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Land tenure reform and grassland degradation in Inner Mongolia, China

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ABSTRACT

Since the start of the land tenure reform in the pastoral areas of China in the 1980s, grassland use rights have increasingly been assigned to individual households. However, this period has also been accompanied by extensive grassland degradation in China, which has raised the question of whether a tragedy of privatisation has occurred. This paper investigates the impact of land tenure reform on the changes in grassland condition, using data from 60 counties in Inner Mongolia between 1985 and 2008. A fixed effects model is employed to control for time-invariant factors. Two alternative model specifications in terms of land tenure reform and time-variant factors are conducted to verify the robustness of the estimation results. The results show that land tenure reform did not affect the grassland condition significantly, and the major drivers of grassland degradation include the land use change and the increase in market demand (meat prices). Thereby, we provide empirical evidence that the privatisation of grasslands did not cause grassland degradation in Inner Mongolia, China.

1. Introduction

The tragedy of the commons, a concept based on the case of grassland use presented by Hardin (1968) 'freedom in the commons brings ruin to all', has long been part of the conventional wisdom in ecology, economics and political science (McEvoy, 1987). The essence of Hardin's theory was that resources held in common, such as pastures, oceans, rivers and air are subject to massive degradation due to the overuse by individuals (Feeny, Berkes, McCay, & Acheson, 1990; Harris, 2010). There are many settings in the world where the tragedy of the commons has occurred and continues to occur, and many countries have passed national legislation to assign the administrative responsibilities for managing common resources to centralized agencies to solve the tragedy of the commons (Ostrom, 2008). Theoretical research contended that the degradation of common resources was inevitable unless the commons were either privatised or maintained as common land with clear rights of entry and use (Hardin, 1968). Similarly, in the theorem of property rights (Coase, 1960), a clear assignment of property rights is proposed as a precondition for economically efficient resource

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allocation and environmental sustainability. As a consequence, the privatisation of property rights or use rights over resources has been implemented widely by governments around the world (Lesorogol, 2003; Little, 1992; Squires, Lu, Lu, Wang, & Yang, 2009; Ybarra, 2009). This privatisation trend is observed both in Inner Asia and Africa regarding the reform of grassland tenure (Sneath, 1998; Lesorogol, 2008; Liu, Huang, Dries, Heijman, & Zhu, 2017).

However, Hardin's theory of the tragedy of the commons and Coase's theorem of property rights have been rejected by some pastoral specialists, who claim that these theoretical findings provided a poor guide to understanding pastoralism (Behnke, 1994; Sneath, 1998; Tiffen, Mortimore, & Gichuki, 1994). Many studies questioned Hardin's theory and provided evidence of users being able to restrict access to the common resource and establish rules among themselves for its sustainable use (Feeny et al., 1990). Some scholars (e.g. Li & Zhang, 2009; Ostrom, 1990) found that traditional common use systems of grasslands often met the criteria for sustainable Social-Ecological Systems (Ostrom, 2009), such as the exclusion of outsiders and the self-organization of resource users (Ostrom, 1990). Moreover, it has been pointed out that exclusionary land tenure is counterproductive to protect the grassland condition in arid and semi-arid areas (Galvin, 2009; Turner, 1999). A growing number of academic studies criticises the effects of the prevailing privatisation of grassland property rights or use rights on the grassland condition. In this regard, some studies – especially those based on the theory of equilibrium versus non-equilibrium grassland systems – assert that grassland privatisation puts an end to mobile pastoralism by introducing inflexible boundaries and identify this as a main driver for grassland degradation (e.g. Fernandez-Gimenez & Le Febre, 2006; Li & Zhang, 2009; Vetter, 2005). Contrary to the well-known “tragedy of the commons”, the existence of “a tragedy of privatisation” has been claimed (Guelke, 2003; Li & Huntsinger, 2011). In this view, it suggests that the privatisation of grassland property rights or use rights resulted in grassland fragmentation, which has impeded the mobility, flexibility and reciprocity of grassland use (Hobbs et al., 2008; Wang, Brown, & Agrawal, 2013; Wang, Pan, Wang, Shen, & Lu, 2013). However, mobility is a way to make sustainable use of grasslands by pastoralists, both economically and environmentally, as a response to strong spatial and temporal heterogeneity in resources of grassland and livestock nutritional needs (IFAD, 2009; Tessema, Ingenbleek, & van Trijp, 2014). Flexibility can be an important risk management strategy and cope with spatial variability of vegetation and vulnerability of grasslands (McCarthy & Di Gregorio, 2007). Reciprocity of social relationships at different scales (among households, villages or regions) in terms of access to grazing and other productive resources supports the mobility and flexibility of resource management strategies (Fernandez-Gimenez, 2002; Tu, Mol, Zhang, & Ruben, 2011). Sneath (1998), using satellite images, revealed that grassland degradation was much less severe in Mongolia – which kept the common use system for grasslands – than in the Russian and Chinese parts of Inner Asia where the privatisation of grassland property rights or use rights was implemented. Nevertheless, these arguments are mainly based on a qualitative analysis or a simple quantitative comparation without considering the impacts from other factors. Empirical studies have been barely conducted to verify “the tragedy of privatisation”. Therefore, our paper aims to provide empirical evidence of whether there is “a tragedy of privatisation” existing in the case of China's grasslands.

Grassland degradation has been a worldwide problem in recent decades. It has been illustrated that about 40% of global grasslands experienced degradation between 1982 and 2006, based on the long-term data of remotely sensed Normalized Difference Vegetation Index (NDVI) as a proxy for global land degradation (Le, Nkonya, & Mirzabaev, 2016; Kwon et al., 2016; Wiesmair, Feilhauer, Magiera, Otte, & Waldhardt, 2016). Steinfeld et al. (2006) estimated that about 20% of global pasture and 73% of the grasslands in the drylands have been degraded. According to Chinese governmental reports, 10% of the total area of grasslands was degraded in the 1970s, increasing to 30% in the 1980s and 50% in the middle of the 1990s (Meng & Gao, 2002). By the 2000s, about 90% of the grasslands were degraded to various extents, with significant regional variation (Unkovich & Nan, 2008; Waldron, Brown, & Longworth, 2010). Grass production per hectare has decreased about 40% since the 1950s, and weeds and poisonous grasses have thrived at the expense of high-quality species (Liu & Diamond, 2005). The manifestation of grassland degradation involves a reduction in the extent of grass cover, a reduction in the density of grass cover, a reduction in the output of forage material, an increase in unpalatable grass species, an increase in soil compaction, changes in plant functional groups or a combination of all of them (Feng, Lu, Tokola, Liu, & Wang, 2009; Li et al., 2013; Lin et al., 2015). An important and far-reaching question for us is whether land tenure reform is one reason for China's grassland degradation.

In China, land tenure reform started with the Household Production Responsibility System in the cropland areas in the late 1970s and spread to the pastoral areas by the early 1980s (Liu et al., 2017). The land tenure reform in the pastoral areas aims at privatizing use rights of grasslands to individual households and displacing traditional common use (Banks, Richard, Ping, & Zhaoli, 2003). It is noted the grassland privatisation in this paper mean that the use rights of grasslands are contracted to individual households for a duration of 30–50 years. Some differences have been observed in the tenure reform of grasslands among the provinces. For instance, the grasslands tenure reform started in Inner Mongolia in 1982, Ningxia in 1983 and Heilongjiang in 1984 (Ho, 2000). Furthermore, the privatisation of grassland use rights in some provinces was ahead of the national decision about the tenure reform of grasslands, as the first Grassland Law of China was introduced only in 1985. Nevertheless, it is reported that most of the grasslands in China have experienced various degrees of degradation since the 1980s (Li, Gong, & Li, 2014). The concurrent deteriorating grassland condition has led to policy debates on whether the land tenure reform caused the grassland degradation in China (Fernandez-Gimenez, Wang, Batkhishig, Klein, & Reid, 2012).

Climate change and human activities are commonly found to be the main driving forces of worldwide grassland degradation (Field, 2001; Haberl, 1997; Wang, Deng, Song, Li, & Chen, 2017; Yang et al., 2016). Guelke (2003) showed that, in the case of South Africa, the grassland condition deteriorated with the introduction of privatisation. Although some studies exist that discuss the impact of the land tenure reform on the grassland condition in China (e.g. Ho, 2001; Li & Zhang, 2009), there is a lack of empirical analysis based on long-term data on a large-scale (Lu et al., 2015). This paper addresses this gap and uses information on the changes in grassland condition and progress of the land tenure reform in a typical pastoral area in China over a relatively long period (1985–2008) to estimate the effect of land tenure reform on the grassland condition. Grassland condition is measured by using spatial

information based on remote sensing technology. Estimating a fixed effects model, our results show that the land tenure reform has had no significant impacts on the grassland condition. In other words, the analysis shows that the privatisation of grasslands is not a driver of China's grassland degradation, which provides the empirical evidence against the existence of "a tragedy of privatisation".

In the following sections, we first provide background information about the grassland tenure reform in China, including the progress in the assignment of formal use rights and the actual private use of grasslands. Next, the materials of our empirical research are described, and the empirical model is presented. After that, the consistent model results under two model specifications are reported and discussed. We conclude with remarks about the privatisation of grasslands in China and the related policy implications.

2. Land tenure reform for the grasslands

2.1. A review of the legislation on grassland tenure in China

In the collectivist period of China, grasslands were assigned to production teams or People's communes and the grasslands were managed and used communally by all households in the same production team (Hua & Squires, 2015; Taylor, 2006). After that period, given the successful experience of privatizing land use rights to individual households and resulting output growth in the cropland regions in the late 1970s (Abdulai, Owusu, & Goetz, 2011; Kousar & Abdulai, 2016; Lin, 1992), the Chinese central government introduced the household-based privatisation of land use rights into the pastoral areas in the early 1980s. Since then, the management of grasslands has increasingly become the responsibility of individual households (Banks et al., 2003).

The first Grassland Law of China was initiated in 1985 and stipulated that the property rights over grasslands are owned either by the state or the collective but that use rights to the grasslands can be contracted out to either households or collectives (Ho, 2000). According to the current Law on the Contracting of Rural Land, the grassland use rights can be contracted to individual households for a duration of 30–50 years. In practice, local governments started to assign grassland use rights to households through a Double Contracting System ("cao xu shuang cheng bao") in the 1980s. Every household which has been assigned private grassland use rights is obliged to obey a carrying capacity, which is the maximum livestock population that can be grazed by households within their entitled private grassland area (Conte & Tilt, 2014; Li, Ali, & Zhang, 2007). In 2002, the revised Grassland Law reaffirmed the devolution of land use rights from the state and collectives to individual households (National People's Congress of the People's Republic of China, 2002). The State Council emphasised the specific allocation of the contracted items (e.g. the location and area of the parcels, user-right certificates etc.) to households to ensure the long-term stability of contract relations in a government report in 2011 (Li, 2012). With these legislative efforts, the privatisation of the grasslands has been conducted gradually in the pastoral areas of China, and increasingly private use by households has replaced traditional open access to land (Hua & Squires, 2015; Yang, Zhang, Wu, Wang, & Bao, 2004). By 2014, the total area of grasslands that has been assigned to individual households reached 223 million hectares, out of 400 million hectares of grasslands in China (Ministry of Agriculture of China, 2015).

