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The impacts of the eco-environmental policy on grassland degradation and livestock production in Inner Mongolia, China: An empirical analysis based on the simultaneous equation model

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ABSTRACT

Grassland degradation has been deteriorating while the demands for meat products have been surging in China over the past few decades, leading to multiple policy initiatives to balance the grassland ecosystem and livestock production of the pastoral areas. This paper investigates the impacts of a prevailing eco-environmental program, i.e. Subsidy and Incentive System for Grassland Conservation (SISGC), in the pastoral areas of Inner Mongolia, on grassland condition and livestock production. The Normalized Difference Vegetation Index (NDVI), measured with remote sensing technology, is used to quantify grassland condition. Our empirical analysis was based on the data of 52 counties across a 15-year timespan covering 10 years before the introduction of SISGC and 5 years after its implementation. Simultaneous equation models are employed to study the mutual relationship between grassland condition and livestock production. The results suggest that the SISGC has significantly improved grassland condition. The total livestock population, especially the sheep population, has decreased due to SISGC, but the large animal population has not been impacted. On the other hand, growing meat prices (market demands) have resulted in an increase in the population of sheep, large animals, and total livestock. Implications are that the SISGC has been successful in preventing grassland degradation by controlling the increase in livestock population of the pastoral areas. Other policy initiatives need to consider how to prevent grassland degradation not only by controlling the livestock population given the soaring meat demand by the Chinese population and to address the high level of poverty among pastoralists.

1. Introduction

Grasslands account for 26% of the world's total land area and 70% of its agricultural area. With the worsening worldwide grassland degradation, surging demands for livestock products and a high level of poverty among pastoralists, the sustainable use and management of grasslands have been of great concern to academics, policy-makers and NGOs (Fernández-Giménez and Swift, 2003; Morrison, 2006; FAO, 2015; Liu, 2018). As a result, eco-environmental policies have been implemented in various countries, with the aim of balancing grasslands conservation, livestock production and the livelihoods of agricultural households. How effective are these prevailing policy interventions in contributing to the sustainable use and management of grasslands? This paper aims to assess the impact of a specific eco-environmental policy, called Subsidy and Incentive System for Grassland Conservation (SISGC hereafter), on grassland conservation and livestock production in the typical pastoral area of China.

China has approximately 392 million hectares of grasslands, accounting for 12% of the world's grasslands and 41.7% of China's land area (Fan et al., 2008). Nearly 80% of these grasslands are in arid and semi-arid regions, which are most vulnerable to degradation, desertification, and salinization (Feng et al., 2009; National Bureau of Statistics of China, 2009; Liu et al., 2003). Livelihoods of approximately 17 million people rely on grasslands through livestock grazing (Li et al., 2014). The grasslands in China are concentrated in six provinces or autonomous regions (i.e. Xinjiang, Tibet, Qinghai, Sichuan, Gansu and Inner Mongolia), together accounting for 75% of China's grasslands and accommodating 70% of its grazing livestock (Morrison, 2006). These

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areas maintained traditional pastoralism for centuries, before undergoing a land tenure reform since the 1980s and a series of eco-environmental policies since around 2000 (Liu, 2017).

On the one hand, livestock production has soared in China to meet the ever-growing demand for meat with a growing population, urbanization and rising disposable incomes (Cao et al., 2013; Liu and Li, 2017). According to the FAOSTAT database, China's meat production accounted for only 10.8% of the world's total production in 1980 and the share rose to 27.2% in 2014 (FAOSTAT, 2014). The annual growth rate in meat production between 1980 and 2014 was 7.7% in China, compared with the worldwide figure of 3.6% (FAOSTAT, 2014). China's mutton and beef outputs in 2017 were about 10.6 and 23.6 times those of 1980, and 1.8 and 1.2 times those of 2013 (National Bureau of Statistics of China, 2014, 2018). Meanwhile, the mutton consumption per capita increased by 44% from 2013 to 2017, and 27% for beef (National Bureau of Statistics of China, 2014, 2018). Livestock production in the pastoral areas has considerable capacity to alleviate the increasing stress of livestock product demands (FAO, 2015).

On the other hand, grassland degradation is particularly severe in China, although it is a worldwide problem (Ho and Azadi, 2010). Despite no official data being available regarding the severity of China's grassland degradation, its occurrence has been generally acknowledged by pastoralists, scholars, and governments (Harris, 2010; Waldron et al., 2007). A well-known estimate is that about 90% of China's grasslands were degraded to some extent by the 2000s (Unkovich and Nan, 2008; Waldron et al., 2007), and that around 2 million hectares of grassland deteriorate annually (Ren et al., 2007; Harris, 2010; Cao et al., 2013). Feng et al. (2009) found that the total grassland area in Qinghai province decreased significantly during the period 1976-2006. Cao et al. (2013) warned that the northern grassland boundary has moved about 200 km southward and the western boundary about 100 km eastward in the past few decades. Grassland degradation includes the loss of grassland productivity, reduction in soil fertility, soil compaction, increased presence of unpalatable species of grass, or a combination thereof (Li et al., 2013). Most importantly, the degradation and desertification of the grasslands in northern China have been identified to be a major cause of a number of natural disasters in the late 1990s (Kang et al., 2007; Wu et al., 2015). These natural disasters include frequent flooding of the Yangtze River, droughts in the Yellow River valleys and sandstorms in northern metropolitan areas, resulting in substantial economic losses and impairment of human health (Harris, 2010). Hence, grassland degradation does not only endanger pastoralists' livelihoods, but it also threatens nationwide ecological security (Harris, 2010; Huang et al., 2013).

With growing attention being paid to improving grassland ecosystems, various environmental policies and programs have been introduced in China. These policy interventions have been mainly targeted at grassland conservation by sowing grass and especially by reducing the livestock population of the pastoral areas since overgrazing is widely believed to be a main cause of grassland degradation (Morrison, 2006; Ge et al., 2015; Miao et al., 2015). For the latter, several eco-environmental programs have targeted pastoralists in the pastoral areas to reduce the population of their grazing livestock and raise animals in captivity instead of pastoral grazing (Hua and Squires, 2015; Ministry of Agriculture of China, 2016). Moreover, because degraded grassland becomes unfit for grazing, livestock production relies increasingly on crop stalks, bran, and other byproducts of grain which are more readily available in the crop areas (FAO, 2015). The Chinese central government has therefore also called for the relocation of cattle and sheep production from the traditional grazing regions to the grain-producing provinces since the 1990s, a strategy which was strengthened after a series of environmental disasters in the 2000s. What followed has been a steady increase in the total livestock outputs in China but a decrease in the share of livestock production from the pastoral areas (Li, 2009). However, the implementation of eco-environmental programs and the reallocation of livestock production have hampered the livelihoods of traditional pastoralists who depend on grazing in the pastoral areas. Pastoralists might suffer from economic losses when receiving little or no compensation for reducing their grazing livestock, which in turn impedes the implementation of these restrictions by pastoralists (Liu, 2017; Dai and Tan, 2018).

