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How does land tenure reform impact upon pastoral livestock production? An empirical study for Inner Mongolia, China

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ABSTRACT

This paper investigates how land tenure reform has affected livestock production in the pastoral areas of China. County-level data for Inner Mongolia between 1985 and 2008 are used in a fixed effects model to disentangle the effects of land tenure reform on livestock production from factors related to market forces, grassland condition, technological development and environmental heterogeneity. The results show that the implementation of the land tenure reform slowed down the increase in livestock production, although it did not completely stop this increase. It therefore appears that land reform is in itself unable to offset the impact of other factors that accelerate the increase in livestock production. Moreover, the constraining effect of the land tenure reform on the increase in livestock production decreases over time, and ultimately disappears. Finally, the constraining effect of the land tenure reform was shown to be stronger on the increase of the livestock population than on that of meat output. This indicates that the land tenure reform has helped to improve livestock productivity.

1. Introduction

Land tenure reform in China is characterised by assigning long-term land use rights to individual households, involving cropland, grassland, and forest land (see e.g. Banks, 2003; Hu, 1997; Zhang et al., 2012a). According to the current Law of the People's Republic of China on the Contracting of Rural Land, use rights of grassland are contracted to individual households for a duration of 30–50 years. At the end of the 1970s, land tenure reform was first implemented through the Household Production Responsibility System in the crop farming areas of China and was completed rapidly and successfully. Research showed that the assignment of individual cropland use rights gave farmer the incentive of improved agricultural production and spurred the marketing of agricultural goods (see e.g. Banks, 2003; Ho, 1996; Hu, 1997; Krusekopf, 2002). Based on this outcome, the central government of China continued land tenure reform in pastoral areas in the early 1980s and assigned grassland use rights as well as livestock property rights that had been owned by the communes to individual households. However, the assignment of grassland use rights has not been completed as successfully as that of cropland in China (Liu et al., 2017a). For instance, compared with the cropland in China, where household-based use rights were assigned overnight, the assignment of grassland use rights is still incomplete despite efforts for 30 years. By 2014, around 84% of grasslands had been allocated to individual households in China, and the central government continues to emphasise the need for clarifying grassland use rights for individual households (Ministry of Agriculture of China, 2015).

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In practice, in some areas of Inner Mongolia, only the grasslands for mowing forages have been allocated to individual households while the grazing grasslands are still owned and used by all of the local households (Li et al., 2007). Scholars (e.g. Li, 2012; Li and Zhang, 2009; Richard et al., 2006) have identified a number of possible barriers to the completion of the land tenure reform in the pastoral areas of China. This paper will explore possible reasons by focussing on the aspect of pastoral livestock production.

Land tenure has been the concern of academia for a long time (Harris, 1953; Perz et al., 2017). The privatisation of grassland property rights or use rights has been regarded as a panacea to avoid overgrazing and protect the grassland ecosystem, in order to avoid the situation termed 'the tragedy of the commons' (Hardin, 1968; McEvoy, 1987; Ybarra, 2009). Coase (1960) theorem stipulated that a clear assignment of property rights is a precondition for economically efficient resource allocation. The followers of the 'tragedy of the commons' and property rights theories advocate that the grassland resource should be either privatised or maintained as common land while clearly assigning rights of entry and use to promote the sustainable use of grassland through exclusiveness. Following this conventional wisdom, most governments in the world have assigned grassland property rights or use rights in an attempt to ensure the sustainable development of grasslands (Bański, 2017; Li et al., 2014). In line with observations about the effects of privatisation of cropland, the central government of China believes that the assignment of private grassland use rights provides land users with incentives to graze animals within the carrying capacity of the land, as well as to increase land investment in order to conserve their own grasslands (Banks, 2003).

However, the findings on the effects of privatizing grassland resources are complex (e.g. see Li and Zhang, 2009; Liu et al., 2017a). During recent years, some scholars have expressed concern about the replacement of the traditional common-use system and nomadism by private use and settlement due to grassland privatisation (Banks et al., 2003; Li and Zhang, 2009). This transformation of traditional pastoralism has impeded mobility and flexible grazing (Fernandez-Gimenez, 2000; Wang et al., 2013) and limited herders' access to emergency pastures and other key productive resources (Fernandez-Gimenez, 2002; Niamir-Fuller and Turner, 1999). This, in turn, has increased feeding costs and reduced herders' ability to withstand natural risks (e.g. Li et al., 2007), causing constraints on the development of animal husbandry in pastoral areas. Some voices have also stated that grassland privatisation reduces the amount of land available for livestock grazing, further leading to a reduction in the number of livestock that an individual can potentially own, ultimately resulting in poverty (Mwangi, 2007). In addition, research has shown that the carrying capacity of grassland is reduced due to decreased access to heterogeneous landscapes (Boone et al., 2005; Boone and Hobbs, 2004; Hobbs et al., 2008). As such, the total population of livestock that could be supported by a grassland ecosystem is predicted to decline as a result of the spatial and social boundaries stemming from privatisation.

In fact, much of the growth in animal supply has been coming from rapidly expanding intensive breeding systems rather than through traditional grazing systems in pastoral areas (FAO, 2015). Similarly, the main production areas for livestock products in China have experienced a geographic shift from pastoral areas to crop farming areas (Li et al., 2008). The market share of livestock products from grazing systems is decreasing compared to that of crop-livestock mixed or industrialised systems (Squires et al., 2009; Wang et al., 2016). This trend is suggested to be attributed to the reduction in grass yields due to grassland degradation, and raises environmental concern about the ecosystem of permanent grassland (Li et al., 2008; Liu et al., 2017b; Squires et al., 2009). Besides these possible factors, we wish to ascertain whether the privatisation of grasslands has played a role in the changes in livestock production of pastoral areas. Despite an abundance of academic arguments and government reports on the results of the privatisation of grassland, there is a lack of quantitative studies, especially based on large-scale areas and long-term observations (e.g. Conte, 2015; Li and Huntsinger, 2011; Yu and Farrell, 2013). Moreover, the existing literature is short of empirical analysis targeting the impact of grassland privatisation on livestock production, although some studies are concerned with ecological effects. Nevertheless, animal husbandry provides livelihoods to millions of people in pastoral areas and has the potential capacity to meet the rapidly increasing global demand for livestock products which is stimulated by growing populations, urbanisation and rising disposable incomes (FAO, 2015). In this regard, livestock production in pastoral areas is an issue of high societal relevance and one which deserves being paid close attention to.

In the following section, we first describe the land tenure reform and the current livestock production in the research region. Next, in Section 3, the data collection method is explained and a descriptive analysis based on the collected data is used to elaborate on the changes in livestock production in the pastoral areas compared to crop farming areas. In Sections 4 and 5, we present the empirical model used in the study and the estimation results. In Section 6, we discuss the model results and their underlying reasons. We conclude this paper with some final observations on the effects of grassland privatisation on livestock production in pastoral areas.

1.1. Research region

China has around 400 million hectares of grassland, accounting for nearly 40% of its total territory, this being the second largest area of grassland in the world after Australia (Hua and Squires, 2015). Inner Mongolia, a province[1] located in the arid and semi-arid areas of northern China, has 118.3 million hectares of land; in 2014, its permanent population was 25 million. It accounts for 21.7% of China's permanent area of grasslands. Approximately 67% of the total land area in Inner Mongolia is classified as grassland, the majority of which can be sub-classified as temperate grassland (Angerer et al., 2008). Inner Mongolia plays an important role in the supply of animal products as well as in the ecosystem of China due to its extensive grasslands. In the pastoral areas populated by Mongolians, the vast majority of local people maintain their livelihoods through grazing their livestock on the grasslands (Angerer et al., 2008). Inner Mongolia was one of the first regions in which land tenure reform was implemented on grasslands in China

[1] The full name is Inner Mongolia Autonomous Region.