2.2. The implementation of the land tenure reform on grasslands

Table 1 provides a typology of the assignment of use rights and the actual ways of grassland use in the pastoral areas of China since the start of the land tenure reform. This typology is in line with the investigation of land tenure reform on the Tibetan plateau by Banks et al. (2003). Three types of assignment of grassland use rights existed during the last three decades, namely, formal use rights assigned to individual households, to a group of households or to a collective. Correspondingly, there were three ways of grassland use, including private use, joint use and common use. Private use indicates that a certain area of grasslands is managed and used by an individual household, while other users are excluded. Joint use means that a group of households manage and use an area of grasslands together, and group members are often neighbours or relatives that have small parcels of grasslands and wish to make their land larger and contiguous. Finally, common use means that the grasslands within a collective or administrative village are used by all the members of the collective or all the villagers. It is noted that considering that some counties have private use, joint use and common use simultaneously. In our study, we denoted a county as having private use if > 50% of the grassland area of this county was used by individual households.

When the use rights are assigned to a collective or an administrative village, the actual way of grassland use is always common use. If use rights are assigned to a group of households, actual use can be common use or joint use. Private use, joint use and common use can all occur when the use rights are assigned to individual households. The intention of the land tenure reform in the pastoral

Table 1
The assignment of formal use rights of grasslands and the actual ways of grassland use.
Source: Adapted from "formal and de facto grassland management units" (Banks et al., 2003).

Formal use rights assigned to	Actual use of grasslands		
	Private use	Joint use	Common use
Individual households	+	+	+
Group of households	n.a.	+	+
Collective/administrative village	n.a.	n.a.	+

Notes: n.a. stands for non-existent situations. + for existent situations.

areas is, however, to achieve full private use when use rights are assigned to households. This has spurred criticisms and claims of failure of the privatisation process in China's extensive grasslands, compared to the case of the cropland areas where household-based use rights were assigned overnight, and private use was established simultaneously (Banks et al., 2003; Ho, 2000). Scholars (e.g. Li, 2012; Li & Zhang, 2009; Richard, Yan, & Du, 2006) have identified a number of possible barriers to the completion of the land tenure reform in the pastoral areas of China: (1) the inflexible boundaries stemming from the privatisation of grassland use rights is incompatible with the need for livestock mobility due to the heterogeneity of resources in arid and semi-arid areas (Li & Zhang, 2009); (2) there is a lack of financial resources for protecting private property rights, e.g. to build fences (Banks, 2003; Ho, 1996; Li et al., 2007); (3) individual household ownership is inconsistent with local or traditional knowledge about property or use rights (Richard et al., 2006); and (4) private use by individual households destroys the traditional institutions of grassland use and management (Li, 2012). In what follows, we will investigate another possible explanation for why the adoption of private use is lagging, namely whether privatisation negatively affects the grassland condition.

3. Data

3.1. Study area

The grasslands of China are mainly distributed on the Inner Mongolia Plateau, the Loess Plateau and the Qinghai-Tibetan Plateau. The extensive grasslands have been classified into three subclasses based on the density of grass cover, including dense grassland, moderate grassland and sparse grassland, which were adopted from the research by Feng et al. (2009) and Deng, Huang, Huang, Rozelle, and Gibson (2011). The grass cover of dense grassland is > 50%. Moderate grassland has grass covering 20–50% of the land, sparse grassland has a grass cover between 5 and 20%, while the areas with < 5% of grass cover are not counted as grasslands (none-grasslands). These three subclasses of grasslands and none-grasslands have a combined distribution ranging from the northeast plain adjacent to Mongolia to south of the Tibetan Plateau, as shown in Fig. 1.

To explore the effect of land tenure reform on the grassland condition in the pastoral areas of China, we selected Inner Mongolia, the first region for implementation of the land tenure reform in the grassland area, to conduct our empirical study (Li & Huntsinger, 2011). Inner Mongolia belongs to the arid and semi-arid areas of China that is vulnerable to degradation, desertification and salinization (Feng et al., 2009). It contains 21.7% of the area of China's natural grasslands. Approximately 67% of the total land in Inner Mongolia is classified as grassland, the majority of which is temperate grassland (Angerer, Han, Fujisaki, & Havstad, 2008). The distribution of the grasslands in Inner Mongolia is presented in Fig. 1.

As a traditionally pastoral region populated by Mongolians, the vast majority of local people maintain their livelihoods upon the

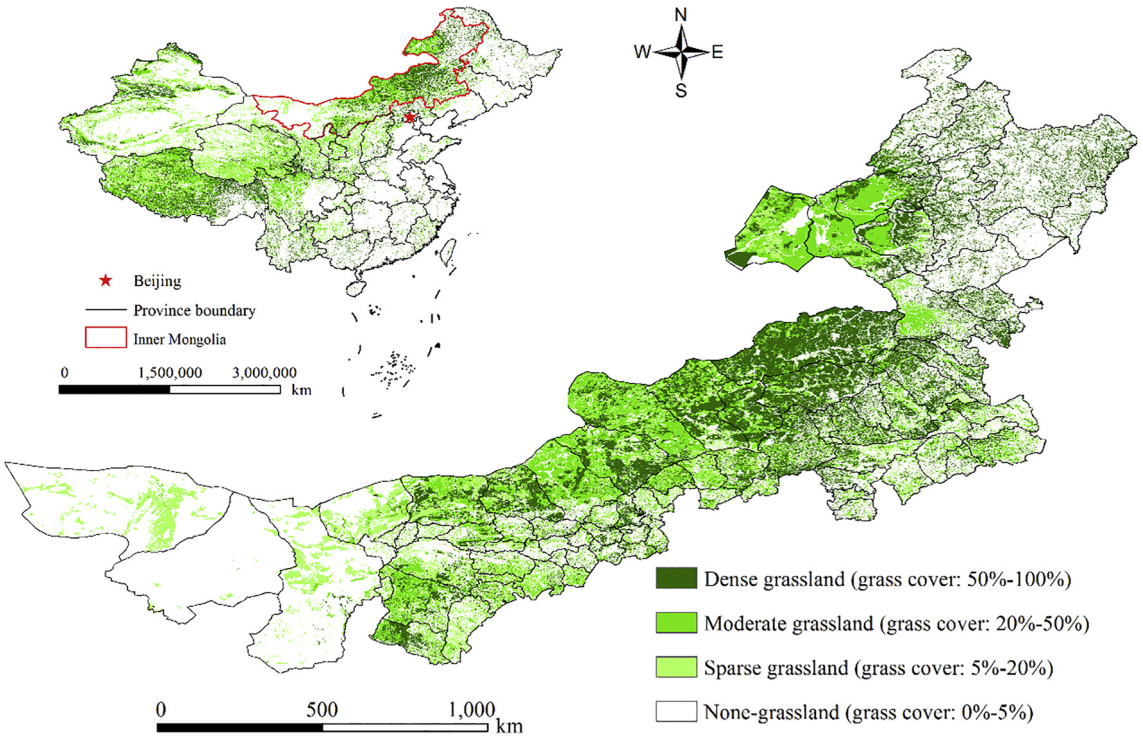

Fig. 1. The distribution of grasslands in China and in Inner Mongolia.
Source: Authors' compilation based on the data from land use database developed by the Chinese Academy of Sciences.

Table 2
The changes in grassland condition in Inner Mongolia from 1985 to 2008 (10^7ha).
Source: Authors' compilation based on data from the land use database developed by the Chinese Academy of Sciences.

	1985	1995	2000	2005	2008
Dense grassland area	2.285	2.267	2.186	2.192	2.190
Moderate grassland area	1.671	1.665	1.652	1.636	1.637
Sparse grassland area	0.724	0.713	0.739	0.726	0.733
Total grassland area	4.680	4.646	4.577	4.555	4.560

Note: The data presented in this table is from the 60 counties in our sample and do not include all the counties of Inner Mongolia.

permanent grasslands and the region has a relatively low population density in spite of rapid economic growth and a soaring population growth elsewhere in China (Angerer et al., 2008). The grassland condition in Inner Mongolia has been a major concern because the region is not only one of the main production regions for animal products of China (Li et al., 2016), it also functions as an ecological barrier for northern China. For instance, the colossal dust storms which rumbled through hundreds of cities and villages of northern China and blanketed the sky of Beijing between 1998 and 2001, are said to have originated from dryland areas and degraded grasslands mainly in Inner Mongolia (Wu, Zhang, Li, & Liang, 2015). In terms of its status as main region for livestock production in China, the mutton output of Inner Mongolia accounted for 22% of the total output of China in 2013, while 8% of all Chinese beef was produced here (China Animal Industry Yearbook, 2014). Therefore, continued grassland degradation in Inner Mongolia is expected to harm economic development as well as cause ecosystem instability in China (Meyer, 2006). By the end of the twentieth century, 90% of the grassland condition of Inner Mongolia had been degraded to various extents (Mei, Zhang, Gan, Ranlong, & Han, 2013), which has stimulated growing attention to the protection of grasslands in recent decades. Table 2 presents the changes in grassland condition in Inner Mongolia between 1985 and 2008. In this period, the dense, moderate and total grassland areas decreased in general, and the sparse grassland area increased.

According to provincial government reports for Inner Mongolia, the land tenure reform of local grasslands began officially through the Double Contracts System in 1982. Because of its limited uptake, the implementation of privatizing grassland use rights was strengthened by the Two Rights and One System policy (Shuang Quan Yi Zhi) in 1996 (Bureau of Animal husbandry of Inner Mongolia, 2000; Li & Zhang, 2009). This is regarded as the second round of grassland privatisation in Inner Mongolia. To this date, local governments continue to work on clarifying the boundaries of grassland use rights for each household and on issuing certificates (Bureau of Animal husbandry of Inner Mongolia, 2015). In practice, the specific timing and extent of conducting the land tenure reform differed among counties in Inner Mongolia. The county-level data used in this paper, therefore, allow to disentangle the effects of privatisation on the grassland condition.

Table 3 gives indications of the land tenure reform progress for grasslands in the sample counties of Inner Mongolia between 1985 and 2008. In 1985, only 6.67% of the 60 counties had assigned grassland use rights to individual households. By 2008, this proportion had increased to 81.67%, and the average number of years since formal use rights had been contracted to individual households was 11.55. Actual changes in the use of the grasslands followed this institutional evolution. In 1985, only 5% of the selected counties had adopted the practice of private use. In 2008, this percentage had reached to 63.33% and the average number of years since private use had been adopted was 8.72. These observations about the land tenure reform in the sample counties demonstrate that the adoption of private use lagged behind the privatisation of formal use rights.

3.2. Data sources

County-level data were collected for the period 1985–2008, the main period during which the land tenure reform was implemented across Inner Mongolia. Information about the land tenure reform was collected through questionnaires. The questionnaires were sent to the Office of General Affairs in the Animal Husbandry Bureau of each county and answered by the officers who are/were in charge of the implementation of local grassland tenure reform. The questions mainly involved information about: whether the land tenure reform has been implemented in the surveyed county; if yes, when the land tenure reform implementation started in the surveyed county, and when the implementation of land tenure reform was finished in the surveyed county; whether the individual households in the surveyed county have adopted the private use; if yes, when the adaptation of private use started in the surveyed county, and when the area of grasslands in private use exceeded 50% of the total grassland area in the surveyed county; other questions are about the progress of common use and joint use. In a second phase, interviews were conducted by telephone to

Table 3
Land tenure reform progress in the selected counties, 1985–2008.
Source: Authors' compilation based on the survey data.