Have the eco-environmental policies (like SISGC) been effective in grassland conservation? And have they affected livestock production in the pastoral areas? These questions have especially concerned academic circles and governments. Government reports show that SISGC has contributed to grassland restoration and reduction of the grazing livestock population (Ministry of Agriculture of China, 2012, 2013, 2014, 2015, 2016), but some field surveys by academics show continued overgrazing (Yin et al., 2019) and grassland degradation in some pastoral areas (e.g. Dai and Tan, 2018). These inconsistent conclusions regarding the impact of China's environmental policies could to some extent be explained by the differences in the research areas studied and methods used. For instance, many researchers based their conclusions on surveys of small-scale areas, and surveys of a larger scale and with long-term observations are generally lacking (Li and Zhang, 2009; Ho and Azadi, 2010). This may lead to findings that are potentially biased, especially when a survey was only conducted on grasslands with severe degradation. On the other hand, the government reports are mostly only based on superficial observation and calculation, which cannot disentangle the impacts of other important factors on grassland condition and livestock production, such as climate factors, market prices, agricultural activities and so forth. A recent study by Yin et al. (2019) has found empirically that grazing intensity has significantly increased four years after the initialization of the program, based on a survey of 726 herder households from Inner Mongolia. However, they have not investigated the impact of the program on grassland quality. To address these shortcomings, we employ a large panel dataset which covers the whole pastoral area of Inner Mongolia and spans 15 years. Most importantly, a simultaneous equation model is used to study the interaction between grasslands and livestock while controlling for factors such as climate, meat prices and agricultural activities.

In the following sections, we first review China's grassland policies. Next, the study region is introduced in Section 3 and data is described in Section 4. In Sections 5 and 6, we present the econometric models and the model results. Discussions and policy implications are presented in Section 7. The aim of our systematic review of China's grassland policies and the comprehensive analysis of SISGC is to provide valuable insights for other countries that are also struggling to balance grassland conservation and livestock production.

2. Review of China's policies/programs on grassland conservation

In 1985, China passed the first national Grassland Law which explicitly stipulated the protection and improvement of grasslands by imposing grazing quotas on pastoralists in major pastoral areas. The monitoring of the implementation of the quotas was however lax (Ho, 2000). With the continuous deterioration of grasslands in China, and especially after the serious droughts in 1997 and the massive floods in 1998, the government has responded by developing eco-environmental policies and national programs to prevent grassland degradation (Hua and Squires, 2015). Several large-scale eco-environmental programs for grassland protection have been initiated in recent decades (Wu et al., 2015). For example, the Sloping Land Conversion Program (also known as the Grain for Green Program), with an overall budget of 225 billion RMB (around $37 billion), was mainly implemented in the 2000s, involving 90% of Chinese provinces. The main focus was to convert sloping or deserted farmlands to forests, shrubland or artificial grasslands (Liu et al., 2010). Another major program especially for grassland conservation was the Returning Grazing to Grassland Program launched in 2003, which was one of the largest of its kind in the 2000s. This program aimed at promoting grassland conservation by sowing grass on seriously-degraded grasslands as well as by restricting grazing, while compensating pastoralists with cash, grain or grass seeds to cover their economic losses (Morrison, 2006). Restricting grazing involved grazing bans (either permanently or seasonally), rotational grazing or grazing quota (Li et al., 2014; Hua and Squires, 2015). Apart from these two major programs in the 2000s, other local programs, such as the Program to Combat Desertification in Beijing and Tianjin, have employed similar policy measures for grassland conservation.

Since 2011, the latest major eco-environmental program for grassland conservation, the Subsidy and Incentive System for Grassland Conservation (SISGC) program, has been initiated in 13 provinces with the largest areas of natural grasslands of China, namely Inner Mongolia, Xinjiang, Tibet, Qinghai, Sichuan, Gansu, Ningxia, Yunnan, Hebei, Shanxi, Liaoning, Jilin and Heilongjiang. SISGC aims at protecting natural grassland from degradation, prompting intensification instead of extensive grazing to maintain livestock production, and improving local pastoralists' livelihoods (Hua and Squires, 2015; Ministry of Agriculture of China, 2016). Under the SISGC, the grazing ban in some areas and livestock-forage balance in other areas remain in place. The livestock-forage balance means to raise livestock based on the carrying capacity of the grassland (similarly for the grazing quota). The major difference compared with earlier eco-environmental programs on grassland conservation is that the SISGC covers a much wider area of natural grasslands which almost includes all the rural households in the grasslands, and it provides pastoralists with much higher levels of compensation. Moreover, more efforts have been taken to monitor the policy implementation by hiring professional monitoring staff (known as *Guan Hu Yuan*) by local governments. The first round of SISGC was between 2011 and 2015, and the second round has been running from 2016 to 2020.

3. Study region

We base our empirical study on Inner Mongolia, which accounts for 21.7% of the area of China's natural grasslands. The extensive grasslands in Inner Mongolia are a crucial part of China's ecosystem. For instance, the dust storms which rumbled through hundreds of cities and villages of northern China and blanketed the sky of Beijing between 1998 and 2001 were said to have originated from dryland areas and degraded grasslands mainly in Inner Mongolia (Wu et al., 2015). Meanwhile, it is one of the main production regions for animal products in China. In 2016, Inner Mongolia accounted for 19.5% of the sheep population and 21.5% of the mutton output of China, making it the largest sheep and mutton producer among all Chinese provinces. In addition, 7.8% of China's total beef output was produced there, ranking the province third in China (National Bureau of Statistics of China, 2017). The administrative units of Inner Mongolia encompass 103 counties, among which 33 are pastoral counties and another 21 are semi-pastoral counties. These 54 counties include almost all the natural grasslands of Inner Mongolia. The remaining 49 counties are dominated by crop farming or urban districts. In the pastoral area, most residents are pastoralists who are reliant on grazing animals on the natural grasslands to maintain their livelihoods (Liu et al., 2018).