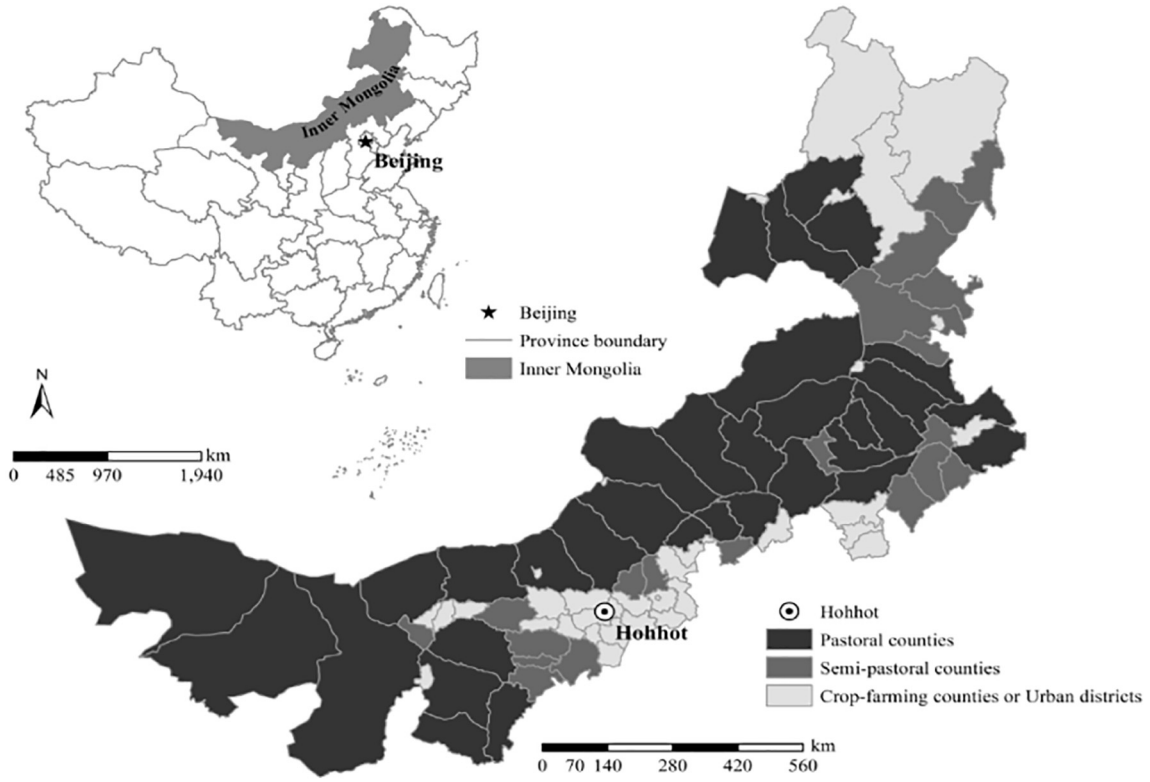

Fig. 1. Inner Mongolia and its 102 counties.

because of its crucial position in China's grassland resource and livestock production (Li and Huntsinger, 2011).

According to the current administrative divisions of Inner Mongolia, there are 102 counties, including 33 pastoral counties and 21 semi-pastoral counties. The remaining 48 counties are dominated by crop farming or urban districts. Pastoral counties are characterised by traditional grazing systems and permanent grassland is the dominant land type. In semi-pastoral counties, both permanent grassland and cropland are the dominant land types. Mixed crop-livestock systems also exist, where intensive animal husbandry and cropping both occur (Waldron et al., 2010). The majority of the pastoral areas of Inner Mongolia are found in the pastoral counties as well as semi-pastoral counties. Fig. 1 presents the location of Inner Mongolia in China and its three types of counties.

1.2. Land tenure reform in the pastoral areas of Inner Mongolia

Land tenure reform started in Inner Mongolia with the Double Contracts System (Cao Xu Shuang Cheng Bao) in 1982. This system aimed at assigning to individual households the livestock and grasslands that were managed by the communes during the collectivist period of China. Meanwhile, the users (individual households) of the grasslands are regulated in order to control their livestock numbers according to a determinant stocking rate with the aim of avoiding overuse of grasslands (Ho, 2000). The assignment of property rights over livestock was completed promptly but grasslands were not strictly assigned to individual households in the majority of the pastoral areas in the 1980s. Particularly, the use of grasslands merely indicated a rough direction and position to herders, but local herders and their animals still roamed wherever they preferred. Hinton (1990) called this phenomenon privately controlled stock of animals on publicly owned lands in Inner Mongolia. The result was an uncontrolled scramble for wherever forage existed, which amounted to a general attack on a range of vegetation (Hu, 1997). Subsequently, the assignment of grassland use rights to individual households 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 and Zhang, 2009). This stimulated the progress of grassland privatisation greatly and is regarded as the second round of land tenure reform in the pastoral areas of Inner Mongolia (Yang, 2007). In recent years, growing attention has been paid to ensure the long-term stability of grassland use rights to individual households, such as confirming grassland plots, areas and contracts (Li, 2012). In 2015, local governments in Inner Mongolia are still working on clarifying the boundaries of grassland use rights for each household and issuing certificates (Bureau of Animal husbandry of Inner Mongolia, 2015).

Compared with crop farming areas, the implementation of the land tenure reform on grasslands is relatively complex and has taken a long time. More specifically, the grasslands have been subject to several different types of ownership (Yu and Farrell, 2013) and correspondingly, various types of land use have arisen since the start of the land tenure reform in Inner Mongolia. Table 1 provides a typology of the land tenure reform in terms of formal use rights and actual types of grassland use. This typology is consistent with that of the Tibetan plateau by Banks et al. (2003).

Table 1
Typology of land tenure reform on grasslands of Inner Mongolia.
Adapted from "formal and de facto grassland management units" (Banks et al., 2003).

Formal use rights owned by	Actual grassland use		
	Private use	Joint use	Common use
Individual households	+	+	+
A group of households	na	+	+
Collective/administrative village	na	na	+

na = indicates not available.

As presented in Table 1, with the implementation of land tenure reform, three types of ownership of formal grassland use rights have arisen, namely individual household ownership, ownership by a group of households and collective ownership. There are also three types of actual grassland use, these being private use by individual households, joint use by a group of households and common use by all of the villagers. When formal use rights are owned by an administrative or natural village, the only type of grassland use is common use. This arose primarily before or at the beginning of the implementation of the land tenure reform when the grassland rights had not yet been assigned. If the formal use rights are owned by a group of households, the land use is either common or joint. This situation mostly occurs in areas where the grassland resource is too scarce to be assigned to individual households, or where grassland use rights have not been assigned to individual households. Private use, joint use and common use exist simultaneously when the formal use rights are owned by individual households. The intention of the land tenure reform in the pastoral areas, however, is to achieve full private use when use rights are assigned to households. This reflects the gap between the household-based assignment of formal use rights and the actual adoption of private use. In practice, the specific timing and extent of conducting the land tenure reform,[2] including the changes in formal use rights and use patterns, differed among counties in Inner Mongolia.