	Unit	1985	1995	2000	2005	2008
The proportion of counties in which grassland use rights have been assigned to individual households	Percentage	6.67	23.33	76.67	80.00	81.67
The average number of years since the use rights have been assigned to households	Years	0.18	1.92	5.17	9.13	11.55
The proportion of counties with actual private use of grasslands	Percentage	5.00	15.00	58.33	63.33	63.33
The average number of years since actual private use has been adopted	Years	0.13	1.22	3.68	6.82	8.72

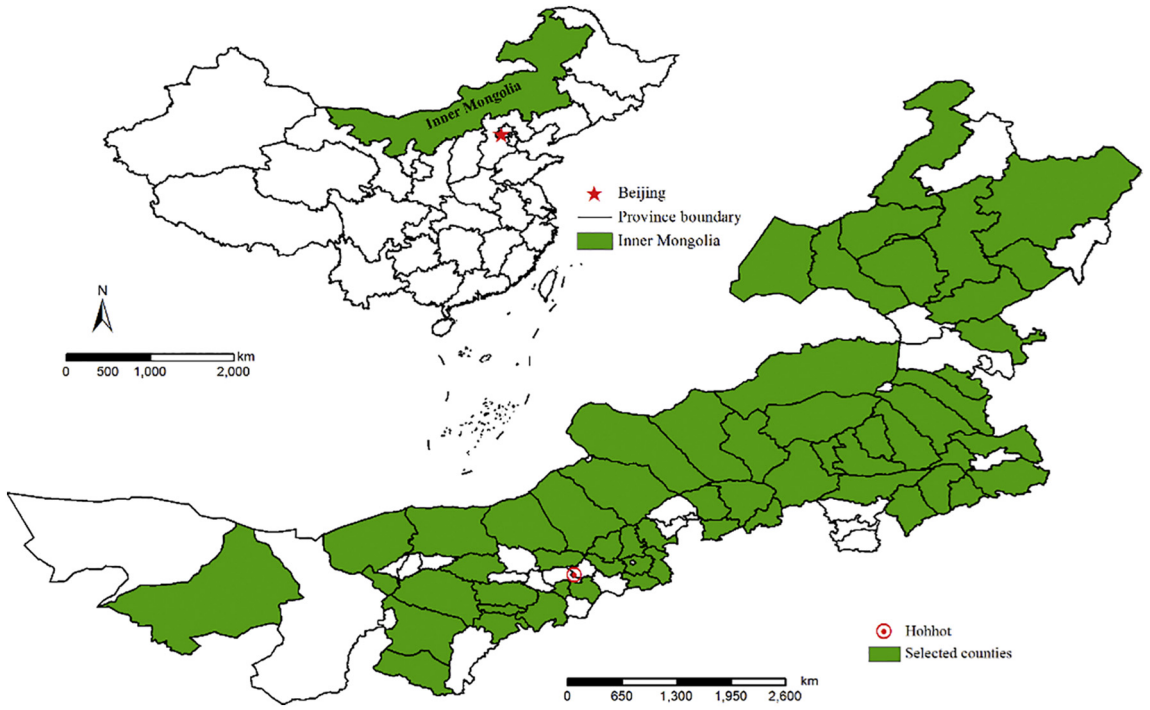

Fig. 2. Inner Mongolia and the selected counties in this study.
Source: Authors' compilation based on the survey data.

confirm the answers that were received. A total of 74 valid questionnaires were obtained out of 102 counties of Inner Mongolia. Besides the questionnaires, we had interviews with the officers who are working in the provincial institutes of Animal Husbandry of Inner Mongolia and with local herders to verify the information about the progress of land tenure reform on local grasslands. After dropping the urbanised counties and those counties that experienced changes in administrative regions, 60 counties out of 74 counties with valid questionnaires are retained as the research sample for this study, as marked in Fig. 2. It is noted that these 60 sample counties account for 87% of grassland area and 75% of sheep population of Inner Mongolia in 2008.

In the existing literature, grassland condition is indicated by grass cover, height, density, biomass production or density of perennial vegetation (Gu & Li, 2013; Yu & Farrell, 2013). Commonly used methods to measure these indicators include small-scale sampling tests in field studies and data analysis with remote sensing technology and GIS (Geographic Information System) over large areas. The former focuses on measuring the specific indices of grass production and vegetation diversity directly, while the latter estimates the general grassland condition based on satellite images (Gu & Li, 2013). In this study, the method with remote sensing and GIS is more appropriate because we aim to quantify the spatial and temporal differences in grassland condition across extensive grasslands during a long period. Therefore, our information on grassland condition relies on a land use database developed by the Chinese Academy of Sciences with original data from Landsat Thematic Mapper/Enhanced Thematic Mapper (Plus) (TM/ETM+) images which have a spatial resolution of 30*30 m (Deng et al., 2011). Visual interpretation and digitization of Landsat TM/ETM+ images were conducted to generate land use maps for the years 1985, 1995, 2000, 2005 and 2008 (Resources and Environment Scientific Data Centre, 2010). The land cover classification system was applied to distinguish grasslands from cultivated land, forestry area, water area, built-up area, and unused land. Grasslands were further classified into dense, moderate and sparse grasslands according to the density of grass cover (Deng et al., 2011). Meteorological data was collected based on the database of 51 national weather stations located in the different regions of Inner Mongolia (China Meteorological Administration, 2017) and included monthly average temperature and precipitation. In addition, socio-economic information was derived from statistical data collected by local governments.

4. Empirical model

4.1. Fixed effects model

The fixed effects model has been widely used in economic research and is employed primarily to study the causes of changes within entities over time (e.g., Fergusson, Swain-Campbell, & Horwood, 2002; Huang, Rozelle, Lohmar, Huang, & Wang, 2006). It is an estimation method that takes the observable as well as unobservable time-invariant explanatory variables into account (Fergusson et al., 2002; Verbeek, 2012). The fixed effects model is appropriate to investigate our research question considering that the results of the land tenure reform within each county can be studied effectively by controlling for the unmeasured heterogeneity among

counties. As shown in Table 3, the progress in land tenure reform changes substantially across our research period and for a considerable proportion of the counties in our dataset, which satisfies the basic requirement of the fixed effects model (Daun-Barnett, 2011).

4.2. Variable definitions and descriptive analysis

The dependent variable in the empirical analysis is the grassland condition. The grassland condition includes both the quantity and quality of grasslands, which are quantified as the extent and density of grass cover. These indicators are seen as the crucial manifestations of grassland degradation (Feng et al., 2009; Li et al., 2013). Specifically, the quantity of grasslands is measured by the total area of grasslands in hectares. The quality of grasslands is presented as the areas of grasslands of different types, including dense, moderate and sparse grasslands. We assume that grassland degradation is manifested by a decrease in total, dense and moderate grassland areas, and an increase in the sparse grassland area. Grassland degradation may also occur if the total grassland area remains unchanged but dense and moderate grasslands degrade into sparse grassland. This was observed, for instance, when the grassland centre of gravity in China moved during the period 1976–1996 (Feng et al., 2009). Hence, four dependent variables are used in the empirical analysis to indicate the grassland condition: total; dense; moderate; sparse grassland areas.

The following model specification is derived from the general fixed effects model:

$$G_{jit} = g_{ji} + a_{1j}P_{it} + a_{2j}T_{it} + a_{3j}TV_{it} + a_{4j}F_{it} + a_{5j}FV_{it} + a_{6j}C_{it} + a_{7j}W_{it} + year_t + \gamma_{it} \quad (1)$$

$$G_{jit} = m_{ji} + b_{1j}L_{it} + b_{2j}T_{it} + b_{3j}TV_{it} + b_{4j}F_{it} + b_{5j}FV_{it} + b_{6j}C_{it} + b_{7j}W_{it} + year_t + \mu_{it} \quad (2)$$

where i and t present the i^{th} county and year t, and t equals 1985, 1995, 2000, 2005 or 2008. G_{jit} is a vector of the dependent variables, which are measured by the share of grassland area over county area. j (equals 1, 2, 3, and 4) presents the four types of grassland areas, being total, dense, moderate and sparse grassland areas. Hence, Eqs. (1) and (2) each represents four models: the total grassland model; dense grassland model; moderate grassland model; sparse grassland model.

P_{it} and L_{it} indicate the main variables of our interest, the progress of the land tenure reform in county i in year t. P_{it} in Eq. (1) is a dummy variable that equals 1 if county i had private use in year t, otherwise it is 0. Considering that the effect of land tenure reform may be accumulated, we also include L_{it}, a variable that presents the number of years that private use has been adopted in county i until year t in Eq. (2). It can be expected that the actual use will affect the grassland condition, therefore the variables of land tenure reform are presented by the years of actual adoption of private use instead of the years of the assignment of formal use rights to households. As was shown in Table 3, the adoption of actual private use lags behind the assignment of formal use rights. However, the adoption of private use may be determined by local economic and ecological conditions, which will cause an endogenous problem. Thus, we employ IVP_{it} and IVL_{it} as the instrumental variables of P_{it} *and* L_{it}, respectively, which will be further explained in Section 5. We also consider the nonlinear relationship between land tenure reform and grassland condition. The results of these estimations are presented in Appendix D.

To correctly estimate the effect of the land tenure reform, we control for other factors that may cause grassland degradation, which include climate (Gao et al., 2010; Li, Verburg, Lv, Wu, & Li, 2012; Lu et al., 2015), changes in land use (He, Tian, Gao, & Zhao, 2015; Hua & Squires, 2015), overgrazing, the development of technology and the natural endowments of regions (Deng et al., 2011; He et al., 2015; Lin et al., 2010). Climate is presented by the annual average temperature (T_{it}) and precipitation (F_{it}), as well as their annual variations (TV_{it} and FV_{it}) (Gong et al., 2015; Zhou, Wang, & Wang, 2002). C_{it} is the percentage change in cultivated land in county i in the 5 years preceding year t. C_{it} is considered to control for the effects of the switch of land between grassland and arable land which was shown to have a significant and direct effect on grassland quantity in China (Feng et al., 2009; Li et al., 2013; Zhang, Yu, Li, Zhou, & Zhang, 2007). Overgrazing of livestock has also been claimed as one of the main sources of grassland degradation (Harris, 2010). However, stocking density is endogenous to the grassland condition. Moreover, land tenure reform actually incorporates stocking densities because it has stipulated that those using contracted grassland are restricted in terms of the grazing livestock population. We therefore do not include a specific variable of overgrazing or stocking density, but we have included model results that use the variable of livestock population in Appendix 0. As an alternative, we include real procurement prices of mutton and beef to reflect the situation of overgrazing. Increasing market demand, as reflected in increasing prices for meat products, is claimed to have led to a substantial increase in livestock production in pastoral areas (Harris, 2010), the. To be more specific, a 1-year lag of the mutton price is included, considering the timespan during which local herders adjust their sheep population to respond to the changes in sheep prices. Similarly, a 3-year lag is used for beef prices because large animals (such as cows and camels) have a longer growth period than sheep. It is noted that the models with a 1-year and 2-year lag of prices are also shown in Appendices B and C to show the robustness of the results of market demand on the grassland condition. To avoid multicollinearity stemming from mutton and beef prices, the weighted price (W_{it}) is used in the empirical models. W_{it} is presented by the mutton price in county i in year $t-1$ (MP_{it-1}) and the beef price in county i in year $t-3$ (BP_{it-3}), i.e. W_{it} equals β *times* MP_{it-1} and $(1-\beta)$ *times* BP_{it-3}. The weight (β) is a constant that is based on the proportion of the sheep population and the large animal population in the base year 1985.

Finally, the time variable ($year_t$) is included to control for the factor of technology development in livestock production and other factors that may change over time. The heterogeneity among counties, such as elevation, slope, soil type, distance to the provincial capital and other natural endowments, that do not change over time are regarded as time-invariant (fixed) factors in the model, denoted by g_{ji} and m_{ji} in Eqs. (1) and (2). In this case, the model actually represents a two-way fixed effects model that includes time effects and time-fixed effects. The specific variable definitions and the overall descriptive statistics of the main variables are listed in Table 4.

