, S. L. Hutchinson, and N. A. Brunsell. 2012. "Timing of climate variability and grassland productivity." *Proceedings of the National Academy of Sciences* 109(9), 3401-3405. doi: 10.1073/pnas.1118438109.

Debrah, G., and K. Adanu. 2022. "Does the inverse farm size-productivity hypothesis hold. beyond five hectares? Evidence from Ghana." *Journal of Agricultural and Applied Economics* 54(3), 548-559. doi: 10.1017/aae.2022.20.

Deininger, K., S. Jin, Y. Liu, and S. K. Singh. 2018. "Can labor-market imperfections explain changes in the inverse farm size–productivity relationship? Longitudinal evidence from rural India." *Land Economics* 94(2), 239-258. doi: https://doi.org/10.3368/le.94.2.239.

Fay, P. A., S. M. Prober, W. S. Harpole, J. M. Knops, J. D. Bakker, E. T. Borer, ... and L. H. Yang. 2015. "Grassland productivity limited by multiple nutrients." *Nature Plants* 1(7), 1-5. doi: 10.1038/nplants.2015.80.

Feng, X., H. Qiu, J. Pan, and J. Tang. 2021. "The impact of climate change on livestock production in pastoral areas of China." *Science of the Total Environment* 770, 144838. doi: 10.1016/j.scitotenv.2020.144838.

Foster, A. D., and M. R. Rosenzweig. 2022. "Are there too many farms in the world? Labor market transaction costs, machine capacities, and optimal farm size." *Journal of Political Economy* 130(3), 636-680. doi: 10.1086/717890.

Gao, X., X. Shi, and S. Fang. 2021. "Property rights and misallocation: Evidence from land. certification in China." *World Development* 147, 105632. doi: 10.1016/j.worlddev.2021.105632.

Hou, L., P. Liu, and X. Tian. 2023. "Grassland tenure reform and grassland quality in China." *American Journal of Agricultural Economics* 105(5), 1388-1404. doi: 10.1111/ajae.12357.

Hou, L., F. Xia, Q. Chen, J. Huang, Y. He, N. Rose, and S. Rozelle. 2021. "Grassland ecological compensation policy in China improves grassland quality and increases herders' income." *Nature Communications* 12(1), 4683. doi: 10.1038/s41467-021-24942-8.

Jia, L., and M. Petrick. 2014. "How does land fragmentation affect off-farm labor supply: Panel data evidence from China." *Agricultural Economics* 45(3), 369-380. doi: 10.1111/agec.12071.

Kreutzmann, H. 2013. "The tragedy of responsibility in high Asia: modernizing traditional pastoral practices and preserving modernist worldviews." *Pastoralism: Research, Policy and Practice* 3, 1-11. doi: 10.1186/2041-7136-3-7.

Lamb, R. L. 2003. "Inverse productivity: Land quality, labor markets, and measurement error." *Journal of Development Economics* 71(1), 71-95. doi: 10.1016/S0304-3878(02)00134-7.

Li, A., J. Wu, X. Zhang, J. Xue, Z. Liu, X. Han, and J. Huang. 2018. "China's new rural "separating three property rights" land reform results in grassland degradation: Evidence from Inner Mongolia." *Land Use Policy* 71, 170-182. doi: 10.1016/j.landusepol.2017.11.052.

Li, S. P., Y. Q. Dong, L. X. Zhang, and C. F. Liu. 2021. "Off-farm employment and poverty alleviation in rural China." *Journal of Integrative Agriculture* 20(4), 943-952. doi: 10.1016/S2095-3119(21)63616-X.

Li, Y., B. Gong, and W. Li. 2014. *A review of China's rangeland management policies*. IIED country report. Available online at https://www.iied.org/sites/default/files/pdfs/migrate/10079IIED.pdf.

Liu, M., L. Dries, W. Heijman, X. Zhu, X. Deng, and J. Huang. 2019. "Land tenure reform and grassland degradation in Inner Mongolia, China." *China Economic Review* 55, 181-198. doi: 10.1016/j.chieco.2019.04.006.

Liu, M., J. Huang, L. Dries, W. Heijman, and X. Zhu. 2020. "How does land tenure reform impact upon pastoral livestock production? An empirical study for Inner Mongolia, China." *China Economic Review* 60, 101110. doi: 10.1016/j.chieco.2017.09.009.

Looga, J., E. Jürgenson, K. Sikk, E. Matveev, and S. Maasikamäe. 2018. "Land fragmentation and other determinants of agricultural farm productivity: The case of Estonia." *Land Use Policy* 79, 285-292. doi: 10.1016/j.landusepol.2018.08.021.

McGahey, D., J. Davies, N. Hagelberg, R. Ouedraogo. 2014. *Pastoralism and the Green Economy–a natural nexus.* Nairobi: IUCN and UNEP. x+ 58p. Available online at https://portals.iucn.org/library/sites/library/files/documents/2014-034.pdf.

Muyanga, M., and T. S. Jayne. 2019. "Revisiting the farm size-productivity relationship based on a relatively wide range of farm sizes: Evidence from Kenya." *American Journal of Agricultural Economics* 101(4), 1140-1163. doi: 10.1093/ajae/aaz003.

O'Mara, F. P. 2012. "The role of grasslands in food security and climate change." *Annals of Botany* 110(6), 1263-1270. doi: 10.1093/aob/mcs209.

Qi, Y., and W. Li. 2021. "A nested property right system of the commons: perspective of resource system-units." *Environmental Science and Policy* 115, 1-7. doi: 10.1016/j.envsci.2020.10.009.

Ritter, M., S. Hüttel, M. Odening, and S. Seifert. 2020. "Revisiting the relationship between land price and parcel size in agriculture." *Land Use Policy* 97, 104771. doi: 10.1016/j.landusepol.2020.104771.

Schaak, H., L. Meissner, and O. Musshoff. 2023. "New insights on regional differences of the farmland price structure: an extended replication study on the parcel size–price relationship." *Applied Economic Perspectives and Policy* 45(3), 1427-1449. doi: 10.1002/aepp.13366.

Sheng, Y., J. Ding, and J. Huang. 2019. "The relationship between farm size and productivity in agriculture: Evidence from maize production in Northern China." *American Journal of Agricultural Economics* 101(3), 790-806. doi: 10.1093/ajae/aay104.

Xia, F., L. Hou, S. Jin, and D. Li. 2020. "Land size and productivity in the livestock sector: evidence from pastoral areas in China." *Australian Journal of Agricultural and Resource Economics* 64(3), 867-888. doi: 10.1111/1467-8489.12381.

Zhang, X., L. Hu, and X. Yu. 2023. "Farmland Leasing, misallocation Reduction, and agricultural total factor Productivity: Insights from rice production in China." *Food Policy* 119, 102518. doi: 10.1016/j.foodpol.2023.102518.

Zhao, Y., Z. Liu, and J. Wu. 2020. "Grassland ecosystem services: a systematic review of. research advances and future directions." *Landscape Ecology* 35, 793-814. doi: 10.1007/s10980-020-00980-3.