1.3. Livestock production in Inner Mongolia

Inner Mongolia is one of the main production regions for animal products in China. In 2013, it accounted for 18% of the population of sheep[3] of China, ranking first out of all Chinese provinces. The mutton output accounted for 22% of the total mutton output in China. Six per cent of cattle were raised in Inner Mongolia, and 8% of China's total beef output was produced there, in both cases ranking second in China. Figs. 2 to 4 present the livestock production of Inner Mongolia from 1979 to 2013, based on data from the China Statistical Yearbook (Zhong Guo Tong Ji Nian Jian). Livestock production is interpreted by the livestock population and meat output. Sheep and cattle are the dominant animals being raised in Inner Mongolia (Zhang et al., 2012b). We therefore employ the population of sheep and cattle to represent the livestock population, and the outputs of mutton and beef for meat output.

Fig. 2 shows that the population of sheep decreased from 1982 to 1984 and then generally presented an increasing trend until 1999, apart from a decrease during 1991–1993. It experienced a sharp increase from 2001 to 2004 after a decrease from 1999 to 2001, and remained relatively steady between 2005 and 2013. The population of cattle saw slight fluctuations but remained almost unchanged between 1979 and 2000. It reached the lowest point in 2001 after a slight decrease from 1999 and then experienced an increase between 2002 and 2010, followed by a slight decrease until 2013.

Fig. 3 depicts Inner Mongolia's mutton and beef outputs from 1979 to 2013. Until 2002, the outputs of mutton and beef experienced fluctuating and slow increases. The output of mutton and beef increased sharply between 2002 and 2005, after which the output of mutton remained relatively steady, while beef continued to increase slightly between 2006 and 2013. In general, mutton output exceeded beef output during the whole period. Mutton output in 2013 was around 14 times higher than in 1979, while beef output was 19 times higher in 2013 than in 1979.

Fig. 4 illustrates the development of livestock productivity in Inner Mongolia from 1979 to 2013. The livestock productivity for both sheep and cattle has increased. The increase of productivity for cattle experienced obvious fluctuations, while the productivity for sheep saw a slight and steady increase.

Although livestock population, meat output and livestock productivity have generally increased in Inner Mongolia over time, the importance and competitiveness of its livestock production within China have been threatened by Henan and Shandong provinces, which are the dominant crop farming areas of China where intensive animal husbandry systems have developed in recent years (Su, 2010). Furthermore, a number of ecological projects for grassland conservation and the promotion of non-farming industries have been introduced in Inner Mongolia and have impacted upon the development of animal husbandry in the region (Squires et al., 2009). As a result, the share represented by animal husbandry in the gross domestic product of Inner Mongolia has decreased. Moreover, since 2001, the provincial government of Inner Mongolia has laid emphasis on the development of livestock production in its crop farming areas instead of in the pastoral areas. In 2007, 70% of livestock production in Inner Mongolia was located in crop farming areas (Su, 2010). This geographic shift from pastoral areas to the crop farming areas is discussed in the following section.

[2] In the remainder of the paper, the term land tenure reform refers to the assignment of the grassland use rights to individual households.
[3] The term 'sheep' in this paper includes both sheep and goats, in accordance with the China Statistical Yearbook.

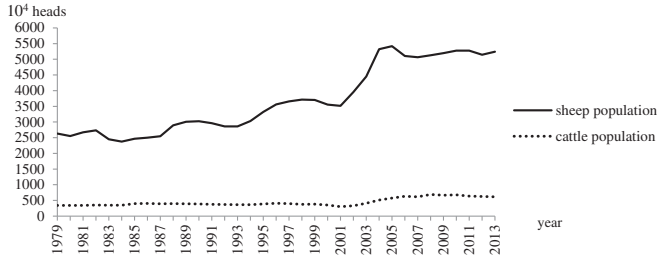

Fig. 2. Livestock population of Inner Mongolian from 1979 to 2013.

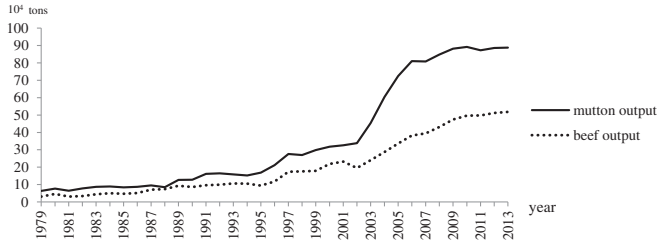

Fig. 3. Mutton and beef outputs of Inner Mongolia from 1979 to 2013.

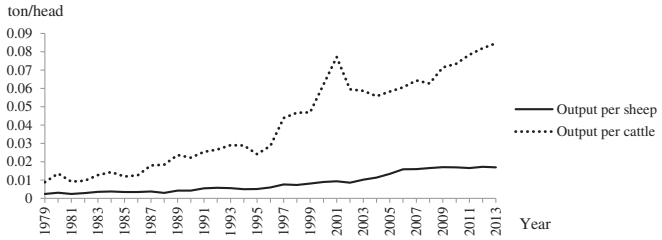

Fig. 4. Livestock productivity of Inner Mongolia from 1979 to 2013.

2. Data description

2.1. Data collection

We aim to estimate the impact of land tenure reform on pastoral livestock production. The pastoral areas are therefore distinguished from the crop farming areas for the purposes of data collection. Given that the timing and extent of the implementation of land tenure reform differed between counties, our empirical study of the effects of the reform on livestock production is conducted based on county-level data.

First, the data on land tenure reform was collected via questionnaires in each county in Inner Mongolia. Based on the typology shown in Table 1, the questionnaire focused on when formal use rights were owned by collectives, groups and individual households respectively, and when grassland was actually in common use, joint use or private use. Questionnaires were sent to the Animal Husbandry Bureau of each county and were answered by key informants on local land tenure reform. Interviews were conducted by telephone to confirm the answers after receiving feedback from each county. We ultimately obtained valid feedback from 74 out of 102 counties. In addition, we conducted interviews with the officers who are working in the provincial institutes of Animal Husbandry of Inner Mongolia as well as with local herders to verify the progress of land tenure reform on local grasslands. Second, information about grassland conditions was obtained based on remote sensing and an analysis of Geographic Information Systems. This relies on a database developed by the Chinese Academy of Sciences with original data from Landsat Thematic Mapper/Enhanced Thematic Mapper (Plus) (TM/ETM +) images (Deng et al., 2011). GIS satellite images were only collected in 1985, 1995, 2000, 2005 and 2008. We therefore use the average growth rate of grassland areas between the years of observation to estimate the grassland condition for each year. Third, the data on socio-economic indicators is based on existing statistical data collected by local governments. Specifically, the data about livestock production was gathered from the Statistical Yearbooks of Inner Mongolia. Market forces are represented by the real producer price of mutton and beef. This information was collected based on the Annual Compilation of Cost-benefit Data of Chinese Agricultural products (Zhong Guo Nong Chan Pin Cheng Ben Shou Yi Hui Bian) and deflated by a producer price index. Specific data on technological development is lacking, and is thus proxied by a time variable. The factor of environmental heterogeneity among counties is removed by the fixed effects model as a time-invariant variable.