According to official statistics, by the early 2000s, 90% of the grasslands in Inner Mongolia suffered from desertification, degradation, or salinization (Briske et al., 2015). Moreover, the results of large-scale ecological field surveys highlighted that the average grassland biomass productivity in Inner Mongolia has plunged from 1871 kg/ha in 1961 to 900 kg/ha in 2010 (Wang et al., 2013). The pastoral areas of Inner Mongolia have been a typical region targeted by various eco-environmental policies and programs. The SISGC was first introduced in Inner

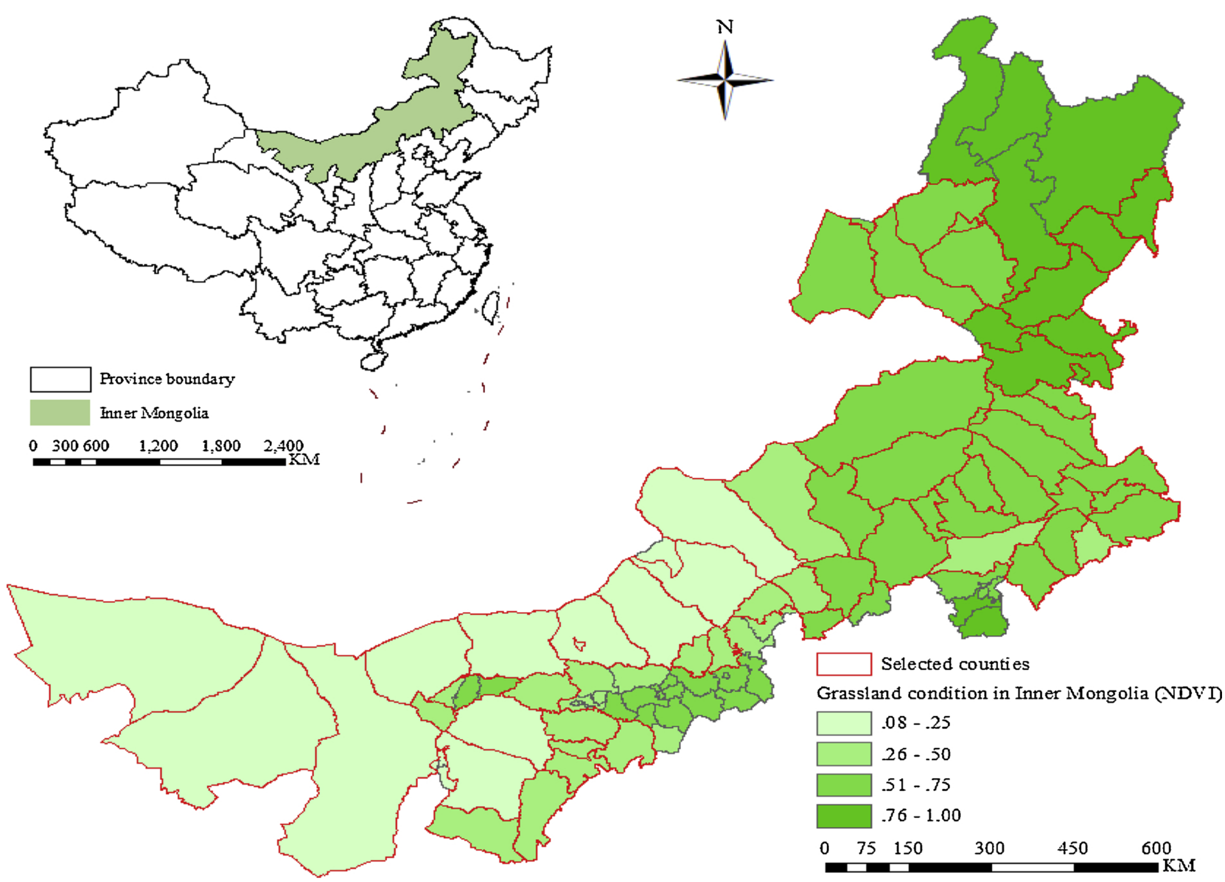

Fig. 1. Locations of Inner Mongolia and the sample counties.
Source: Authors' compilation based on the NDVI measured by remote sensing technology.

Mongolia in 2011. According to local government reports, the program covered 67.5 million hectares of natural grasslands in its first phase from 2011 to 2015, which included almost all available natural grassland of Inner Mongolia (Provincial government office of Inner Mongolia, 2016). Of these, 36.5 million hectares were selected for a grazing ban and the remaining 31 million hectares were put under livestock-forage balance. All counties in the pastoral areas contained some grasslands which were subject to the grazing ban, livestock-forage balance or both. All rural households whose grasslands were covered by SISGC received subsidies conditional on their compliance with grazing regulations. In the second phase (i.e. between 2016 and 2020), the grassland area under SISGC increased slightly to 68 million hectares. Additionally, the subsidies to pastoralists in the second phase were slightly higher than in the first phase.

Fig. 1 illustrates the location of Inner Mongolia and our sample counties for this study. The sample counties include the whole pastoral area of Inner Mongolia, except for two semi-pastoral counties (i.e. Keerqin District and Arun Banner) because of missing data. As such, 52 counties were retained for the empirical analysis, which account for 69% of the natural grasslands of Inner Mongolia.

4. Econometric methods

The research objective is to estimate the impacts of the eco-environmental policy on grassland degradation and livestock production. Simultaneous equation modelling is used considering the bidirectional relationship between grassland condition and livestock production. This allows us to control for unobserved heterogeneity while dealing with simultaneity (Alam and Mamun, 2016). The model is an equation-by-equation technique, where the endogenous regressors on the right-hand side of one equation are instrumented by regressors from the other equation (Bakhsh et al., 2017). The main advantage of the simultaneous estimation of multiple equations is that it is more efficient than a separate estimation of the equations, because it allows the errors terms of multiple equations to be correlated (Bakhsh et al., 2017). Referring to the existing literature (e.g. Li and Zhang, 2009; Liu et al., 2017), grassland condition and livestock population are jointly determined as follows:

$$\begin{cases} GRASS = f(ANIM,\ X_1,\ \varepsilon) \\ ANIM = f(GRASS,\ X_2,\ \omega) \end{cases},\ where\ E\left[\varepsilon,\ \omega\right] \neq 0 \tag{1}$$

where $GRASS$ represents grassland condition, $ANIM$ indicates livestock production, and X_1 and X_2 represent a vector of potential variables influencing grassland condition and livestock production, respectively. ε and ω are *i.i.d.* error terms which are allowed to be correlated.

The system of Eq. (1) shows that $GRASS$ and $ANIM$ are both dependent and independent variables for each other to capture the interaction of grassland condition and livestock production. Livestock production in the pastoral areas depends largely on the grassland condition because the quality of grasslands directly determine the amount of feed available to animals (Li and Zhang, 2009). Moreover, animals in the pastoral areas mainly feed on fresh grass on the natural grasslands. Overgrazing has been identified as a principal reason for grassland degradation (Akiyama and Kawamura, 2007; Zhang et al., 2007; Harris, 2010), although other studies have argued that overgrazing only leads to degradation in certain areas and that there is insufficient evidence suggesting that overgrazing *per se* is responsible for grassland degradation (Cao et al., 2013). We thereby include livestock production ($ANIM$) as an explanatory variable to estimate its effects on grassland condition ($GRASS$).