Table 4
Variable definitions and descriptive statistics of the main variables.
Source: Authors' compilation based on the survey data and the data from Statistical Yearbooks of Inner Mongolia.

Variables	Variable definition	Unit	Obs.	Mean	Std. Dev.	Min	Max
G_{1it}	The share of total grassland area over county area of county i in year t	Percentage	300	0.52	0.22	0.01	0.92
G_{2it}	The share of dense grassland area over county area of county i in year t	Percentage	300	0.23	0.15	0.00	0.71
G_{3it}	The share of moderate grassland area over county area of county i in year t	Percentage	300	0.20	0.14	0.00	0.60
G_{4it}	The share of sparse grassland area over county area of county i in year t	Percentage	300	0.09	0.08	0.00	0.36
P_{it}	$=1$ if county i adopted private use in year t, $=0$ otherwise	n.a.	300	0.41	0.49	0.00	1.00
IVP_{it}	$=1$ if county i formally assigned use rights in year t, $=0$ otherwise (The instrumental variable of P_{it})	n.a.	300	0.54	0.50	0.00	1.00
L_{it}	The number of years until year t that actual private use of grasslands has been adopted in county i	Year	300	4.11	6.09	0.00	26.00
IVL_{it}	The number of years until year t that formal use rights of grasslands have been assigned in county i (The instrumental variable of L_{it})	Year	300	5.59	6.70	0.00	26.00
T_{it}	The average temperature of county i in year t	Celsius degree	300	4.42	3.09	−4.83	9.39
TV_{it}	The standard deviation of temperature of 12 months of county i in year t	Celsius degree	300	14.15	1.88	11.09	19.56
F_{it}	The average precipitation of county i in year t	Millimeter	300	25.89	9.89	5.26	47.97
FV_{it}	The standard deviation of precipitation of 12 months of county i in year t	Millimeter	300	35.23	16.58	7.92	86.63
C_{it}	The average percentage change in the area of cultivated land in county i in the 5 years preceding year t	Percentage	300	0.02	0.07	−0.29	0.40
W_{it}	Weighted price of real mutton price in year $t-1$and real beef price in year $t-3$ of county i	RMB/Kilogram	300	1.27	0.56	0.57	1.97

Note: 1 dollar = 6.8 RMB in 2018.

5. Results

5.1. Statistical tests and instrumental variables

Cross–sectional dependence in panel–data models (also called contemporaneous correlation) was tested with the Pasaran CD test considering that our panel data includes many more cross-sectional units (60) than time periods (5). Test results showed that residuals are not correlated across entities and hence no cross–sectional dependence occurs in any of the models. Homoskedasticity of the panel data was tested as well. We then examined whether the variables of (actual) private use P_{it} and L_{it} are endogenous variables. This may be the case because the moment at which actual private use was adopted in a county could be decided by local households. The Durbin-Wu-Hausman test was employed to examine endogeneity of the variables P_{it} and L_{it}. The test results rejected the null hypothesis of exogeneity of P_{it} and L_{it}. This indicates that endogeneity exists in these models, which therefore require instrumental variables. We investigated whether the assignment of formal use rights (IVP_{it}) and the number of years with formal use rights (IVL_{it}) can be used as instrumental variables for P_{it} and L_{it}. The correlation coefficient of IVP_{it} and P_{it} is 0.775, and that of IVL_{it} and L_{it} is 0.825. Table 5 shows that the coefficients of the variables of formal use rights (IVP_{it} and IVL_{it}) are significant at 1% significance level in the regressions on private use (P_{it} and L_{it}). This indicates that IVP_{it} and IVL_{it} are strong instrumental variables, and the first-stage F-statistic in Table 5 confirms the validity of the instruments (e.g. Guifu & Hamori, 2009; Wang, Xie, Zhang, & Huang, 2018).

In addition, the assignment of formal use rights is assumed to be exogenous because its implementation was not decided by the local government or households, but it followed the policy guidelines from higher-level governments. For instance, the privatisation of land use rights started to be introduced in the pastoral areas in the 1980s by the Chinese government after it was shown to be successful in the cropland regions in the late 1970s (Lin, 1992). The implementation of privatizing formal use rights of grasslands was further strengthened when the Two Rights and One System policy was issued by the provincial government of Inner Mongolia in 1996

Table 5
The results of the first stage of the IV estimate.

	P_{it}	L_{it}
IVP_{it}	0.658*	
	(12.17)	
IVL_{it}		0.747*
		(14.96)*
Other explanatory variables	Yes	Yes
Year FE	Yes	Yes
County FE	Yes	Yes
First stage F-statistic	53.83	89.05
p-Value	0.000	0.000
N	300	300

Note: t statistics based on robust standard errors in parentheses.
* $p < .010$.

Table 6
Model results of Eq. (1).

	Benchmark 1				Benchmark 2				Eq. (1)			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
P_{it}	0.0017	0.0038	0.0011	−0.0024	0.0017	0.0038	0.0011	−0.0024	−0.0006	0.0019	0.0043	−0.004
	(0.52)	(1.65)	(0.38)	(−1.51)	(0.52)	(1.65)	(0.38)	(−1.51)	(−0.12)	(0.51)	(0.96)	(−1.58)
T_{it}									−0.002	0.004*	−0.007**	0.002
									(−0.65)	(1.81)	(−2.41)	(1.02)
TV_{it}									−0.001	0.004**	−0.004*	−0.00004
									(−0.44)	(2.19)	(−1.96)	(−0.03)
F_{it}									0.001**	0.0005*	0.0007*	0.00002
									(2.52)	(1.67)	(1.92)	(0.11)
FV_{it}									−0.0004**	−0.00002	−0.001***	−0.00001
									(−2.35)	(−0.14)	(−2.90)	(−0.13)
C_{it}									−0.03*	−0.012	−0.02	0.008
									(−1.81)	(−1.20)	(−1.59)	(1.15)
W_{it}					−0.013***	−0.01***	−0.004**	0.002*	−0.012**	−0.01***	−0.001	0.0002
					(−5.71)	(−7.01)	(−2.18)	(1.74)	(−2.25)	(−3.77)	(−0.26)	(0.09)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

Table 7
Model results of Eq. (2).

	Benchmark 1				Benchmark 2				Eq. (2)			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
L_{it}	0.0001	0.0003	−0.0006**	0.0003*	0.0001	0.0003	−0.0006**	0.0003*	−0.00009	−0.0005	0.00006	0.0002
	(0.48)	(1.55)	(−2.37)	(1.90)	(0.48)	(1.55)	(−2.37)	(1.90)	(−0.21)	(−1.59)	(0.17)	(0.90)
T_{it}									−0.0019	0.005**	−0.0071**	0.0015
									(−0.58)	(2.03)	(−2.44)	(0.89)
TV_{it}									−0.001	0.004**	−0.004*	−0.0002
									(−0.42)	(2.29)	(−1.93)	(−0.17)
F_{it}									0.001**	0.0004	0.0006*	0.0001
									(2.54)	(1.35)	(1.77)	(0.54)
FV_{it}									−0.0004**	0.00003	−0.0004***	−0.00005
									(−2.35)	(0.22)	(−2.75)	(−0.58)
C_{it}									−0.025*	−0.015	−0.02	0.01
									(−1.82)	(−1.44)	(−1.63)	(1.43)
W_{it}					−0.013***	−0.012***	−0.0003	−0.0007	−0.012**	−0.01***	0.0007	−0.003
					(−5.13)	(−6.43)	(−0.11)	(−0.55)	(−2.37)	(−3.04)	(0.16)	(−1.06)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

(Bureau of Animal husbandry of Inner Mongolia, 2000). Moreover, from interviews with the key informants on local land tenure reform we also learned that the implementation of assigning formal use rights of grasslands followed a top-down approach in Inner Mongolia. This meant that county-level governments assigned grasslands out according to the official documents from the provincial government on how to contract local grasslands to individual households or collectives, and the provincial government followed the instruction of grassland tenure reform from the central government of China (Ho, 2000; National People's Congress of the People's Republic of China, 2002).

Hence, we consider whether the formal use rights have been assigned (IVP_{it}) and the number of years with formal use rights (IVL_{it}) as the instrumental variables of P_{it} and L_{it}, respectively, which is just identified (Verbeek, 2012). Hence, the empirical models that stem from Eqs. (1) and (2) were run using fixed effects and including the instrumental variables to overcome the problem endogeneity. The comparison of the model results for Eqs. (1) and (2) without and with instrumental variables is presented in Appendix E.

5.2. Model results

Tables 6 and 7 show the model results. Table 6 illustrates the results stemming from Eq. (1) in which land tenure reform is presented by the dummy variable P_{it}. Table 7 illustrates the results stemming from Eq. (2) in which land tenure reform is presented by the number of years after adopting private use (L_{it}). In Tables 6 and 7, the columns under benchmark 1 present the model results of Eqs. (1) and (2) that only include P_{it} (or L_{it}), county fixed effects and year fixed effects. The columns under benchmark 2 present the regression results that add the variable of price (W_{it}) to benchmark 1. The regression results in the columns under Eqs. (1) and (2) further add the variables of land use change and weather conditions to benchmark 2. In Table 6, the coefficients of P_{it} are insignificant under benchmark 1, benchmark 2 after the variable of price (W_{it}) is added, and under Eq. (1) after the variables of land use change and weather conditions are added. Hence, the result that the land tenure reform (P_{it}) does not have a significant impact on the grassland condition is robust. Similarly, in Table 7, the coefficients of L_{it} under the benchmarks 1 and 2 are only significant in the moderate and sparse grassland models. After the variables of land use change and weather conditions are added to benchmark 2, all the coefficients of L_{it} under Eq. (2) become insignificant. The results in Appendix D confirm that there are also no nonlinear relationships between the land tenure reform and the grassland condition. As a first main conclusion, we conclude that our model specifications and results are robust to prove that the land tenure reform has had no significant impact on the grassland condition in the pastoral areas of Inner Mongolia.

As shown in Tables 6 and 7, temperature (T_{it}) and temperature variation (TV_{it}) affect dense grassland significantly and positively but have negative impacts on moderate grassland. Specifically, the coefficients of T_{it} for dense grassland (0.004) and for moderate grassland (-0.007) indicate that the dense grassland area increases 0.4% and the moderate grassland area decreases 0.7% if the annual average temperature increases 1 °C when other factors are not changed. The coefficients of F_{it} indicate that precipitation has significantly positive impacts on total, dense, and moderate grasslands. For instance, the total grassland area increases 0.1%, the dense grassland area increases 0.05%, and the moderate grassland area increases 0.07% if the annual average precipitation increases 1 mm when other factors are unchanged. The variation of precipitation (FV_{it}) shows a negative impact on total and moderate grasslands. The coefficients of C_{it} are significant and negative in the total grassland model under Eqs. (1) and (2). This indicates that the total grassland area decreases 3% if the local cultivated land increases 1% every 5 years. That is, the changes in land use types lead to serious degradation of grassland quantity.

Finally, market demand has been reflected by the meat price (W_{it}), which shows a significant and negative impact on total and dense grasslands in Tables 6 and 7. This indicates that market demand was a significant determinant of the degradation of the total grassland area and the dense grassland area. To be more specific, the coefficient of W_{it} for total grassland (-0.012) shows that the total grassland area decreases 1.2% if the meat price increases one RMB/k when other factors are not changed, among which especially the area of dense grassland decreases 1% as shown by the coefficient of W_{it} for dense grassland (-0.01). The variables of year and county have controlled for changes over time and regions in factors that have not been explicitly included in the model, such as changes in policies other than the land tenure reform, technological developments etc.