The research period covers 1985–2008, which includes the main period when land tenure reform was implemented on the

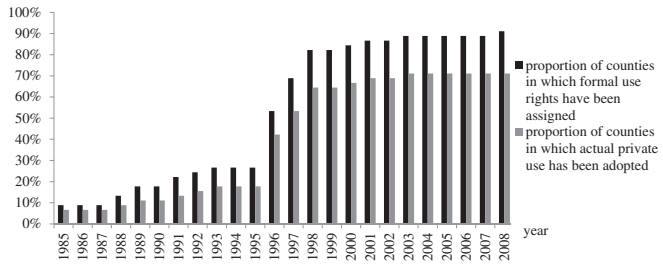

Fig. 5. Progress of the land tenure reform in the pastoral areas of Inner Mongolia from 1985 to 2008.

grasslands of Inner Mongolia. To be more specific, the land tenure reform started around 1982. By 2008, most of the grasslands were assigned to individual households in Inner Mongolia. In recent years, i.e. after 2008, livestock production in the grassland areas has mainly been affected by Ecological Construction Programs instead of the land tenure reform. After excluding the urbanised counties and counties that underwent changes in administrative regions during the research period, 60 counties are retained in the research sample. They include 27 pastoral counties, 18 semi-pastoral counties and 15 crop farming counties. The following descriptive analysis presents the relative changes in livestock production between crop farming areas (crop farming counties) and pastoral areas (pastoral and semi-pastoral counties).

2.2. Descriptive analysis

Based on the collected data, we first illustrate the progress of the land tenure reform[4] in the pastoral areas of Inner Mongolia from 1985 to 2008. In Fig. 5, the proportion of counties in which formal use rights were assigned to households increased from 9% in 1985 to 91% in 2008; the proportion of counties that adopted actual private use rose from 7% in 1985 to 71% in 2008. A sharp increase in formal and actual use rights adoption is observed between 1995 and 1998. This is consistent with the second round of land tenure reform implemented in this period. It can be seen that the adoption of actual private use lagged behind the assignment of formal use rights; neither were fully completed until 2008.

Figs. 6, 7 and 8 demonstrate the changes in livestock production and productivity of the pastoral areas relative to the crop farming areas from 1985 to 2008. The changes are represented as an index where the level in 1985 is set equal to 100. Fig. 6 indicates that both sheep population and mutton output increased in pastoral areas as well as in crop farming areas from 1985 to 2008, and that the increase of sheep population was slower than that of mutton output, especially after 1995. In addition, after 2001, the growth rate of the sheep population in crop farming areas significantly exceeded that in pastoral areas. And the growth rate of mutton output of crop farming areas greatly exceeded that of pastoral areas from 1999 onwards. Nevertheless, there was a clear decline in the sheep population and mutton output in crop farming areas after 2005.

Fig. 7 shows that the cattle population increased slightly compared with 1985, and that the output of beef has increased significantly in both pastoral and crop farming areas over the past 24 years. The increase of beef output was more obvious than that of cattle population. Moreover, the growth rate of the cattle population in pastoral areas was exceeded by that in crop farming areas from 2001 onwards. Also, the growth rate of the beef output in pastoral areas was exceeded by the beef output in crop farming areas after 2000.

Fig. 8 compares the development of livestock productivity between pastoral and crop farming areas from 1985 to 2008. This shows that the output per sheep in pastoral areas was higher than that of crop farming areas between 2003 and 2008, with the exception of 2007. The increment of output per cattle in pastoral areas was larger than that of crop farming areas since 1999. The development of output per cattle was faster than per sheep in both areas.

In short, land tenure reform was implemented progressively in the pastoral areas in the period 1985–2008. Meanwhile, it appears that the increase of livestock production was faster in crop farming areas than in pastoral areas, but conversely the development of livestock productivity was slower in crop farming areas. It can be seen that the competitiveness of animal husbandry in pastoral areas has been threatened by crop farming areas in recent decades as the livestock population and meat output has grown faster in crop farming areas since around 2000. This is consistent with the fact that in China, the main producing areas of livestock products have experienced an adjustment, moving from a grazing system to a crop-livestock mixed system and from pastoral areas to crop farming areas (Li et al., 2008). Interestingly, the development of livestock productivity was faster in pastoral areas than in crop farming areas, which may be attributed to the transformation of traditional pastoralism in the pastoral areas of Inner Mongolia. As such, we hypothesize that land tenure reform constrained the increase of livestock production, but spurred the development of livestock productivity of pastoral areas. We will test this hypothesis with an empirical model based on the data from 45 sample counties of pastoral areas in Inner Mongolia.

[4] Considering that some counties did not complete the land tenure reform fully, we denote a county as having implemented the land tenure reform if at least 50% of the grassland area of this county has been assigned to individual households.

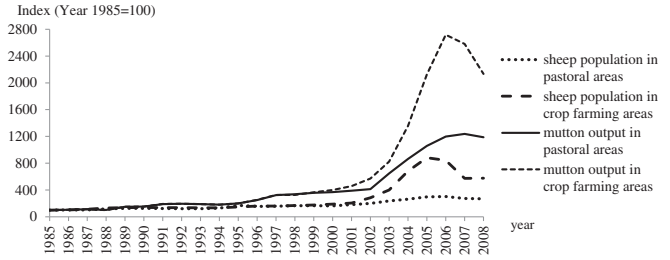

Fig. 6. Comparison of sheep population and mutton output between pastoral and crop farming areas of Inner Mongolia from 1985 to 2008.

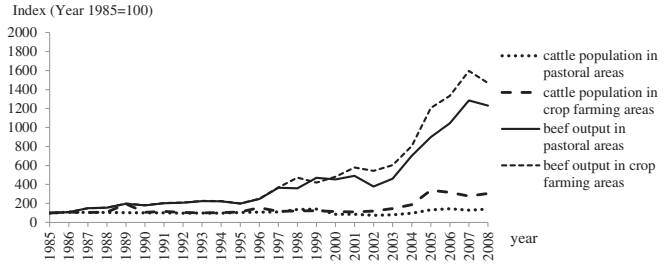

Fig. 7. Comparison of cattle population and beef output between pastoral and crop farming areas of Inner Mongolia from 1985 to 2008.

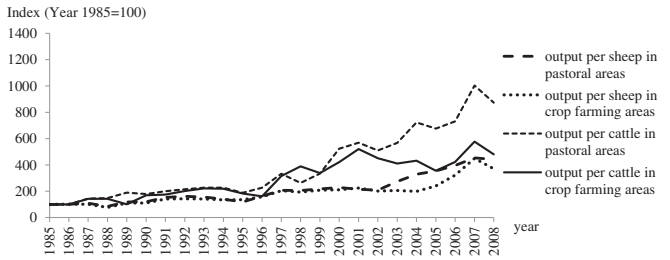

Fig. 8. Comparison of livestock productivity between pastoral and crop farming areas of Inner Mongolia from 1985 to 2008.