In addition, climate-related factors are generally acknowledged to be significant drivers of changing grassland condition in arid and semi-arid areas (Liu et al., 2018). For example, the distribution of precipitation was found to be a principal factor causing changes to the grassland condition (Harris, 2010; Cao et al., 2013), while temperature was found to be a driver of biomass production of grasslands (Piao et al., 2006). The agricultural activities measured by the sowing area is also considered to impact the grassland condition. Next, a main factor expected to affect livestock production is the market demand for meat products (Liu et al., 2017). Our main variable of interest concerns the implementation of SISGC, which may have effects on livestock production through the regulations of grazing bans and livestock-forage balance. Inserting the above variables into the system of Eq. (1), we obtain the following system of equations by assuming that the functions of $GRASS$ and $ANIM$ can be written as linear forms:

$$\begin{cases} log\,(GRASS_{it}) = a_0 + a_1 log\,(ANIM_{it}) + a_2 POLICY_{it} + a_3 Pland_{it} \\ \qquad + \sum_{m=1}^{12} a_{4m} TEM_{itm} \\ + \sum_{m=1}^{12} a_{5m} RAIN_{itm} + a_{6i} county_i + \varepsilon_{it} \\ log\,(ANIM_{it}) = b_0 + b_1 log\,(GRASS_{it}) + b_2 POLICY_{it} + b_3 PRICE_{it-n} \\ \qquad + b_{4i} county_i + \omega_{it} \end{cases} \tag{2.1}$$

where i and t represent the ith county and year t, respectively. $GRASS_{it}$ represents grassland condition. $ANIM_{it}$ represents livestock production, which includes the sheep population ($SHEEP_{it}$), the large animal population ($LARGE_{it}$), or the total livestock population ($LIVESTOCK_{it}$). Therefore, three groups of models are conceptualized depending on the combination of dependent variables which include: $NDVI_{it}$ and $SHEEP_{it}$ (***MODEL*** 1), $NDVI_{it}$ and $LARGE_{it}$ (***MODEL*** 2), and $NDVI_{it}$ and $LIVESTOCK_{it}$ (***MODEL*** 3).

The dummy variable of $POLICY_{it}$ indicates the implementation of SISGC. $PRICE_{it-n}$ is a vector of variables to represent producer prices, including purchasing price of live sheep (PS_{it-1}), purchasing price of live large animals (PC_{it-2}), and the weighted average of purchasing prices of live sheep and large animals ($PRICE_{iw}$). They are used as proxy variables for market demand for livestock. The price of large animals is based on the purchasing price of cows because the price data on other large animals is limited and cows comprise the majority of large animals in the pastoral areas. It should be noted that $PRICE_{it-n}$ is a n-year lag variable where live sheep price is used with a one-year lag and live cow price with a two-year lag because the length of the breeding period of sheep and cows is one and two years, respectively. For the weighted price ($PRICE_{iw}$), the weight is based on the proportion of sheep (β) and large animals (1-β) of Inner Mongolia in the base year 2001. $Pland_{it}$ indicates the change rate of sowing area of county i in year t, compared with its base condition in 2001. TEM_{itm} and $RAIN_{itm}$ are the average daily temperature over each month and total monthly precipitation from January to December (m ranges from 1 to 12). The heterogeneity among counties, such as the natural resources endowment of each county, is controlled for by the variable of $county_i$. a_0 - a_{6i} and b_0 - b_{4i} are parameters to be estimated. ε_{it} and ω_{it} are error terms.

Before the estimation of the simultaneous equation model, it is necessary to test the validity of the instrument variables. In the system of equations (2), $GRASS_{it}$ is the endogenous variable in the first sub-equation, which is instrumented by the exclusive variables of TEM_{itm} and $RAIN_{itm}$ from the second sub-equation. Meanwhile, $ANIM_{it}$ is the endogenous variable in the second sub-equation, which is instrumented by the exclusive variable of $PRICE_{it}$ from the first sub-equation. The Three-Stage Least Squares (3SLS) estimator is employed to take into account the contemporaneous correlation between ε_{it} and ω_{it}.

5. Data

5.1. Data collection

The empirical analysis uses a panel dataset which includes 52

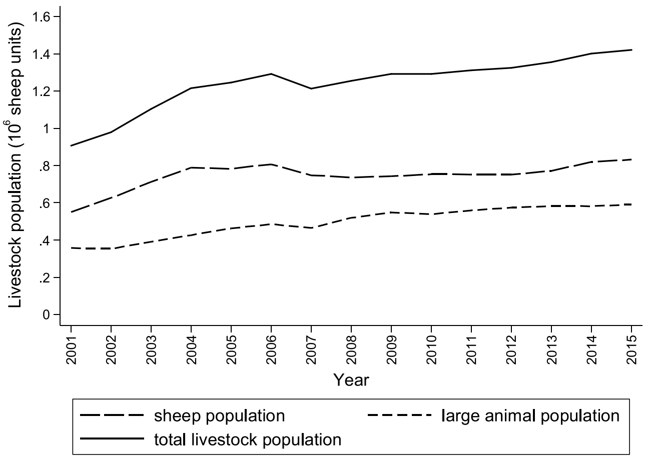

Fig. 2. The livestock population in the pastoral areas of Inner Mongolia 2001–2015.
Source: Authors' compilation based on the data of livestock production from Statistical Yearbooks of Inner Mongolia.

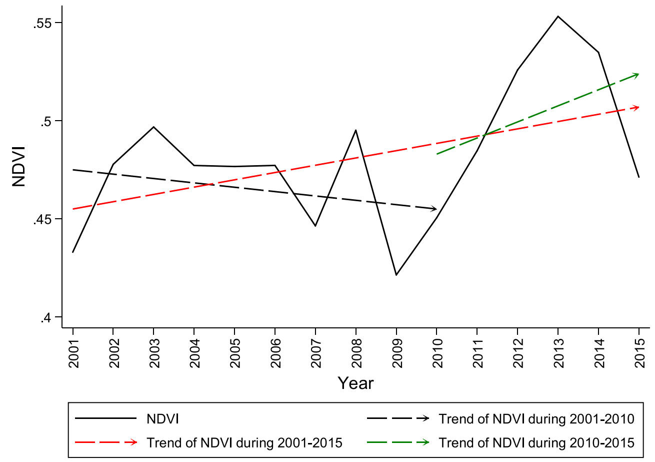

Fig. 3. The changes in NDVI in the pastoral areas of Inner Mongolia, 2001–2015.
Source: Authors' compilation based on the NDVI measured by remote sensing technology.

counties spanning 15 years from 2001 to 2015, involving ten years before the SISGC and five years after its initialization. The data collected includes grassland condition, livestock population, climatic information, and several other socio-economic characteristics.