6. Conclusions and discussion

On the one hand, a firm belief exists among scholars and policymakers about the existence of “the tragedy of the commons”. As a result, the privatisation of grassland property rights or use rights has been advocated all over the world. In contrast, a growing number of scholars argues that grassland privatisation impeded the mobility and flexibility of grassland use and identify it as a significant reason for grassland degradation (e.g. Hobbs et al., 2008; Li & Zhang, 2009; Vetter, 2005). Therefore, arguments have been raised for “a tragedy of privatisation”, as opposed to the well-known “tragedy of the commons” (Guelke, 2003; Li & Huntsinger, 2011).

Given these contradicting views in the literature about the effect of privatisation on the grassland condition, this paper used a quantitative analysis to investigate the relationship between grassland privatisation and grassland degradation. First, a review was made of the controversial views on the privatisation of grasslands. Next, we summarized the progress in the land tenure reform in the pastoral areas of China. After that, we conducted empirical research to examine the impact of the land tenure reform on the grassland condition based on the case of Inner Mongolia, China. In the empirical models, the land tenure reform was presented in two ways: (1) by a dummy variable that indicated whether the private use was adopted in the research years; (2) as the amount of years since private use was adopted to reflect potential accumulated effects of private use. The evolution of the grassland degradation was

measured based on the remote sensing technology. The observations include 60 counties of Inner Mongolia from 1985 through 2008. The span of the research period covered the main period during which the grassland tenure reform was implemented in Inner Mongolia. A fixed effects model was employed to disentangle the effects of the land tenure reform on the grassland condition and factors related to land use change, climate, and market demand. Time-variation and heterogeneity among counties were controlled for. The potential endogeneity of actual adoption of the land tenure reform was also taken into account. The consistent model results show that our empirical models are robust in terms of examining the impacts of the land tenure reform on the grassland condition.

The empirical model results showed that the implementation of the land tenure reform did not have a significant impact on the grassland condition. This contradicts the economists' view that grassland privatisation will solve the tragedy of the commons will lead to a positive impact on the grassland condition (Feeny et al., 1990; Hardin, 1968). On the other hand, it also does not provide clear support for the claim of pastoral specialists that grassland privatisation will negatively affect the grassland condition because it puts an end to mobile pastoralism, a practice that is especially valuable in regions with strong spatial and temporal heterogeneity in natural resources, such as in arid and semi-arid areas (Fan, Li, & Li, 2015; Fernandez-Gimenez, 2002; Fernandez-Gimenez & Le Febre, 2006; Tessema et al., 2014). The insignificant effect of land tenure reform in our study may suggest that neither the positive impacts nor the negative impacts of grassland privatisation are significant enough to make a difference to the grassland condition. An alternative interpretation could be that the positive impacts of grassland privatisation have been offset by the negative impacts. Unfortunately, this study cannot prove which of these two possibilities may be more correct. In short, our model results ascertain that the privatisation of grasslands is not a significant driver of grassland degradation in Inner Mongolia, China, which indicates that the tragedy of privatisation did not occur there. In addition, we show that grassland degradation can be attributed to climate factors and market demand, and changes in land use when time and county fixed effects are controlled for.

This paper contributes to the academic debates on the existence of “the tragedy of privatisation” in grasslands. We provide empirical evidence that the tragedy of privatisation did not occur in the grasslands of Inner Mongolia. Moreover, this paper contributes to the policy debate on whether the privatisation of grassland use rights should be continued in China. Our results show that the current tenure arrangements have not resulted in grassland degradation in Inner Mongolia, which suggests that the privatisation of grassland use rights can be continued. Considering that the privatisation did not cause grassland degradation and that grassland resources are heterogeneous, we derive the following policy implications. First, we suggest putting more effort in the consolidation of the grasslands through the land rental market, instead of focusing on the debate about whether China should continue the grassland tenure reform or not. With clear property rights over grasslands, grassland consolidation through the land rental market can be an efficient way to enlarge the scale of land use as it has done in the crop area of China (Deininger & Jin, 2005; Huang & Ding, 2016; Huang, Gao, & Rozelle, 2012). Second, the findings of this research on the major factors that caused grassland degradation also suggest that there are a number of other efforts that could be helpful to improve the grassland condition of China. For instance, the demand for livestock products by the Chinese population will continue to rise with the increase in urbanisation and rising incomes, which will result in more pressure on the grassland resource of China (FAO, 2015). Trade liberalization of livestock products could be helpful to reduce the stress on grassland use in China. Exploring the potential to increase the productivity of the domestic livestock is another way to address this concern, for instance through the diffusion of techniques for feeding and fattening and by promoting the use of improved breeds (Liao, 2009).

Finally, we would like to point out several limitations of our research. First, the longest duration with private use until 2008 was 26 years. Possibly, the impact of the land tenure reform will only become clear after a period of several decades. Second, we used market demand as a proxy to estimate the impacts of livestock production on the grassland condition instead of the livestock population because this could cause a problem of endogeneity. Due to data limitations, we used the meat price at the provincial level to control for the effects of market demand, but local counties' meat prices would be more accurate. Similarly, the yearly dummy variables are employed to control for the impacts of factors that have changed over time. The analysis could be further improved if specific data for variables that change over time are available at county level, such as indicators of local technological development, pollution from local industries, the occurrence of bushfires, etc. Third, the potential stock effect of grasslands (more degradation in the past may lead to more degradation in the future) is not included because of data limitations. Fourth, the Chinese government attempted to assign land use rights as well as livestock numbers to individual households in the 1980s, and livestock privatisation was completed quickly. This paper did not discuss the impacts of livestock privatisation on the grassland condition. Another challenge for future empirical research is to investigate the impact of land tenure reform in the long run and to take into account the effects of ecological reconstruction projects that have been initiated to protect the grassland condition in China since the 2000s. The major ecological reconstruction projects on grasslands have been implemented mainly after 2011 (Liu et al., 2018), while the research period of this study only covers the period 1985–2008. Although there were some ecological reconstruction projects implemented on the grasslands of China during the 2000s, the efforts were very few and partial (Jiang, 2006; Li et al., 2014; Liu et al., 2017) and we therefore did not include specific variables on the ecological reconstruction projects.

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Appendix A. Appendix

Table A presents the estimated results under the Eqs. (A.1) and (A.2) that include the variable of the growth rate of livestock population. The coefficients of the variables of land tenure reform are still not significant in all the models. The model results in Table A are consistent with that in Tables 6 and 7 of Eqs. (1) and (2). It indicates our model results are robust. The land tenure reform has no significant impacts on the grassland degradation

$$G_{jit} = h_{ji} + c_{1j}P_{it} + c_{2j}T_{it} + c_{3j}TV_{it} + c_{4j}F_{it} + c_{5j}FV_{it} + c_{6j}C_{it} + c_{7j}Z_{it-1} + c_{8j}year_t + \eta_{it} \quad (A.1)$$

$$G_{jit} = f_{ji} + d_{1j}L_{it} + d_{2j}T_{it} + d_{3j}TV_{it} + d_{4j}F_{it} + d_{5j}FV_{it} + d_{6j}C_{it} + d_{7j}Z_{it-1} + d_{8j}year_t + \zeta_{it} \quad (A.2)$$

Table A
Model results with the variable of the growth rate of livestock population.

	Eq. (A.1)				Eq. (A.2)			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
P_{it}	−0.0006	0.0018	0.0043	−0.0041	–	–	–	–
	(−0.12)	(0.51)	(0.98)	(−1.60)				
L_{it}	–	–	–	–	0.00002	−0.0005	0.00027	0.00008
					(0.05)	(−1.43)	(0.71)	(0.39)
T_{it}	−0.0018	0.0044*	−0.0064**	0.0014	−0.0018	0.005**	−0.0069**	0.0014
	(−0.56)	(1.87)	(−2.26)	(0.86)	(−0.55)	(2.05)	(−2.39)	(0.84)
TV_{it}	−0.0009	0.0042**	−0.004*	−0.0003	−0.0009	0.0045**	−0.0041*	−0.0004
	(−0.34)	(2.26)	(−1.78)	(−0.23)	(−0.35)	(2.32)	(−1.78)	(−0.32)
F_{it}	0.0009**	0.0005	0.0006	0.00008	0.0009**	0.0004	0.0005	0.0001
	(2.36)	(1.55)	(1.64)	(0.40)	(2.42)	(1.29)	(1.53)	(0.77)
FV_{it}	−0.0004**	−0.000004	−0.0004***	−0.00004	−0.0004**	0.00004	−0.0004**	−0.00007
	(−2.20)	(−0.03)	(−2.64)	(−0.41)	(−2.25)	(0.26)	(−2.55)	(−0.78)
C_{it}	−0.0230*	−0.0109	−0.0159	0.00616	−0.0227	−0.0140	−0.0153	0.0076
	(−1.66)	(−1.09)	(−1.32)	(0.88)	(−1.62)	(−1.34)	(−1.24)	(1.08)
Z_{it-1}	0.0018	0.0009	0.0031***	−0.0018***	0.0018	0.0006	0.0033***	−0.0017**
	(1.31)	(0.98)	(2.60)	(−2.59)	(1.28)	(0.56)	(2.70)	(−2.44)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Z_{it-1} is the growth rate of livestock population of county i in year $t-1$ relative to of that in the base year of 1984, which is to control the effects of livestock production. According to the index of Statistical Yearbooks of Inner Mongolia, one large animal equals 5 sheep units. Therefore, the livestock population equals large animal population times five and plus sheep population in our case. t statistics based on robust standard errors in parentheses.Obs. = 300.

* $p < .10$.

** $p < .05$.

*** $p < .01$.

Appendix B. Appendix

Table B presents the estimated results that include the variable of mutton and beef prices with one-year lagged. That is, W_{1it} equals β times $MP_{it-1}$and $(1-\beta)$ times BP_{it-1}. The model results in Table B are consistent with that in Tables 6 and 7 of Eqs. (1) and (2). It indicates the model results are robust. The land tenure reform has no significant impacts on the grassland degradation. The specific model results are as below

Table B
Model results with the mutton and beef prices that are both lagged 1 year.