3. Empirical model

A fixed effects model is widely used in economic research, primarily to study the causes of changes within entities over time (e.g., Fergusson et al., 2002; Huang et al., 2006). The model employs within transformation to remove all time-invariant (fixed) explanatory variables, i.e. the model is performed in deviations from individual means (Verbeek, 2012). As such, the fixed effects model provides a method that takes observable as well as unobservable time-invariant explanatory variables into account, but the estimation is not dependent on the value of time-invariant (fixed) variables (Verbeek, 2012). Such an approach is appropriate in this study considering that the results of land tenure reform within each county over time can be studied effectively by controlling for the unmeasured heterogeneity among counties. On the other hand, the land tenure reform we are interested in shows changes in value across our research period for a substantial proportion of counties in our data (see Fig. 5), which satisfies the basic requirement of the fixed effects model (Daun-Barnett, 2011). In addition, our research sample attempts to include all counties in the pastoral areas of Inner Mongolia, rather than random draws, which preliminarily indicates that a fixed effects model is more appropriate than a random effects model (Verbeek, 2012).

Based on the theoretical framework of the fixed effects model, we formulate the following empirical model for estimating the effects of the land tenure reform and other potential factors on livestock production:

$$log(S_{it}) = s_i + a_1 log(R_{it-1} + 0.01) + a_2(1/(R_{it-1} + 0.01)) + a_3 log(M_{it-1}) + a_4 log(T_{it-1}) + a_5 log(G_{it-1}) + a_6 Y_t + a_7 P_i^* Y_t + \varepsilon_{it} \quad (1)$$

$$log(C_{it}) = g_i + b_1 log(R_{it-1} + 0.01) + b_2(1/(R_{it-1} + 0.01)) + b_3 log(B_{it-1}) + b_4 log(T_{it-1}) + b_5 log(G_{it-1}) + b_6 Y_t + b_7 P_i^* Y_t + \mu_{it} \quad (2)$$

$$log(U_{it}) = u_i + c_1 log(R_{it-1} + 0.01) + c_2(1/(R_{it-1} + 0.01)) + c_3 log(M_{it-1}) + c_4 log(T_{it-1}) + c_5 log(G_{it-1}) + c_6 Y_t + c_7 P_i^* Y_t + \lambda_{it} \quad (3)$$

$$log(F_{it}) = f_i + d_1 log(R_{it-1} + 0.01) + d_2(1/(R_{it-1} + 0.01)) + d_3 log(B_{it-1}) + d_4 log(T_{it-1}) + d_5 log(G_{it-1}) + d_6 Y_t + d_7 P_i^* Y_t + \delta_{it} \quad (4)$$

where i and t present the ith county and year t. Variables are defined in Table 2 and summary statistics are provided.

Table 2
Definition of variables and summary statistics[a].

Variable	Variable definition	Unit	Observations	Mean	Std. dev.	Min	Max
S_{it}	Ratio of sheep population of county i in year t over that in 1985	na	1080	1.73	1.74	0.20[b]	23.12
C_{it}	Ratio of cattle population of county i in year t over that in 1985	na	1080	1.08	0.89	0.12	18.68
U_{it}	Ratio of mutton output of county i in year t over that in 1985	na	1080	4.29	6.47	0.60	68.90
F_{it}	Ratio of beef output of county i in year t over that in 1985	na	1080	4.30	5.93	0.14	64.58
R_{it-1}	Number of years that formal grassland use rights have been assigned to individual households in county i until year $t-1$	Years	1035	4.28	5.69	0	25
M_{it-1}	Real producer price of mutton in year $t-1$	Yuan/kilo	1035	1.15[c]	0.49	0.59	1.94
B_{it-1}	Real producer price of beef in year $t-1$	Yuan/kilo	1035	1.29[d]	0.71	0.63	3.10
T_{it-1}	Ratio of total grassland area of county i in year t over that in 1985, with one year lag	na	1035	0.98	0.05	0.79	1.11
G_{it-1}	Share of good quality grassland area in total grassland area of county i in year t, with one year lag	na	1035	0.80	0.20	0.09	1.00
Y_t	Year t	na	1080	12.50	6.93	1	24
P_i	$=1$ if county i is a pastoral county, $=0$ otherwise	na	1080	0.60	na	0	1

[a] The summary statistics based on the variables that are used in the model can be found in Appendix A.

[b] It is noted that the minimum (or maximum) values for livestock production may appear to be unusually small (or large). On the one hand, these extreme values can be attributed to the high (or low) values in the base year (1985). On the other hand, livestock structures may have sharply changed due to government interventions. For instance, the implementation of the grazing ban severely decreased the sheep population in several counties. In our analyses, we assume that these government-driven factors are captured by the time variable.

[c] 1.15 Yuan/kilo is around 0.17 US dollars/kilo.

[d] 1.29 Yuan/kilo is around 0.19 US dollars/kilo.

Sheep and cattle population and mutton and beef output are used to represent the livestock production. The ratios of these four indicators in year t compared with the base year 1985 ($S_{it}, C_{it}, U_{it}$and F_{it}), expressed in logarithms, are employed as the four dependent variables in Eqs. (1)–(4). The four equations are denoted as the sheep population, cattle population, mutton output and beef output models, respectively. Variable R_{it} indicates the land tenure reform of county i in year t, which is presented by the number of years in which the formal use rights of grassland have been owned by individual households in county i by year t. We assume that land tenure reform has a non-linear relationship with livestock production. Plenty of scholars have proved the existence of a non-linear relationship between access to land and agricultural production (e.g. Finan et al., 2005). Ostrom (2007) claimed that the problems linked with social-ecological systems require serious study which take account of complex, multivariable, non-linear, cross-scale, and changing systems. Our functions attempt to explore the trend of livestock production under the land tenure reform over time based on the assumption of their non-linear relationship, which can be concave, convex, quasi-concave or quasi-convex. The logarithm and reciprocal of the variable of land tenure reform are employed to present the non-linear relationships. Considering that the value of the land tenure reform variable is zero for some counties as they had not implemented the reform by 2008, a very small value (0.01) is added, i.e. $\log(R_{it}+0.01)$ and $1/(R_{it}+0.01)$ are used in the equations. We have also tested the robustness of the model with a quadratic term instead of the reciprocal to specify the non-linear relationship (see Appendix B for details of the specification with the quadratic form).

Based on the existing academic research, the factors of market forces, grassland condition, technology development and environmental heterogeneity are widely suggested to impact the pastoral livestock production (Li et al., 2008; Squires et al., 2009; Tessema et al., 2014). As such, they are considered as control variables in our functions for disentangling the impact of land tenure reform. Market forces are proxied by the local mutton price (M_{it}) and the beef price (B_{it}) which are expected to affect supply decisions of livestock producers (Komarek et al., 2012). The grassland condition refers to the quantity and quality of grasslands. It indicates the carrying capacity for livestock, reflecting grassland degradation and climate change factors such as temperature and water availability (Henry et al., 2012). Specifically in our model, the ratio of total grassland area in year t over that in 1985 is used to present the changes in quantity of grassland (T_{it}). The grassland quality is presented by the share of the area of good quality grassland[5] in the total grassland area in year t (G_{it}). We therefore collected three types of data at the county-level in Inner Mongolia: survey data on land tenure reform of each county, observational data on grassland conditions and statistical data on socio-economic indicators.