The existing literature employs two methods to measure grassland condition, i.e. direct sampling through fieldwork, and remote sensing technology (e.g. Liu et al., 2004; Gu and Li, 2013; Sutton et al., 2016; Chen et al., 2017). In this study, we employ the latter method to calculate the Normalized Difference Vegetation Index (NDVI) of grasslands of each sample county. NDVI infers grassland condition from vegetation characteristics that show variations in absorption, transmittance, and reflection of energy in the red and near-infrared portions of the electromagnetic spectrum (Yang et al., 1998; Liu et al., 2013; Gong et al., 2015; Senay and Elliott, 2000). NDVI is then calculated as the ratio of the difference in these electromagnetic bands over their sum. Based on the dataset of MOD13A1 from NASA's Earth Science Data Systems Program, i.e. the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery with 500 m spatial resolution and 16 days temporal resolution, we employed the Maximum Value Composite (MVC) method to obtain the NDVI of each year during 2001–2015 (Holben, 1986). The image layer of administrative divisions of Inner Mongolia was used to determine the county-level NDVI.

Other variables used in our study include the year-specific status of SISGC implementation inferred by data from the Agriculture and Animal Husbandry Bureau of Inner Mongolia; the producer prices of live sheep and cows were collected based on the Annual Compilation of Cost-Benefit Data of Chinese Agricultural Products and deflated with the Producer Price Index of Agricultural Products of Inner Mongolia; and livestock production, sowing area, and climatic indicators inferred by the Statistical Yearbooks of Inner Mongolia. The data of temperature and precipitation were based on daily surface climate dataset for the period 2001–2015 from 838 meteorological stations in China, and spatial interpolation method utilizing the Anusplin software was employed to generate the monthly temperature and precipitation of each county (Hong et al., 2005; Liu et al., 2019a,b).

5.2. Descriptive analysis

Before the empirical analysis, we present the changes in livestock population and grassland condition during the research period with the preliminary statistical analysis. Fig. 2 shows the sheep population, large animals and all livestock in our 52 sample counties. The Statistical Yearbooks of Inner Mongolia classify ruminant animals into two categories, i.e. large animals and sheep. The former includes cows, cattle, horses and other big ruminant animals while the latter includes sheep and goats. One large animal is equivalent to 5 sheep units (The 12th Standing Committee of the Inner Mongolian People's Congress, 2016). The total livestock population equals the total sheep units of large animals and sheep. Fig. 2 shows a general trend that the total livestock population has been increasing from 2001 to 2015, apart from the sharp decrease from 2006 to 2007. When SISGC was implemented during 2011–2015, the population of sheep and large animals increased by 11% and 5%, respectively.

Fig. 3 shows that the NDVI of the pastoral areas in Inner Mongolia fluctuated between 2001 and 2015, especially before the implementation of SISGC in 2011. The trend lines of NDVI show that the grassland condition was generally improving from 2001 to 2015 (see the black dashed line). However, a deteriorating trend was seen between 2001 and 2010 (see the red dashed line), followed by an improving trend since the initialization of SISGC in 2011 (see the red dashed line). More notably, the black solid line shows that the NDVI manifested a steady increase between 2011 and 2013, followed by a decrease in 2014 and 2015.

Table 1 shows whether the increasing trends implied in Figs. 2 and 3 are statistically significant between the periods before and after the implementation of SISGC in 2011. Our panel dataset includes 52 counties over 15 years, amounting to 795 observations. Of these, 520 were observations before the SISGC and 260 after. *t*-test is used to compare the means of these two sets of data. It shows that NDVI was significantly higher after SISGC than before. Likewise, sheep, large animals and total livestock population were also significantly higher

Table 1
Grassland condition and livestock population before and after the implementation of the SISGC program.
Source: Authors' compilation based on the data collected by remote sensing technology and Statistical Yearbooks of Inner Mongolia.

	Units	After SISGC	Before SISGC	Diff.
NDVI	n.a.	0.49	0.46	0.03**
The number of sheep per hectare	Sheep units/ha	1.81	1.52	0.29**
The number of large animals per hectare	Sheep units/ha	1.55	1.20	0.35***
The number of total animals per hectare	Sheep units/ha	3.36	2.72	0.64***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

after SISGC. However, the direct comparisons did not control for other factors, such as climatic factors, market prices, agricultural activities and so forth. Therefore, we further test for this assumption based on the empirical analysis in the next section. The definitions of all variables and their descriptive statistics are presented in Table 2.

6. Empirical results

Based on above data we collected, three-Stage Least Squares (3SLS) estimator is employed to simultaneously estimate the system of Eq. (2.1). The results of the first stage of the 3SLS estimate in Table 3 confirm the validity of the instruments (e.g. Chen and Hamori, 2009; Wang et al., 2018). Table 4 displays the second-stage model results. In all three models, the Breusch-Pagan test statistic is highly significant, indicating that there exists a contemporaneous correlation between ε_{it} and ω_{it} (Bakhsh et al., 2017). In *MODEL 1* (dependent variable: $log(NDVI_{it})$ and $log(SHEEP_{it})$, the coefficient of $POLICY_{it}$ is significantly positive in the sub-equation of $NDVI_{it}$, which indicates that the implementation of SISGC has improved the grassland condition. Moreover, the coefficient of $SHEEP_{it}$ is significantly negative, which suggests that the grassland condition deteriorates with the increase in sheep population. The coefficient of $Pland_{it}$ is insignificant, indicating that grassland condition is not associated with the changes in sowing area between 2001 and 2015. In the sub-equation of $SHEEP_{it}$, the coefficient of $POLICY_{it}$ is significantly negative, which indicates that the implementation of SISGC has reduced sheep population. The coefficient of $NDVI_{it}$ is significantly positive, which suggests that the sheep population increases with the improvement of the grassland condition. The significant and positive coefficient of PS_{it-1} demonstrates that the sheep population rises with sheep price.

In *MODEL 2* (dependent variable: $\log(NDVI_{it})$ and $\log(LARGE_{it})$), the coefficient of $POLICY_{it}$ is also significantly positive in the sub-equation of $NDVI_{it}$, which is in line with *MODEL 1*. Moreover, the coefficient of $LARGE_{it}$ is significantly negative, which suggests that the grassland condition gets worse with the increase in large animal population. $Pland_{it}$ still presents an insignificant influence on NDVI. In the sub-

Table 2
Variable definitions and summary statistics.