	Eq. (1) with W_{1it}				Eq. (2) with W_{1it}			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
P_{it}	−0.0006	0.0019	0.0043	−0.0041	–	–	–	–
	(−0.12)	(0.51)	(0.96)	(−1.58)				
L_{it}	–	–	–	–	−0.00009	−0.0005	0.00006	0.0002
					(−0.21)	(−1.59)	(0.17)	(0.90)
T_{it}	−0.002	0.004*	−0.007**	0.002	−0.0019	0.005**	−0.0071**	0.0015
	(−0.65)	(1.81)	(−2.41)	(1.02)	(−0.58)	(2.03)	(−2.44)	(0.89)

(*continued on next page*)

Table B (*continued*)

	Eq. (1) with W_{1it}				Eq. (2) with W_{1it}			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
TV_{it}	−0.001	0.004**	−0.004*	−0.00004	−0.0011	0.00442**	−0.0044*	−0.0002
	(−0.44)	(2.19)	(−1.96)	(−0.03)	(−0.42)	(2.29)	(−1.93)	(−0.17)
F_{it}	0.001**	0.0005*	0.0007*	0.00002	0.001**	0.0004	0.0006*	0.0001
	(2.52)	(1.67)	(1.92)	(0.11)	(2.54)	(1.35)	(1.77)	(0.54)
FV_{it}	−0.0004**	−0.00002	−0.0005***	−0.00001	−0.0004**	0.00003	−0.0004***	−0.00005
	(−2.35)	(−0.14)	(−2.90)	(−0.13)	(−2.35)	(0.22)	(−2.75)	(−0.58)
C_{it}	−0.025*	−0.0119	−0.0193	0.0081	−0.0253*	−0.0148	−0.0200	0.0101
	(−1.81)	(−1.20)	(−1.59)	(1.15)	(−1.82)	(−1.44)	(−1.63)	(1.43)
W_{1it}	−0.0111**	−0.0134***	−0.0011	0.0002	−0.011**	−0.0105***	0.0006	−0.0025
	(−2.25)	(−3.77)	(−0.26)	(0.09)	(−2.37)	(−3.04)	(0.16)	(−1.06)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

Appendix C. Appendix

Table C presents the estimated results that include the variable of mutton and beef prices with 2-year lag. That is, W_{2it} equals β times MP_{it-2} and $(1-\beta)$ times BP_{it-2}. The model results in Table C are consistent with that in Tables 6 and 7 of Eqs. (1) and (2). It indicates the model results are robust. The land tenure reform has no significant impacts on the grassland degradation. The specific model results are as below

Table C
Model results with the mutton and beef prices that are both lagged 2 years.

	Eq. (1) with W_{2it}				Eq. (2) with W_{2it}			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
P_{it}	−0.0006	0.002	0.004	−0.004	–	–	–	–
	(−0.12)	(0.51)	(0.96)	(−1.58)				
L_{it}	–	–	–	–	−0.00009	−0.0005	0.00006	0.0002
					(−0.21)	(−1.59)	(0.17)	(0.90)
T_{it}	−0.002	0.004*	−0.007**	0.002	−0.002	0.005**	−0.007**	0.002
	(−0.65)	(1.81)	(−2.41)	(1.02)	(−0.58)	(2.03)	(−2.44)	(0.89)
TV_{it}	−0.0011	0.0041**	−0.0045*	−0.00004	−0.001	0.004**	−0.004*	−0.00023
	(−0.44)	(2.19)	(−1.96)	(−0.03)	(−0.42)	(2.29)	(−1.93)	(−0.17)
F_{it}	0.001**	0.0005*	0.0007*	0.00002	0.001**	0.0004	0.00062*	0.00011
	(2.52)	(1.67)	(1.92)	(0.11)	(2.54)	(1.35)	(1.77)	(0.54)
FV_{it}	−0.0004**	−0.00002	−0.0005***	−0.00001	−0.0004**	0.00003	−0.0004***	−0.00005
	(−2.35)	(−0.14)	(−2.90)	(−0.13)	(−2.35)	(0.22)	(−2.75)	(−0.58)
C_{it}	−0.025*	−0.0119	−0.0193	0.00813	−0.0253*	−0.0148	−0.0200	0.0101
	(−1.81)	(−1.20)	(−1.59)	(1.15)	(−1.82)	(−1.44)	(−1.63)	(1.43)
W_{2it}	−0.011**	−0.0133***	−0.001	0.0002	−0.0109**	−0.0104***	0.0006	−0.002
	(−2.25)	(−3.77)	(−0.26)	(0.09)	(−2.37)	(−3.04)	(0.16)	(−1.06)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

Appendix D. Appendix

Table D presents the estimated results under the Eqs. (D.1) and (D.2) that include the interaction terms of the variables of land tenure reform and year to detect the nonlinear effects. The coefficients of the interaction terms are not significant in all the models, besides $P_{it} * year_{1995}$ in dense and sparse grassland models, and $L_{it} * year_{2000}$ in dense grassland model. The model results in Table D are consistent with that in Tables 6 and 7 of Eqs. (1) and (2). It indicates our model results are robust. The land tenure reform

generally has no significant nonlinear impacts on the grassland degradation

$$G_{jit} = m_{ji} + p_{1j}P_{it} * year_t + p_{2j}T_{it} + p_{3j}TV_{it} + p_{4j}F_{it} + p_{5j}FV_{it} + p_{6j}C_{it} + p_{7j}W_{it} + +p_{8j}year_t + \psi_{it} \quad (D.1)$$

$$G_{jit} = n_{ji} + q_{1j}L_{it} * year_t + q_{2j}T_{it} + q_{3j}TV_{it} + q_{4j}F_{it} + q_{5j}FV_{it} + q_{6j}C_{it} + q_{7j}W_{it} + +q_{8j}year_t + \omega_{it} \quad (D.2)$$

Table D
Model results with the interaction terms of the variables of land tenure reform and year.

	Eq. (D.1)				Eq. (D.2)			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
$P_{it} * year_{1995}$	0.0079	0.0133**	0.0091	−0.0096**	–	–	–	–
	(1.03)	(2.33)	(1.35)	(−2.52)				
$P_{it} * year_{2000}$	0.0005	−0.0069	0.0067	0.0006	–	–	–	–
	(0.07)	(−1.30)	(1.07)	(0.16)				
$P_{it} * year_{2005}$	−0.0064	−0.0068	−0.0009	0.0007	–	–	–	–
	(−0.90)	(−1.29)	(−0.14)	(0.19)				
$P_{it} * year_{2008}$	0.0006	−0.0062	0.0037	0.002	–	–	–	–
	(0.07)	(−1.06)	(0.53)	(0.52)				
$L_{it} * year_{1995}$	–	–	–	–	0.0006	0.0008	0.0008	−0.0006
					(0.63)	(1.07)	(1.02)	(−1.29)
$L_{it} * year_{2000}$	–	–	–	–	0.0001	−0.001*	0.0007	0.0002
					(0.14)	(−1.88)	(1.07)	(0.71)
$L_{it} * year_{2005}$	–	–	–	–	−0.0002	−0.0005	−0.00003	0.0002
					(−0.34)	(−1.35)	(−0.07)	(0.70)
$L_{it} * year_{2008}$	–	–	–	–	0.00002	−0.0004	0.00006	0.0002
					(0.04)	(−1.16)	(0.15)	(0.88)
T_{it}	−0.0019	0.0046*	−0.0071**	0.0017	−0.0019	0.0054**	−0.0073**	0.0014
	(−0.59)	(1.91)	(−2.48)	(1.04)	(−0.55)	(2.18)	(−2.47)	(0.83)
TV_{it}	−0.0012	0.0044**	−0.0048**	−0.00007	−0.001	0.005**	−0.0048**	−0.00039
	(−0.44)	(2.23)	(−2.05)	(−0.05)	(−0.37)	(2.57)	(−2.02)	(−0.29)
F_{it}	0.0011**	0.0004	0.0007*	0.0001	0.00102**	0.00048	0.0006	0.00009
	(2.58)	(1.30)	(1.93)	(0.48)	(2.52)	(1.60)	(1.62)	(0.47)
FV_{it}	−0.0005**	0.00001	−0.0005***	−0.00004	−0.0004**	−0.000002	−0.0004***	−0.00005
	(−2.47)	(0.09)	(−2.99)	(−0.39)	(−2.39)	(−0.01)	(−2.72)	(−0.50)
C_{it}	−0.0274*	−0.0152	−0.0219*	0.0103	−0.0262*	−0.0138	−0.0226*	0.0103
	(−1.93)	(−1.45)	(−1.77)	(1.47)	(−1.85)	(−1.32)	(−1.83)	(1.47)
W_{it}	−0.0128**	−0.0109**	−0.0012	−0.0024	−0.0125**	−0.0122***	0.0007	−0.0025
	(−2.20)	(−2.55)	(−0.24)	(−0.84)	(−2.41)	(−3.17)	(0.15)	(−0.99)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

Appendix E. Appendix

Tables E.1 and E.2 present the comparison of the model results of Eqs. (1) and (2) without and with the instrumental variables (IV)

Table E.1
Model results of Eq. (1) without and with the instrumental variable.

	Without IV				With IV			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
P_{it}	0.002	0.0036	0.0018	−0.0021	−0.0006	0.0019	0.0043	−0.004
	(0.74)	(1.59)	(0.63)	(−1.29)	(−0.12)	(0.51)	(0.96)	(−1.58)
T_{it}	−0.002	0.0043*	−0.0069**	0.0018	−0.002	0.004*	−0.007**	0.002
	(−0.62)	(1.84)	(−2.45)	(1.06)	(−0.65)	(1.81)	(−2.41)	(1.02)
TV_{it}	−0.0012	0.0041**	−0.0044*	−0.00008	−0.001	0.004**	−0.004*	−0.00004
	(−0.46)	(2.18)	(−1.94)	(−0.06)	(−0.44)	(2.19)	(−1.96)	(−0.03)

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Table E.1 (*continued*)

	Without IV				With IV			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
F_{it}	0.0011***	0.0005*	0.0006*	0.00005	0.001**	0.0005*	0.0007*	0.00002
	(2.67)	(1.79)	(1.83)	(0.27)	(2.52)	(1.67)	(1.92)	(0.11)
FV_{it}	−0.0005**	−0.00003	−0.0005***	−0.00003	−0.0004**	−0.00002	−0.001***	−0.00001
	(−2.50)	(−0.24)	(−2.83)	(−0.28)	(−2.35)	(−0.14)	(−2.90)	(−0.13)
C_{it}	−0.0243*	−0.0115	−0.0199	0.0086	−0.03*	−0.012	−0.02	0.008
	(−1.77)	(−1.16)	(−1.64)	(1.23)	(−1.81)	(−1.20)	(−1.59)	(1.15)
W_{it}	−0.013***	−0.015***	0.00008	−0.0008	−0.012**	−0.01***	−0.001	0.0002
	(−2.75)	(−4.34)	(0.02)	(−0.31)	(−2.25)	(−3.77)	(−0.26)	(0.09)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

Table E.2
Model results of Eq. (2) without and with the instrumental variable.

	Without IV				With IV			
	Total grassland	Dense grassland	Moderate grassland	Sparse grassland	Total grassland	Dense grassland	Moderate grassland	Sparse grassland
L_{it}	0.0003	0.0003	−0.0005*	0.0003*	−0.00009	−0.0005	0.00006	0.0002
	(0.85)	(1.27)	(−1.80)	(1.94)	(−0.21)	(−1.59)	(0.17)	(0.90)
T_{it}	−0.002	0.004	−0.006**	0.001	−0.0019	0.005**	−0.0071**	0.0015
	(−0.76)	(1.58)	(−2.19)	(0.81)	(−0.58)	(2.03)	(−2.44)	(0.89)
TV_{it}	−0.001	0.004**	−0.004*	−0.0003	−0.001	0.004**	−0.004*	−0.0002
	(−0.50)	(2.12)	(−1.82)	(−0.22)	(−0.42)	(2.29)	(−1.93)	(−0.17)
F_{it}	0.001***	0.0005*	0.001	0.0001	0.001**	0.0004	0.0006*	0.0001
	(2.66)	(1.71)	(1.61)	(0.60)	(2.54)	(1.35)	(1.77)	(0.54)
FV_{it}	−0.0005**	−0.00002	−0.0004**	−0.00006	−0.0004**	0.00003	−0.0004***	−0.00005
	(−2.51)	(−0.18)	(−2.57)	(−0.66)	(−2.35)	(0.22)	(−2.75)	(−0.58)
C_{it}	−0.024*	−0.011	−0.023*	0.011	−0.025*	−0.015	−0.02	0.01
	(−1.71)	(−1.11)	(−1.87)	(1.50)	(−1.82)	(−1.44)	(−1.63)	(1.43)
W_{it}	−0.013***	−0.014***	0.003	−0.003	−0.012**	−0.01***	0.0007	−0.003
	(−2.78)	(−4.23)	(0.72)	(−1.28)	(−2.37)	(−3.04)	(0.16)	(−1.06)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *t* statistics based on robust standard errors in parentheses. Obs. = 300.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

References

Abdulai, A., Owusu, V., & Goetz, R. (2011). Land tenure differences and investment in land improvement measures: Theoretical and empirical analyses. *Journal of Development Economics, 96*(1), 66–78. https://doi.org/10.1016/j.jdeveco.2010.08.002.