Technological development is presented by the time variable Y_t. It should be noted that the development of technology in pastoral areas is mostly government-driven, mainly as a result of the growing interest of the central government in the ecological benefits of grasslands in recent years. For instance, a series of Ecological Construction Programs for grassland conservation have been implemented since 2000 to develop intensive animal husbandry through improving the technology of animal husbandry (Li et al., 2014). These have stimulated the improvement of forage production, feeding and fattening techniques and the use of improved breeds (Liao, 2009). The time variable Y_t is therefore used to estimate the impact of these ecological programs as well. P_i is a dummy variable that is one for pastoral counties and zero otherwise. The interaction term of Y_t and P_i is included in the equations to recognise the differences between pastoral counties and semi-pastoral counties in terms of technological development and ecological policies. Apart from the time and dummy variables, we treat all independent variables with a one year lag because market forces, grassland

[5] Good quality grassland' denotes grassland where the canopy cover of grass is > 20%. Grasslands are divided into three categories according to the canopy cover, namely dense grassland, moderate grassland and sparse grassland (Deng et al., 2011). In this paper, good quality grassland includes dense grassland and moderate grassland.

condition and land tenure reform are all considered to affect livestock production with a time delay. Moreover, market forces and grassland condition are specified in logarithmic form.

Finally, other factors such as elevation, terrain slope and distance to the provincial capital, which are not expected to change significantly over time, are treated as time-invariant (fixed) factors. They are represented by the terms s_i, g_i, u_i and f_i in the models. The coefficients of the independent variables are a_n, b_n, c_n and d_n ($n = 1, 2, \ldots 7$) and the random error terms are ε_{it}, μ_{it}, λ_{it} and δ_{it}. There are 1035 observations used in the fixed effects model, covering 45 counties and 23 years. The 15 crop farming counties are not included in the empirical model because these counties have limited permanent grasslands and their livestock production relies more on intensive raising than on extensive grazing. Furthermore, the areas of grasslands in most crop farming counties are too small to be subdivided, and therefore household-based assignment of grassland use rights was only partially implemented in the crop farming areas. The year 1985 is excluded automatically in the empirical estimation because it is the base year for the standardisation of the dependent variables.

4. Model results

Before the estimation, we first conduct a Hausman test to choose between the fixed effects or random effects regression as the estimation technique. The test results for the models of sheep population, mutton output and beef output reject the null hypothesis at $p < 0.01$, indicating that the fixed effects regression is more appropriate. Only the test result for the model of cattle population does not reject the null hypothesis at $p < 0.01$. We conducted the random effects and fixed effects regression for the model of cattle population. The results are comparable, with the exception of the coefficient of the constant term. To compare the results of the four models consistently, we use the fixed effects regression for all of them.

Furthermore, we discuss the exogeneity of the variable of land tenure reform (R_{it}). R_{it} indicates the number of years for which formal grassland use rights have been assigned. In practice, the assignment of formal grassland use rights was implemented by the county-level government based on top-down executive orders. According to our survey, the differences in the assignment of formal grassland use rights among counties resulted mainly from the implementation efficiency of each county government and the county's geographical location. For instance, a county that is located in a remote area was less motivated to assign formal use rights. In this regard, the speed of implementation of the land tenure reform by local governments was not related to local livestock production, grassland condition, or other factors that we include in the model. Hence, we treat R_{it} as an exogenous variable. In contrast, the decision by local households to actually adopt private use is likely to have taken into account the grassland condition, living customs, production pattern etc., and would therefore have created a potential problem of endogeneity. As such, we use the implementation by county government instead of the household adaption to measure land tenure reform. The exogeneity of policy implementation in China was also supported by Liu et al. (2010) based on their research about the implementation of the Sloping Land Conversion Program (SLCP).

The fixed effects model is used to estimate our four models based on the panel data set. The estimation results are listed in Table 3.

First, we focus on the coefficients of $\log(R_{it-1} + 0.01)$ and $1/(R_{it-1} + 0.01)$, indicating the effects of the land tenure reform on livestock production over time. All of these coefficients are significant and negative in the four models. Based on the coefficients of

Table 3
Model results of the factors that impact upon livestock production in the pastoral areas.

Variables	Sheep population model $\log(S_{it})$		Cattle population model $\log(C_{it})$		Mutton output model $\log(U_{it})$		Beef output model $\log(F_{it})$	
	Coefficient	*t*	Coefficient	*t*	Coefficient	*t*	Coefficient	*t*
$\log(R_{it-1} + 0.01)$	−0.18***	−5.68	−0.10***	−3.36	−0.09***	−2.63	−0.08*	−1.83
$1/(R_{it-1} + 0.01)$	−0.01***	−4.93	−0.01***	−3.52	−0.004**	−2.33	−0.005*	−1.94
$\log(M_{it-1})$	0.23***	3.28	na	na	0.06	0.87	na	na
$\log(B_{it-1})$	na	na	0.18***	3.83	na	na	0.19***	2.95
$\log(T_{it-1})$	−0.08	−0.21	1.54***	4.10	−0.64	−1.53	0.57	1.09
$\log(G_{it-1})$	1.17**	2.21	−0.25	−0.52	1.67***	3.03	0.83	1.21
Y_t	0.04***	8.18	0.01***	2.58	0.12***	22.08	0.10***	17.11
$P_i{}^*Y_t$	−0.003	−0.91	−0.03***	−8.51	−0.02***	−4.76	−0.05***	−10.65
Constant	0.38**	2.36	0.15	1.00	0.24	1.44	0.50**	2.46
R^2	0.30		0.12[a]		0.77		0.60	
Observations	1035		1035		1035		1035	

[a] The low R^2 for the cattle population model may be explained by the fact that cattle production is much more prominent in crop farming counties and major changes in cattle population overtime also occurred mainly in these counties. Moreover, some factors that affect cattle population are not specifically captured by the explanatory variables of our model. For instance, changes in the cattle population in some counties may have resulted from government-driven adjustment policies. This factor is not explicitly included in our model because of data limitations, and we have merely used the time variable to capture the potential effects of technological and policy developments. We have stated this point in the discussion section as our research limitation. Despite the low value of R^2, the effect of land tenure reform on the cattle population is shown to be significant.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

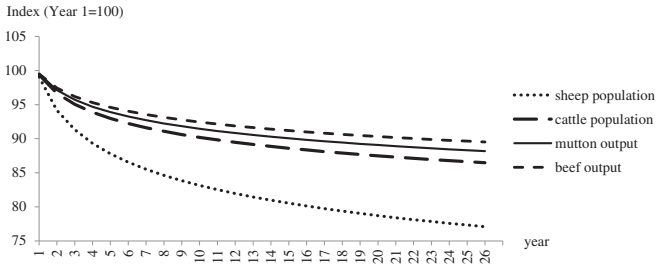

Fig. 9. Relationship between land tenure reform and livestock production.

$\log(R_{it-1} + 0.01)$ and $1/(R_{it-1} + 0.01)$, concave curves are obtained as depicted in Fig. 9. The horizontal axis presents the number of years that the land tenure reform has been implemented and the vertical axis shows the livestock production index (livestock production in the first year of land tenure reform equals 100). Considering the longest duration for formal use rights privatised until 2008 was 26 years in our research sample, we determined the maximum year of the horizontal-axis as 26.

In Fig. 9, the indexes of sheep population, cattle population, mutton output and beef output are all decreasing with the number of years that the land tenure reform is implemented, and the reduction is fastest in the first years of the reform while it slows down in later years. Moreover, the decrease in sheep population is much faster than that of mutton output, indicating that land tenure reform had a more negative impact on the sheep population than on mutton output. Similarly, land tenure reform has affected the cattle population more than beef output as the decrease in cattle population is slightly faster than that of beef output. These results indicate that the implementation of land tenure reform promotes the development of livestock productivity in pastoral areas although it constrains the increase in livestock population. Moreover, the mutton output (sheep population) decreases faster than beef output (cattle population). These model results are consistent with the results of the specification with quadratic terms, instead of the reciprocal, which indicates the model results are robust (see Appendix B).