Variables	Definitions	Units	Obs.	Mean	S.D.
$NDVI_{it}$	NDVI of county *i* at year *t*	n.a.	780	0.47	0.20
$SHEEP_{it}$	The number of sheep per ha over grassland area of county *i* at year *t*	Sheep units/ha	780	1.62	1.80
$LARGE_{it}$	The number of large animals per ha over grassland area of county *i* at year *t*	Sheep units/ha	780	1.32	1.67
$LIVESTOCK_{it}$	Total livestock population (including sheep and large animals) per ha over grassland area of county *i* at year *t*	Sheep units/ha	780	2.94	3.19
$POLICY_{it}$	= 1 if county *i* implemented SISGC in year *t*, and = 0 otherwise	n.a.	780	0.33	0.47
PS_{it-1}	Purchasing price of live sheep in county *i* at year *t*-1	RMB/kg	780	5.16	2.36
PC_{it-2}	Purchasing price of live cows in county *i* at year *t*-2	RMB/kg	780	4.56	1.80
$PRICE_{iw}$	Weighted price $=\beta^*((PS_{it}+PS_{it-1})/2)+(1-\beta)^*((PC_{it}+PC_{it-1}+PC_{it-2})/3)$, $\beta = 0.598$	RMB/kg	780	5.18	2.19
$Pland_{it}$	The sowing area of county *i* at year *t* over the sowing area of county *i* at the base year of 2001	n.a.	780	1.54	2.34
TEM_{it1}	Average daily temperature for January in county *i* at year *t*	°C	780	−14.12	5.12
TEM_{it2}	Average daily temperature for February in county *i* at year *t*	°C	780	−9.74	5.32
TEM_{it3}	Average daily temperature for March in county *i* at year *t*	°C	780	−2.09	3.79
TEM_{it4}	Average daily temperature for April in county *i* at year *t*	°C	780	6.87	3.22
TEM_{it5}	Average daily temperature for May in county *i* at year *t*	°C	780	14.34	2.43
TEM_{it6}	Average daily temperature for June in county *i* at year *t*	°C	780	19.62	2.32
TEM_{it7}	Average daily temperature for July in county *i* at year *t*	°C	780	21.80	1.90
TEM_{it8}	Average daily temperature for August in county *i* at year *t*	°C	780	19.91	1.91
TEM_{it9}	Average daily temperature for September in county *i* at year *t*	°C	780	13.76	2.03
TEM_{it10}	Average daily temperature for October in county *i* at year *t*	°C	780	5.58	2.68
TEM_{it11}	Average daily temperature for November in county *i* at year *t*	°C	780	−4.04	3.62
TEM_{it12}	Average daily temperature for December in county *i* at year *t*	°C	780	−12.37	4.49
$RAIN_{it1}$	Total monthly precipitation for January in county *i* at year *t*	mm	780	1.29	1.89
$RAIN_{it2}$	Total monthly precipitation for February in county *i* at year *t*	mm	780	1.76	2.42
$RAIN_{it3}$	Total monthly precipitation for March in county *i* at year *t*	mm	780	4.54	5.34
$RAIN_{it4}$	Total monthly precipitation for April in county *i* at year *t*	mm	780	12.45	12.05
$RAIN_{it5}$	Total monthly precipitation for May in county *i* at year *t*	mm	780	28.23	21.09
$RAIN_{it6}$	Total monthly precipitation for June in county *i* at year *t*	mm	780	58.69	37.34
$RAIN_{it7}$	Total monthly precipitation for July in county *i* at year *t*	mm	780	76.32	46.04
$RAIN_{it8}$	Total monthly precipitation for August in county *i* at year *t*	mm	780	55.50	30.12
$RAIN_{it9}$	Total monthly precipitation for September in county *i* at year *t*	mm	780	35.21	22.88
$RAIN_{it10}$	Total monthly precipitation for October in county *i* at year *t*	mm	780	12.38	11.28
$RAIN_{it11}$	Total monthly precipitation for November in county *i* at year *t*	mm	780	5.75	8.85
$RAIN_{it12}$	Total monthly precipitation for December in county *i* at year *t*	mm	780	2.29	2.91
$county_i$	County dummies	n.a.	780	n.a.	n.a.

Notes: 6.7 RMB = 1 Dollar (2018 data).

Table 3
The results of the first stage of the 3SLS estimation.