Angerer, J., Han, G., Fujisaki, I., & Havstad, K. (2008). Climate change and ecosystems of Asia with emphasis on Inner Mongolia and Mongolia. *Rangelands, 30*(3), 46–51. https://doi.org/10.2111/1551-501X(2008)30[46:CCAEOA]2.0.CO;2.

Banks, T. (2003). Property rights reform in rangeland China: Dilemmas on the road to the household ranch. *World Development, 31*(12), 2129–2142.

Banks, T., Richard, C., Ping, L., & Zhaoli, Y. (2003). Community-based grassland management in western China rationale, pilot project experience, and policy implications. *Mountain Research and Development, 23*(2), 132–140. https://doi.org/10.1659/0276-4741(2003)023[0132:CGMIWC]2.0.CO;2.

Behnke, R. (1994). Natural resource management in pastoral Africa. *Development and Policy Review, 12*(1), 5–28. https://doi.org/10.1111/j.1467-7679.1994.tb00053.x.

Bureau of Animal husbandry of Inner Mongolia (2000). *History of animal husbandry of Inner Mongolia.* Hohhot: People's publishing house of Inner Mongolia.

Bureau of Animal husbandry of Inner Mongolia (2015). *Report of the progress on privatizing grassland use rights of Inner Mongolia.* Hohhot: Bureau of Animal husbandry of Inner Mongolia.

China Animal Industry Yearbook (2014). *Editorial office of china animal industry yearbook.* Beijing: Agricultural publishing house of China.

China Meteorological Administration. Meteorological data. (2017). http://www.cma.gov.cn/ (Accessed 7 July 2017).

Coase, R. H. (1960). The problem of social cost. *Journal of Law and Economics, 56*, 837–877.

Conte, T. J., & Tilt, B. (2014). The effects of China's grassland contract policy on pastoralists' attitudes towards cooperation in an inner Mongolian banner. *Human*

Ecology, 42(6), 837–846.
Daun-Barnett, N. (2011). Community college baccalaureate: A fixed effects, multi-year study of the influence of state policy on nursing degree production. *Higher Education Policy, 24*(3), 377–398. https://doi.org/10.1057/hep.2011.10.
Deininger, K., & Jin, S. (2005). The potential of land rental markets in the process of economic development: Evidence from China. *Journal of Development Economics, 78*, 241–270. https://doi.org/10.1016/j.jdeveco.2004.08.002.
Deng, X., Huang, J., Huang, Q., Rozelle, S., & Gibson, J. (2011). Do roads lead to grassland degradation or restoration? A case study in Inner Mongolia, China. *Environment and Development Economics, 16*(6), 751–773. https://doi.org/10.1017/S1355770X11000180.
Fan, M., Li, Y., & Li, W. (2015). Solving one problem by creating a bigger one: The consequences of ecological resettlement for grassland restoration and poverty alleviation in Northwestern China. *Land Use Policy, 42*, 124–130. https://doi.org/10.1016/j.landusepol.2014.07.011.
FAO. Livestock and the environment. (2015). http://www.fao.org/livestock-environment/en/ (Accessed 7 July 2017).
Feeny, D., Berkes, F., McCay, B. J., & Acheson, J. M. (1990). The tragedy of the commons: Twenty-two years later. *Human Ecology, 18*(1), 1–19. https://doi.org/10.1007/BF00889070.
Feng, Y., Lu, Q., Tokola, T., Liu, H., & Wang, X. (2009). Assessment of grassland degradation in Guinan county, Qinghai Province, China, in the past 30 years. *Land Degradation & Development, 20*(1), 55–68. https://doi.org/10.1002/ldr.877.
Fergusson, D. M., Swain-Campbell, N. R., & Horwood, L. J. (2002). Deviant peer affiliations, crime and substance use: A fixed effects regression analysis. *Journal of Abnormal Child Psychology, 30*(4), 419–430. https://doi.org/10.1023/a:1015774125952.
Fernandez-Gimenez, M. E. (2002). Spatial and social boundaries and the paradox of pastoral land tenure: A case study from postsocialist Mongolia. *Human Ecology, 30*(1), 49–78. https://doi.org/10.1023/a:1014562913014.
Fernandez-Gimenez, M. E., & Le Febre, S. (2006). Mobility in pastoral systems: Dynamic flux or downward trend? *The International Journal of Sustainable Development and World Ecology, 13*(5), 341–362. https://doi.org/10.1080/13504500609469685.
Fernandez-Gimenez, M. E., Wang, X., Batkhishig, B., Klein, J. A., & Reid, R. S. (2012). *Restoring community connections to the land: Building resilience through community-based rangeland management in China and Mongolia.* Wallingford, UK: CABI Publishing.
Field, C. B. (2001). Sharing the garden. *Science, 294*(5551), 2490–2491. https://doi.org/10.1126/science.1066317.
Galvin, K. A. (2009). Transitions: Pastoralists living with change. *Annual Review of Anthropology, 38*, 185–198. https://doi.org/10.1146/annurev-anthro-091908-164442.
Gao, Q. Z., Wan, Y. F., Xu, H. M., Li, Y., Jiangcun, W. Z., & Borjigidai, A. (2010). Alpine grassland degradation index and its response to recent climate variability in Northern Tibet, China. *Quaternary International, 226*(1–2), 143–150. https://doi.org/10.1016/j.quaint.2009.10.035.
Gong, Z., Kawamura, K., Ishikawa, N., Goto, M., Wulan, T., Alateng, D., ... Ito, Y. (2015). MODIS normalized difference vegetation index (NDVI) and vegetation phenology dynamics in the Inner Mongolia grassland. *Solid Earth, 6*(4), 1185–1194. https://doi.org/10.5194/se-6-1185-2015.
Gu, Y., & Li, W. (2013). Research on the “grazing ban” policy's effect to grassland quality: Analysis on the scale of herdsman households. *Acta Scientiarum Naturalium Universitatis Pekinensis, 49*(2), 288–296.
Guelke, L. (2003). The tragedy of privatisation: Some environmental consequences of the Dutch invasion of KhoiKhoi South Africa. *South African Geographical Journal, 85*(2), 90–98. https://doi.org/10.1080/03736245.2003.9713788.
Guifu, C. H. E. N., & Hamori, S. (2009). Economic returns to schooling in urban China: OLS and the instrumental variables approach. *China Economic Review, 20*(2), 143–152.
Haberl, H. (1997). Human appropriation of net primary production as an environmental indicator: Implications for sustainable development. *Ambio,* 143–146.
Hardin, G. (1968). The tragedy of the commons. *Science, 162*(3859), 1243–1248.
Harris, R. B. (2010). Rangeland degradation on the Qinghai-Tibetan plateau: A review of the evidence of its magnitude and causes. *Journal of Arid Environments, 74*(1), 1–12. https://doi.org/10.1016/j.jaridenv.2009.06.014.
He, C., Tian, J., Gao, B., & Zhao, Y. (2015). Differentiating climate-and human-induced drivers of grassland degradation in the Liao River Basin, China. *Environmental Monitoring and Assessment, 187*(1), 4199. https://doi.org/10.1007/s10661-014-4199-2.
Ho, P. (1996). *Ownership and control in Chinese rangeland management since Mao: The case of free-riding in Ningxia.* Odi: Pastoral Development Network99–132.
Ho, P. (2000). The clash over state and collective property: The making of the rangeland law. *The China Quarterly, 161*, 240–263. https://doi.org/10.1017/S030574100000401X.
Ho, P. (2001). Rangeland degradation in North China revisited? A preliminary statistical analysis to validate non-equilibrium range ecology. *Journal of Development Studies, 37*(3), 99–133. https://doi.org/10.1080/00220380412331321991.
Hobbs, N. T., Galvin, K. A., Stokes, C. J., Lackett, J. M., Ash, A. J., Boone, R. B., ... Thornton, P. K. (2008). Fragmentation of rangelands: Implications for humans, animals, and landscapes. *Global Environmental Change, 18*(4), 776–785. https://doi.org/10.1016/j.gloenvcha.2008.07.011.
Hua, L., & Squires, V. R. (2015). Managing China's pastoral lands: Current problems and future prospects. *Land Use Policy, 43*, 129–137. https://doi.org/10.1016/j.landusepol.2014.11.004.
Huang, J., & Ding, J. (2016). Institutional innovation and policy support to facilitate small-scale farming transformation in China. *Agricultural Economics, 47*(S1), 227–237. https://doi.org/10.1111/agec.12309.
Huang, J., Gao, L., & Rozelle, S. (2012). The effect of off-farm employment on the decisions of households to rent out and rent in cultivated land in China. *China Agricultural Economic Review, 4*(1), 5–17.
Huang, Q., Rozelle, S., Lohmar, B., Huang, J., & Wang, J. (2006). Irrigation, agricultural performance and poverty reduction in China. *Food Policy, 31*(1), 30–52. https://doi.org/10.1016/j.foodpol.2005.06.004.
IFAD. Livestock and pastoralists. Livestock thematic papers tools for project design. (2009). http://www.ifad.org/lrkm/factsheet/Pastoralists.pdf (Accessed 7 July 2017).
Jiang, H. (2006). Decentralization, ecological construction, and the environment in post-reform China: Case study from Uxin Banner, Inner Mongolia. *World Development, 34*(11), 1907–1921. https://doi.org/10.1016/j.worlddev.2005.11.022.
Kousar, R., & Abdulai, A. (2016). Off-farm work, land tenancy contracts and investment in soil conservation measures in rural Pakistan. *Australian Journal of Agricultural and Resource Economics, 60*(2), 307–325. https://doi.org/10.1111/1467-8489.12125.
Kwon, H. Y., Nkonya, E., Johnson, T., Graw, V., Kato, E., & Kihiu, E. (2016). Global estimates of the impacts of grassland degradation on livestock productivity from 2001 to 2011. *Economics of land degradation and improvement – A global assessment for sustainable development* (pp. 197–214). Cham: Springer. https://doi.org/10.1007/978-3-319-19168-3.
Le, Q. B., Nkonya, E., & Mirzabaev, A. (2016). Biomass productivity-based mapping of global land degradation hotspots. *Economics of land degradation and improvement – A global assessment for sustainable development* (pp. 55–84). Cham: Springer.
Lesorogol, C. K. (2003). Transforming institutions among pastoralists: Inequality and land privatization. *American Anthropologist, 105*(3), 531–541. https://doi.org/10.1525/aa.2003.105.3.531.
Lesorogol, C. K. (2008). Land privatization and pastoralist well-being in Kenya. *Development and Change, 39*(2), 309–331. https://doi.org/10.1111/j.1467-7660.2007.00481.x.
Li, J. (2012). Land tenure change and sustainable management of alpine grasslands on the tibetan plateau: A case from hongyuan county, Sichuan province, China. *Nomadic Peoples, 16*(1), 36–49. https://doi.org/10.3167/np.2012.160105.
Li, S., Verburg, P. H., Lv, S., Wu, J., & Li, X. (2012). Spatial analysis of the driving factors of grassland degradation under conditions of climate change and intensive use in Inner Mongolia, China. *Regional Environmental Change, 12*(3), 461–474. https://doi.org/10.1007/s10113-011-0264-3.
Li, W., & Huntsinger, L. (2011). China's grassland contract policy and its impacts on herder ability to benefit in Inner Mongolia: Tragic feedbacks. *Ecology and Society, 16*(2).
Li, W., & Zhang, Q. (2009). *Interpretation the predicament on pastural area of China: Fosucing on the use and management issues for arid and semi-arid grassland.* Beijing: Economic Science Press.
Li, W. J., Ali, S. H., & Zhang, Q. (2007). Property rights and grassland degradation: A study of the Xilingol pasture, Inner Mongolia, China. *Journal of Environmental Management, 85*(2), 461–470. https://doi.org/10.1016/j.jenvman.2006.10.010.
Li, X. B., Li, R. H., Li, G. Q., Wang, H., Li, Z. F., Li, X., & Hou, X. Y. (2016). Human-induced vegetation degradation and response of soil nitrogen storage in typical steppes in Inner Mongolia, China. *Journal of Arid Environments, 124*, 80–90. https://doi.org/10.1016/j.jaridenv.2015.07.013.
Li, X. L., Gao, J., Brierley, G., Qiao, Y. M., Zhang, J., & Yang, Y. W. (2013). Rangeland degradation on the Qinghai-Tibet plateau: Implications for rehabilitation. *Land*