It is interesting to compare Fig. 9 with Figs. 6 and 7 – which present the increasing trends in the sheep population, mutton output and beef output after 1985. The seemingly contradicting trends of livestock production in these figures can be explained by the effects of the other factors considered in our models. For instance, the producer price has a significant and positive effect on livestock production. The mutton price elasticity indicates that the sheep population in year t will increase by 0.23% when the mutton price in year $t-1$ increases by 1%. Similarly, cattle population (beef output) in year t will increase by 0.18% (0.19%) when the beef price in year $t-1$ increases by 1%. The better grassland condition also has a significant and positive effect on livestock production. Cattle population in year t will increase by 1.54% if the total grassland area in year $t-1$ increases by 1%. Sheep population (mutton output) in year t will increase by 1.17% (1.67%) if the good quality grassland area in year $t-1$ increases by 1%. In an attempt to improve grassland condition, China has implemented various ecological projects. However, in reality, 90% of the grasslands are still degraded to various degrees (Mei et al., 2013). For example, between 1991 and 2002, 3.1% of the available natural grassland was lost, either through its being degraded into unused land, or being transformed into other purposes. During the same period, 1.68 million hectares of land was rehabilitated into natural grassland through eco-environmental projects. This resulted in a net decline of 6.38 million hectares (around 2.4% of the available natural grassland) (Qu et al., 2011).

The coefficients of the time variable are significant and positive in all four models. It indicates that the technology development affects livestock production positively, and it can be seen that the positive effects are stronger with respect to meat output than for the livestock population. The interaction term of the time variable and the dummy variable of pastoral counties is also significant, but negative, in the cattle population, mutton output and beef output models. It indicates that cattle population, mutton output and beef output increase less in the pastoral counties than in the semi-pastoral counties with technology development. Sheep population increases significantly without a distinction between pastoral or semi-pastoral counties. In general, it appears that the development of livestock production is slower in the pastoral counties than in the semi-pastoral counties over time, with the exception of the development of the sheep population which does not differ significantly between county types. Notably, Figs. 6 and 7 showed that livestock production experienced a geographic shift from pastoral areas to the crop farming areas. Our results extended this finding to the specific comparison between pastoral counties and semi-pastoral counties. That is, livestock production, with exception of the sheep population, has experienced a geographic shift from semi-pastoral counties to pastoral counties in the pastoral areas.

5. Discussion

The model results demonstrate that the implementation of land tenure reform has significantly constrained the increase of livestock population and meat output in the pastoral areas of Inner Mongolia. This finding can be explained in various ways. On the one hand, the implementation of land tenure reform may have effectively controlled the increase in livestock population, as was the aim of land tenure reform, which expected to internalise the social costs of overgrazing by privatisation and thereby avoid the tragedy of the commons. The increase in meat output is correspondingly restricted due to the constraints on livestock population. On the other hand, the spatial and social boundaries stemming from land tenure reform have impeded livestock production because fragmentation and loss in mobility increase the costs of feeding and reduce herders' ability to withstand natural risks (e.g. Li et al., 2007). The model results also illustrate that the decrease in livestock numbers and meat output occurred especially in the early years of the

land reform and that this effect weakened over time, which may be attributed to the gradual adaptation of production patterns to the privatised grasslands. Moreover, the constraining effects on the increase of livestock production could be a potential reason to explain why land tenure reform was so slow to be implemented and is still in progress after 30 years. This raises doubts about the adaptability of extending policy measures designed for crop farming areas to the pastoral areas. Although the land tenure reform promoted agricultural production successfully in the crop farming areas of China, the pastoral areas may have produced different results.

Compared with the constraining effects of the land tenure reform, market forces have a strong positive effect on livestock production. The passing of time implies technological development, and also promotes the increase in livestock production, although more slowly in pastoral counties than in semi-pastoral counties. This points towards potential approaches for stimulating livestock production in pastoral areas. In addition, improved grassland conditions also have positive effects on livestock production, which suggests that grassland conservation is necessary not only to improve the ecosystem, but also to develop sustainable livestock production.

Given the controlling effects of land tenure reform on the increase in livestock population and the facilitating effects on improving livestock productivity, it is recommended that the government supervises the implementation of assigning grassland use rights to individual households and clarifies fuzzy grassland boundaries between households. However, pastoralism that embraces common use may also have benefits for the sustainable development of animal husbandry in pastoral areas due to the advantages of the mobility, flexibility and reciprocity (e.g. Fernandez-Gimenez, 2002). In this regard, the privatisation of grassland property rights or use rights may be a precondition to ensuring cooperative use based on stable property rights or use rights in practice. In fact, recent institutional innovations in pastoral areas of China has followed two distinct pathways: the strict implementation of clarifying grassland use rights to individual households on the one hand, and the encouragement of co-management and cooperative use of grasslands based on substantive community participation on the other hand (Banks, 2003).

As a final note, we would like to mention a number of limitations of our analysis that present challenges for future research. Our use of the time variable is a simplified way to capture the effect of technological development and ecological policy. One challenge for future work is therefore to ascertain the specific effects of technological improvements and ecological policies on livestock production in pastoral areas. Moreover, the data on the grassland quality only represents the canopy cover, but does not indicate its edibility by animals, which is a serious limitation related to the measurement of the grassland conditions. Furthermore, the accuracy of Chinese livestock statistics is questionable (Waldron, Brown, Longworth, & Cungen, 2007). The statistical collection of data on the livestock population is extremely difficult in China because small rural households raise livestock on a small scale and supply chains are dominated by countless small traders and processors, unlike the centralised slaughter and auction systems that facilitate statistical collection in developed countries (Waldron et al., 2007). In this regard, our research findings should be useful for detecting general trends if not specific numbers.

6. Conclusions

This paper explores the period during which the household-based assignment of grassland use rights has been implemented in order to describe the progress of land tenure reform and to investigate its impact on the livestock production of pastoral areas of China. We focus on comparing the development of livestock production between pastoral areas and crop farming areas under the land tenure reform and evaluating the effect of land tenure reform on livestock production in pastoral areas. Livestock production was represented by sheep population, cattle population, mutton output and beef output. The descriptive analysis shows that land tenure reform was implemented progressively in the pastoral areas, rather than the case of the cropland areas where household-based use rights were completed overnight (Banks et al., 2003; Ho, 2000). It appears that the increase of livestock production was faster in crop farming areas than in pastoral areas, while conversely the development of livestock productivity was slower in crop farming areas. A fixed effects model is employed to estimate the impacts of the land tenure reform on livestock production based on a dataset of 45 counties in the pastoral areas of Inner Mongolia from 1985 to 2008. The model controls for factors that obscure the relationship between livestock production and land tenure reform, such as market forces, grassland condition, technological development and environmental heterogeneity among counties. The model results provide quantitative evidence that land tenure reform has put a ceiling on livestock production, but this constraining effect is unable to offset the impact of other factors that accelerate the increase in livestock production, which explains the actual increase in livestock production. Moreover, the constraining effect of land tenure reform on the increase in livestock production decreases with the number of years since the implementation of land tenure reform and ultimately disappears. Remarkably, the constraining effect is stronger on the increase in livestock population than on that of meat output, which indicates that land tenure reform stimulates the development of livestock productivity. With respect to the other factors, it appears that the cattle population tends to be affected by the quantity of grassland, while the sheep population and mutton output are more affected by the quality of grassland. The factor of technological development impacts on the increase in meat output more than that on the increase in livestock population, and the influence is more evident in the semi-pastoral counties than in the pastoral counties. It can be seen that technological development also prompts the development of livestock productivity.