	MODEL 1				MODEL 2				MODEL 3			
	$log(SHEEP_{it})$		$log(NDVI_{it})$		$log(LARGE_{it})$		$log(NDVI_{it})$		$log(LIVESTOCK_{it})$		$log(NDVI_{it})$	
	Coef.	*t-value*	Coef.	*t-value*	Coef.	*t-value*	Coef.	*t-value*	Coef.	*t-value*	Coef.	*t-value*
$POLICY_t$	−0.052	−0.63	0.115***	5.45	−0.023	−0.25	0.073***	3.93	−0.101*	−1.84	0.100***	4.71
PS_{it-1}	0.027*	1.69	−0.018***	−4.24	—	—	—	—	—	—	—	—
PC_{it-2}	—	—	—	—	0.090***	3.66	−0.012**	−2.42	—	—	—	—
$PRICE_{itw}$	—	—	—	—	—	—	—	—	0.055***	4.79	−0.015***	−3.44
$Pland_{it}$	0.004	0.74	0.003*	1.68	−0.020**	−2.48	0.003	1.63	−0.001	0.80	0.003*	1.68
TEM_{it1}	0.024***	3.23	0.0003	0.15	−0.012	−1.21	0.0001	0.03	0.008*	1.68	−0.001	−0.34
TEM_{it2}	−0.010	−1.20	−0.009***	−4.53	−0.021**	−2.10	−0.008***	−3.92	−0.004	−0.77	−0.009***	−4.32
TEM_{it3}	−0.016	−1.49	0.015***	5.64	0.001	0.08	0.012***	4.53	−0.012*	−1.72	0.015***	5.58
TEM_{it4}	−0.002	−0.20	−0.016***	−7.03	0.003	0.29	−0.017***	−7.34	−0.002	−0.3	−0.017***	−7.20
TEM_{it5}	−0.037**	−2.19	−0.009**	−2.01	0.002	0.11	−0.016***	−3.99	−0.028***	−2.6	−0.010**	−2.49
TEM_{it6}	0.004	0.23	0.003	0.70	−0.063***	−2.95	0.003	0.69	−0.024**	−2.17	0.003	0.82
TEM_{it7}	−0.051***	−2.62	−0.037***	−7.52	0.003	0.13	−0.038***	−7.67	−0.023*	−1.77	−0.037***	−7.49
TEM_{it8}	0.031	1.53	−0.034***	−6.75	0.004	0.17	−0.03***	−6.03	0.017	1.32	−0.033***	−6.53
TEM_{it9}	0.032*	1.76	−0.007	−1.44	−0.038	−1.62	−0.007	−1.43	0.014	1.21	−0.008	−1.64
TEM_{it10}	0.014	1.09	−0.001	−0.36	0.033*	1.98	−0.003	−1.03	0.014	1.6	−0.002	−0.56
TEM_{it11}	−0.017	−1.32	−0.01***	−3.18	−0.006	−0.34	−0.012***	−3.37	−0.01	−1.22	−0.01***	−3.17
TEM_{it12}	0.003	0.26	0.005*	1.70	0.001	0.06	0.004	1.49	−0.001	−0.18	0.004	1.51
$RAIN_{it1}$	−0.006	−0.81	0.001	0.55	−0.003	−0.27	0.002	1.10	−0.0001	−0.02	0.001	0.50
$RAIN_{it2}$	0.017***	2.72	−0.003*	−1.69	−0.004	−0.52	−0.002	−1.28	0.01**	2.55	−0.003*	−1.72
$RAIN_{it3}$	0.004	1.34	0.004***	4.70	0.011***	2.74	0.003***	4.05	0.004**	2.15	0.004***	4.99
$RAIN_{it4}$	−0.002	−1.27	−0.001***	−4.00	0.001	0.31	−0.002***	−4.63	−0.002**	−2.14	−0.001***	−4.20
$RAIN_{it5}$	0.002*	1.98	0.001***	3.54	0.001	0.68	0.001***	2.72	0.001*	1.73	0.001***	3.18
$RAIN_{it6}$	−0.0001	−0.25	0.001***	6.62	−0.001	−1.61	0.001***	6.45	−0.001	−1.57	0.001***	6.67
$RAIN_{it7}$	0.001	1.25	0.001***	4.15	−0.0003	−0.41	0.001***	4.92	0.0004	1.28	0.001***	4.64
$RAIN_{it8}$	0.001*	1.80	0.0002	0.99	−0.001	−0.67	0.0002	0.96	0.001	1.27	0.0002	1.02
$RAIN_{it9}$	0.001	1.05	−0.001***	−3.33	−0.002**	−2.48	−0.001***	−3.58	−0.001	−1.14	−0.001***	−3.73
$RAIN_{it10}$	−0.001	−0.52	0.0002	0.66	0.001	0.47	0.0001	0.38	−0.0002	−0.26	0.0002	0.61
$RAIN_{it11}$	−0.001	−0.34	−0.001	−1.18	−0.005**	−2.11	−0.0003	−0.80	−0.001	−1.22	−0.0005	−1.09
$RAIN_{it12}$	0.001	0.16	0.002	1.00	0.015*	1.89	0.002	1.05	0.005	1.35	0.002	1.03
County FE	Yes		Yes		Yes		Yes		Yes		Yes	
First stage F-statistic	91.82		448.70		131.38		440.96		250.21		444.77	
p-value	0.000		0.000		0.000		0.000		0.000		0.000	
Observations	780		780				780				780	

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Yes in the row of County FE indicates county fixed effects (i.e. county dummy variables).

Table 4
The impacts of SISGC on grassland condition and livestock production estimated by 3SLS estimation.

	MODEL 1		MODEL 2		MODEL 3	
	$log(NDVI_{it})$	$log(SHEEP_{it})$	$log(NDVI_{it})$	$log(LARGE_{it})$	$log(NDVI_{it})$	$log(LIVESTOCK_{it})$
$log(SHEEP_{it})$	−0.589** (-2.15)	—	—	—	—	—
$log(LARGE_{it})$	—	—	−0.160*** (-2.75)	—	—	—
$log(LIVESTOCK_{it})$	—	—	—	—	−0.303*** (-3.37)	—
$log(NDVI_{it})$	—	0.411*** (2.74)	—	0.281 (1.40)	—	0.259*** (2.64)
$POLICY_t$	0.077*** (2.99)	−0.111** (-2.04)	0.078*** (4.16)	0.018 (0.29)	0.073*** (4.62)	−0.113*** (-3.04)
PS_{it-1}	—	0.037*** (3.58)	—	—	—	—
PC_{it-2}	—	—	—	0.075*** (4.86)	—	—
$PRICE_{iw}$	—	—	—	—	—	0.053*** (7.01)
$Pland_{it}$	0.003 (1.48)	—	0.002 (1.17)	—	0.003* (1.74)	—
TEM_{itm}	Yes	—	Yes	—	Yes	—
$RAIN_{itm}$	Yes	—	Yes	—	Yes	—
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Breusch-Pagan Test	χ^2= 611.41 (p = 0.000)		χ^2=251.94 (p = 0.000)		χ^2=250.6 (p = 0.000)	
Observations	780		780		780	

Notes: *t* statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$. Yes in the row of County FE indicates county fixed effects (i.e. county dummy variables).

equation of $LARGE_{it}$, the coefficient of $POLICY_{it}$ is insignificant, which indicates that the implementation of SISGC has not impacted the population of large animals. It should be noted that in some areas the grazing quota for implementing SISGC faced by a household was based on the total number of sheep, regardless of any other animals that the household may own. Next, the significantly positive coefficient of PC_{it-2} demonstrates that an increased price of cows has resulted in a larger animal population.

In *MODEL 3* (dependent variable: $\log(NDVI_{it})$ and $\log(LIVESTOCK_{it})$), the coefficient of $POLICY_{it}$ is again significantly positive in the sub-equation of $NDVI_{it}$, confirming the conclusions in *MODEL 1* and *MODEL* 2. Moreover, the coefficient of $LIVESTOCK_{it}$ is significantly negative, which suggests that grassland condition worsens with the increase in total livestock population. In contrast to MODEL1 and MODEL2, $Pland_{it}$ presents a positive and significant influence on NDVI at the 10% significance level. The potential reason for the positive influence is that the crop production on sowing area offers feed to livestock, which increases the likelihood of rearing animals in captivity instead of purely relying on pastoral grazing. However, it cannot be concluded whether the changes in sowing area between 2001 and 2015 is associated with NDVI due to the inconsistent results in MODEL1-3. In the sub-equation of $LIVESTOCK_{it}$, the coefficient of $POLICY_{it}$ is significantly negative, which indicates that the implementation of SISGC has reduced the total livestock population. The coefficient of $NDVI_{it}$ is significantly positive, which shows that the sheep population increases with the improvement of the grassland condition. The significantly positive coefficient of $PRICE_{iw}$ demonstrates that the total livestock population rises with the increasing price of sheep and cows.