Degradation & Development, 24(1), 72–80. https://doi.org/10.1002/ldr.1108.
Li, Y., Gong, B., & Li, W. (2014). *A review of China's rangeland management policies.* London: IIED Country Report.
Liao, Z. (2009). The changes in price of production factors, technology development and grassland tenure. *Issues in Agricultural Economy, 4*, 64–69. https://doi.org/10.13246/j.cnki.iae.2009.04.012.
Lin, J. Y. (1992). Rural reforms and agricultural growth in China. *The American Economic Review, 82*(1), 34–51.
Lin, L., Li, Y. K., Xu, X. L., Zhang, F. W., Du, Y. G., Liu, S. L., ... Cao, G. M. (2015). Predicting parameters of degradation succession processes of Tibetan Kobresia grasslands. *Solid Earth, 6*(4), 1237–1246. https://doi.org/10.5194/se-6-1237-2015.
Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3–4), 282–292. https://doi.org/10.1016/j.agee.2010.05.013.
Little, P. (1992). *The elusive granary: Herder, farmer and state in northern Kenya.* Cambridge, UK: Cambridge University Press.
Liu, J., & Diamond, J. (2005). China's environment in a globalizing world. *Nature, 435*(7046), 1179. https://doi.org/10.1038/4351179a.
Liu, M., Dries, L., Heijman, W., Huang, J., Zhu, X., Hu, Y., & Chen, H. (2018). The impact of ecological construction programs on grassland conservation in Inner Mongolia, China. *Land Degradation & Development, 29*(2), 326–336. https://doi.org/10.1002/ldr.2692.
Liu, M., Huang, J., Dries, L., Heijman, W., & Zhu, X. (2017). How does land tenure reform impact upon pastoral livestock production? An empirical study for Inner Mongolia, China. *China Economic Review*. https://doi.org/10.1016/j.chieco.2017.09.009.
Lu, X., Yan, Y., Sun, J., Zhang, X., Chen, Y., Wang, X., & Cheng, G. (2015). Short-term grazing exclusion has no impact on soil properties and nutrients of degraded alpine grassland in Tibet, China. *Solid Earth, 6*(4), 1195–1205. https://doi.org/10.5194/se-6-1195-2015.
McCarthy, N., & Di Gregorio, M. (2007). Climate variability and flexibility in resource access: The case of pastoral mobility in Northern Kenya. *Environment and Development Economics, 12*(3), 403–421. https://doi.org/10.1017/s1355770x07003609.
McEvoy, A. F. (1987). Toward an interactive theory of nature and culture: Ecology, production, and cognition in the California fishing industry. *Environmental Review: ER, 11*(4), 289–305. https://doi.org/10.2307/3984137.
Mei, H., Zhang, G., Gan, X., Ranlong, L., & Han, G. (2013). Carbon and nitrogen storage and loss as affected by grassland degradation in Inner Mongolia. *Journal of Food, Agriculture and Environment, 1*, 2071–2076.
Meng, L., & Gao, H. (2002). *The status of grassland degradation of China and the strategies for grassland conservation.* Paper presented at the 6th Chinese International Rangeland Congress, Beijing.
Meyer, N. (2006). Desertification and restoration of grasslands in Inner Mongolia. *Journal of Forestry, 104*(6), 328–331.
Ministry of Agriculture of China. China national grassland monitoring report of 2014. (2015). http://www.moa.gov.cn/zwllm/jcyj/zh/201504/t20150414_4526567.htm/ (Accessed 19 May 2016).
National People's Congress of the People's Republic of China (2002). *The grassland law of the People's Republic of China.* Beijing.
Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action.* Cambridge: Cambridge University Press.
Ostrom, E. (2008). *Tragedy of the commons. The new palgrave dictionary of economics.* 3573–3576.
Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*(5939), 419–422. https://doi.org/10.1126/science.1172133.
Resources and Environment Scientific Data Center. Land use data. (2010). http://www.resdc.cn/data.aspx?DATAID=99/ (Accessed 7 July 2017).
Richard, C., Yan, Z., & Du, G. (2006). *The paradox of the individual household responsibility system in the grasslands of the Tibetan Plateau, China.* Paper presented at the Rangelands of Central Asia: Proceedings of the Conference on Transformations, Issues, and Future Challenges. Salt Lake City, UT.
Sneath, D. (1998). State policy and pasture degradation in Inner Asia. *Science, 281*, 1147–1148. https://doi.org/10.1126/science.281.5380.1147.
Squires, V. R., Lu, X. S., Lu, Q., Wang, T., & Yang, Y. L. (2009). *Rangeland degradation and recovery in China's pastoral lands.* Wallingford, UK: Cambridge University Press.
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & De Haan, C. (2006). *Livestock's long shadow: Environmental issues and options.* Rome: United Nations Food and Agriculture Organization.
Taylor, J. L. (2006). Negotiating the grassland: The policy of pasture enclosures and contested resource use in Inner Mongolia. *Human Organization,* 374–386. https://doi.org/10.17730/humo.65.4.43nlykfuchg1cbk8.
Tessema, W. K., Ingenbleek, P. T., & van Trijp, H. C. (2014). Pastoralism, sustainability, and marketing. A review. *Agronomy for Sustainable Development, 34*(1), 75–92. https://doi.org/10.1007/s13593-013-0167-4.
Tiffen, M., Mortimore, M., & Gichuki, F. (1994). *More people less erosion: Environmental recovery in Kenya.* Nairobi, Kenya: ACTS Press.
Tu, Q., Mol, A. P., Zhang, L., & Ruben, R. (2011). How do trust and property security influence household contributions to public goods?: The case of the sloping land conversion program in China. *China Economic Review, 22*(4), 499–511.
Turner, M. D. (1999). The role of social networks, indefinite boundaries and political bargaining in maintaining the ecological and economic resilience of the transhumance Systems of Sudano-Sahelian West Africa. In M. Niamir-Fuller (Ed.). *Managing mobility in African rangelands: The legitimization of transhumance.* London: Intermediate Technology Publications Ltd.
Unkovich, M., & Nan, Z. (2008). Problems and prospects of grassland agroecosystems in western China. *Agriculture, Ecosystems & Environment, 124*(1–2), https://doi.org/10.1016/j.agee.2007.08.012.
Verbeek, M. (2012). *Models based on panel data: A guide to modern econometrics* (4 ed.). United Kingdom: John Wiley and Sons Ltd.
Vetter, S. (2005). Rangelands at equilibrium and non-equilibrium: Recent developments in the debate. *Journal of Arid Environments, 62*(2), 321–341. https://doi.org/10.1016/j.jaridenv.2004.11.015.
Waldron, S., Brown, C., & Longworth, J. (2010). Grassland degradation and livelihoods in China's western pastoral region: A framework for understanding and refining China's recent policy responses. *China Agricultural Economic Review, 2*(3), 298–320. https://doi.org/10.1108/17561371011078435.
Wang, F., Pan, X., Wang, D., Shen, C., & Lu, Q. (2013). Combating desertification in China: Past, present and future. *Land Use Policy, 31*, 311–313. https://doi.org/10.1016/j.landusepol.2012.07.010.
Wang, J., Brown, D. G., & Agrawal, A. (2013). Climate adaptation, local institutions, and rural livelihoods: A comparative study of herder communities in Mongolia and Inner Mongolia, China. *Global Environmental Change, 23*(6), 1673–1683. https://doi.org/10.1016/j.gloenvcha.2013.08.014.
Wang, X., Xie, Z., Zhang, X., & Huang, Y. (2018). Roads to innovation: Firm-level evidence from People's Republic of China (PRC). *China Economic Review, 49*, 154–170.
Wang, Z., Deng, X., Song, W., Li, Z., & Chen, J. (2017). What is the main cause of grassland degradation? A case study of grassland ecosystem service in the middle-South Inner Mongolia. *Catena, 150*, 100–107. https://doi.org/10.1016/j.catena.2016.11.014.
Wiesmair, M., Feilhauer, H., Magiera, A., Otte, A., & Waldhardt, R. (2016). Estimating vegetation cover from high-resolution satellite data to assess grassland degradation in the Georgian Caucasus. *Mountain Research and Development, 36*(1), 56–65. https://doi.org/10.1659/MRD-JOURNAL-D-15-00064.1.
Wu, J., Zhang, Q., Li, A., & Liang, C. (2015). Historical landscape dynamics of Inner Mongolia: Patterns, drivers, and impacts. *Landscape Ecology, 30*(9), 1579–1598. https://doi.org/10.1007/s10980-015-0209-1.
Yang, D., Zhang, Y., Wu, Y., Wang, D., & Bao, C. (2004). The problems and sustainable development of pratacultural industry in Hulunbeier. *Grassland and Turf (Quarterly), 1*, 14–16.
Yang, Y., Wang, Z., Li, J., Gang, C., Zhang, Y., Zhang, Y., ... Qi, J. (2016). Comparative assessment of grassland degradation dynamics in response to climate variation and human activities in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013. *Journal of Arid Environments, 135*, 164–172. https://doi.org/10.1016/j.jaridenv.2016.09.004.
Ybarra, M. (2009). Violent visions of an ownership society: The land administration project in Peten, Guatemala. *Land Use Policy, 26*(1), 44–54. https://doi.org/10.1016/j.landusepol.2008.01.001.
Yu, L., & Farrell, K. N. (2013). Individualized pastureland use: Responses of herders to institutional arrangements in pastoral China. *Human Ecology, 41*(5), 759–771. https://doi.org/10.1007/s10745-013-9580-1.
Zhang, K., Yu, Z., Li, X., Zhou, W., & Zhang, D. (2007). Land use change and land degradation in China from 1991 to 2001. *Land Degradation & Development, 18*(2), 209–219. https://doi.org/10.1002/ldr.757.
Zhou, G., Wang, Y., & Wang, S. (2002). Responses of grassland ecosystems to precipitation and land use along the Northeast China transect. *Journal of Vegetation Science, 13*(3), 361–368. https://doi.org/10.1111/j.1654-1103.2002.tb02060.x.