The development of livestock productivity that is caused by the implementation of land tenure reform is different from that due to technological development. More specifically, land tenure reform in pastoral areas has transformed the production patterns of pastoralists through the privatisation of grasslands (Ho, 2000). For instance, the indigenous people in Inner Mongolia employed

nomadic management and seasonal transhumance to graze animals in areas where pastures and water were available (Wang et al., 2013). Since the spread of the land tenure reform on the grasslands, a growing number of households have built physical boundaries (such as fences) in order to prevent others from using their grasslands, which implies that mobile grazing is no longer possible and most areas of grassland are in small-scale private use (Hua and Squires, 2015). The traditional nomadic production pattern has therefore gradually been displaced by a sedentary pattern. Our research results essentially indicate that this transformation, resulting from land tenure reform, has prompted livestock productivity in the pastoral areas of Inner Mongolia. In other words, land tenure reform entailing grassland privatisation probably stimulates herders to put more effort into improving the output per animal, instead of increasing the amount of animals, which is beneficial to the development of livestock production systems in pastoral areas. However, the constraining effects of grassland privatisation on the increase in livestock production could also be a possible reason to explain why land tenure reform was implemented with difficulty on grasslands, especially in terms of the lag between the reform and the actual adoption of private use.

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Appendix A

Table A.1
Descriptive statistics of the model variables.

Variables	Mean	Std. Dev.	Min	Max	Observations
$\log(S_{it})$	0.36	0.54	− 1.59	3.14	1080
$\log(C_{it})$	− 0.05	0.49	− 2.08	2.93	1080
$\log(U_{it})$	1.02	0.81	− 0.50	4.23	1080
$\log(F_{it})$	1.05	0.79	− 2.00	4.17	1080
$\log(R_{it-1} + 0.01)$	− 1.13	3.30	− 4.61	3.26	1080
$1/(R_{it-1} + 0.01)$	46.69	49.80	0.04	100	1080
$\log(M_{it-1})$	0.05	0.41	− 0.53	0.66	1035
$\log(B_{it-1})$	0.12	0.50	− 0.45	1.13	1035
$\log(T_{it-1})$	− 0.03	0.06	− 0.23	0.10	1035
$\log(G_{it-1})$	− 0.28	0.42	− 2.40	0.01	1035
Y_t	12.50	6.93	1	24	1080
$P_i^* Y_t$	7.50	8.14	0	24	1080

Appendix B

To test the robustness of our results, we use the quadratic term instead of the reciprocal of land tenure reform variable. That is, $1/(R_{it-1} + 0.01)$ is replaced by $\log({R_{it-1}}^2 + 0.01)$ in each equation, as shown below. Comparing Table 3 with Table B.1, and Fig. 9 with Fig. B.1, model results for these two types of specification are almost the same, which indicates the model results are robust.

$$\log(S_{it}) = s_i + a_1 \log(R_{it-1} + 0.01) + a_2 \log(R_{it-1}^2 + 0.01) + a_3 \log(M_{it-1}) + a_4 \log(T_{it-1}) + a_5 \log(G_{it-1}) + a_6 Y_t + a_7 P_i^* Y_t + \varepsilon_{it} \quad (B.1)$$

$$\log(C_{it}) = g_i + b_1 \log(R_{it-1} + 0.01) + b_2 \log(R_{it-1}^2 + 0.01) + b_3 \log(B_{it-1}) + b_4 \log(T_{it-1}) + b_5 \log(G_{it-1}) + b_6 Y_t + b_7 P_i^* Y_t + \mu_{it}) \quad (B.2)$$

$$\log(U_{it}) = u_i + c_1 \log(R_{it-1} + 0.01) + c_2 \log(R_{it-1}^2 + 0.01) + c_3 \log(M_{it-1}) + c_4 \log(T_{it-1}) + c_5 \log(G_{it-1}) + c_6 Y_t + c_7 P_i^* Y_t + \lambda_{it} \quad (B.3)$$

$$\log(F_{it}) = f_i + d_1 \log(R_{it-1} + 0.01) + d_2 \log(R_{it-1}^2 + 0.01) + d_3 \log(B_{it-1}) + d_4 \log(T_{it-1}) + d_5 \log(G_{it-1}) + d_6 Y_t + d_7 P_i^* Y_t + \delta_{it} \quad (B.4)$$

Table B.1
Model results based on Eqs. ((B.1)–(B.4).

Variables	Sheep population model $\log(S_{it})$		Cattle population model $\log(C_{it})$		Mutton output model $\log(U_{it})$		Beef output model $\log(F_{it})$	
	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
$\log(R_{it-1}+0.01)$	0.19***	4.21	0.15***	3.55	0.10**	2.03	0.12**	1.97
$\log(R_{it-1}{}^2+0.01)$	−0.18***	−4.89	−0.13***	−3.53	−0.09**	−2.31	−0.10*	−1.95
$\log(M_{it-1})$	0.23***	3.26	na	na	0.06	0.86	na	na
$\log(B_{it-1})$	na	na	0.18***	3.83	na	na	0.19***	2.95
$\log(T_{it-1})$	−0.09	−0.21	1.54***	4.10	−0.64	−1.53	0.57	1.09
$\log(G_{it-1})$	1.17**	2.22	−0.25	−0.52	1.67***	3.03	0.83	1.21
Y_t	0.04***	8.17	0.01***	2.57	0.12***	22.08	0.10***	17.11
$P_i^* Y_t$	−0.004	−0.93	−0.03***	−8.52	−0.02***	−4.78	−0.05***	−10.67
Constant	0.37**	2.31	0.14	0.97	0.24	1.42	0.50**	2.44
R^2	0.30		0.12		0.77		0.60	
Observations	1035		1035		1035		1035	

* significant at 10%
** significant at 5%
*** significant at 1%

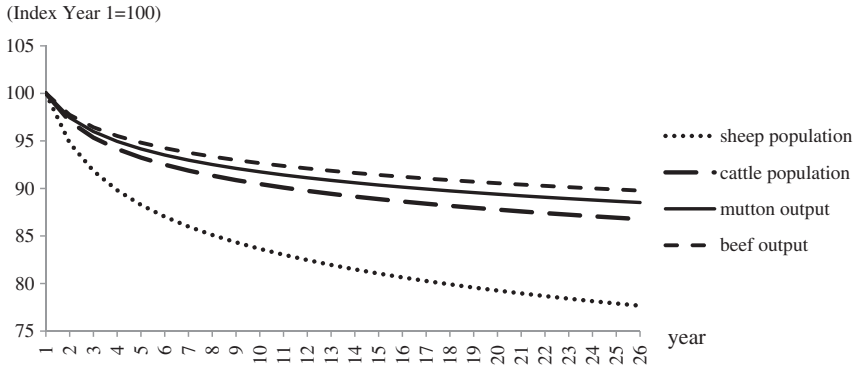

Fig. B.1. Relationship between land tenure reform and livestock production based on the model results in Table B.1

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