In summary, the results in Table 4 consistently show that the grassland condition has significantly improved following the implementation of SISGC. Furthermore, the population of sheep and the total population of livestock have been reduced, but the large animal population has been unchanged by SISGC. Moreover, livestock price has significantly positive impacts on the population of sheep and large animals and on the total population of livestock. It also shows that more sheep, large animals and livestock would cause the grassland condition to deteriorate, while a better grassland condition increases the sheep population and the total population of livestock. As a robustness check, the same models were estimated by Two-Stage Least Squares (2SLS) (see Appendix A), which gave consistent results thus are not discussed further.

7. Conclusions and discussion

How to alleviate grassland degradation while maintaining the rapidly surging demands for meat products in China is of great interest to policy makers. This paper investigates the impacts of the Subsidy and Incentive System for Grassland Conservation (SISGC) on the grassland condition and livestock production in Inner Mongolia, China. Grassland condition was quantified by the Normalized Difference Vegetation Index (NDVI) by means of remote sensing technology. The livestock production was represented by the population of sheep, large animals and the total population of livestock. A panel dataset was used where data of grassland condition and livestock population were collected for 52 counties in Inner Mongolia over a 15-year period. The implementation of SISGC was represented by a dummy variable. Other factors such as climatic conditions, market prices, agricultural activities and the heterogeneity among counties were controlled for. Simultaneous equation modelling was used to estimate the mutual relationship between grassland condition and livestock production. This bridges the research gap in previous studies that have largely overlooked the mutual relationship between grassland degradation and livestock production.

Empirical results show that the grassland condition and livestock population should be simultaneously estimated to assess the effect of SISGC, as the error terms of the equations of grassland condition and livestock population are contemporaneously correlated. Ignoring this correlation can make the estimation results subject to a simultaneous bias. This study reveals that the grassland condition has significantly improved due to the implementation of SISGC. Furthermore, the population of sheep and the total population of livestock have been significantly reduced by SISGC. In conclusion, the study shows that the prevailing eco-environmental policy of China, SISGC, has prevented further grassland degradation. This result is consistent with the research finding that SISGC has been an effective vehicle in protecting the grasslands in Inner Mongolia (Liu et al., 2018). However, SISGC has reduced the population of sheep and the total population of livestock, which implies that the attenuated grassland degradation has been achieved at the cost of restricting the development of livestock production in the pastoral areas. This finding corresponds with Yin et al. (2019) who found that the net livestock income of herder households was dramatically reduced by the program. With unprecedented urbanization and a continuous rural-urban migration (Liu et al., 2014, 2018), livelihood diversification through off-farm employment could be a plausible path to replace the homogeneous livelihood strategy of sheep grazing on pastureland. Policies should be directed to provide more off-farm employment opportunities and to improve social security systems for herders with few livelihood alternatives, so that living standards and long-term livelihoods of herders can be maintained with reducing livestock numbers.

Considering the soaring meat demands by the Chinese population and the high level of poverty among pastoralists, it is necessary to increase livestock production, instead of restricting it by policy intervention. Moreover, the increasing meat prices are significant factors that prompt pastoralists to increase their livestock population, which in turn impedes the implementation of the eco-environmental policy. Hence, the policy implication is that there is a need to help pastoralists raise animals in captivity in order to increase their livestock population. However, high costs and limited affordability are the main factors inhibiting the shift toward captive breeding (Yu, 2016). In this regard, it is necessary to provide more support to enable the building of facilities for animal rearing in captivity, such as sheds, silage silos, and forage fields. In addition, herders usually stick to the traditional way of raising livestock, i.e. grassland grazing, and are generally lacking sufficient skills for raising livestock in sheds, making technological assistance and training essential to promoting captive breeding. Moreover, the implication for SISGC is that more attention should be paid not only to sheep numbers but also to the large animal population, because large animals also affect the grassland condition negatively, while they have not been affected by SISGC.

Our study has several limitations. Firstly, the policy variable was merely represented by a dummy variable due to data limitations. As a result, we were only able to assess the overall effectiveness but could not disentangle the impacts of different policy instruments, i.e. the grazing ban, livestock-forage balance, and compensation. Secondly, we have based our analyses on secondary data, such as the Statistical Yearbooks of Inner Mongolia, which may be subject to accuracy issues. The reason for this is that its data collection follows a bottom-up procedure, which may be vulnerable to misreporting by pastoralists and local officials hoping to please higher-level governments that want to reduce the population of grazing animals during the implementation of SISGC (Waldron et al., 2007; Liu et al., 2017). Thus, the impacts of SISGC on controlling livestock population might be overestimated as the statistical data from county level. Moreover, the livestock population is an overall measure such that it was unknown to us how much livestock was raised by grazing on the pastoral areas or kept in barns. The producer prices are based on provincial-level rather than county-level data. Nevertheless, our research findings have at least detected some general, if not specific, trends in livestock production. Thirdly, our analysis only included the first five years after the initiation of SISGC, rendering its longer-term effectiveness not investigated. This could be of interest for future research.

Declaration of Competing Interest

None.

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Appendix A

Table A1 presents the impacts of SISGC on grassland condition and livestock production estimated by 2SLS estimation. The model results are consistent with that in Table 4. It indicates our model results are robust.

Table A1
Model results estimated by 2SLS estimation.

	MODEL 1		*MODEL 2*		*MODEL 3*	
	$log(NDVI_{it})$	$log(SHEEP_{it})$	$log(NDVI_{it})$	$log(LARGE_{it})$	$log(NDVI_{it})$	$log(LIVESTOCK_{it})$
$log(SHEEP_{it})$	−0.642 (-1.55)	—	—	—	—	—
$log(LARGE_{it})$	—	—	−0.132** (-2.07)	—	—	—
$log(LIVESTOCK_{it})$	—	—	—	—	−0.277*** (-2.77)	—
$log(NDVI_{it})$	—	0.411*** (2.64)	—	0.281 (1.35)	—	0.259** (2.54)
$POLICY_t$	0.081** (2.07)	−0.111* (-1.97)	0.070*** (3.43)	0.018 (0.28)	0.072*** (4.06)	−0.113*** (-2.93)
PS_{it-1}	—	0.037*** (3.45)	—	—	—	—
PC_{it-2}	—	—	—	0.075*** (4.69)	—	—
$PRICE_{iw}$	—	—	—		—	0.053*** (6.76)
$Pland_{it}$	0.005 (1.17)	—	−0.000006 (-0.00)	—	0.002 (1.20)	—
TEM_{itm}	Yes	—	Yes	—	Yes	—
$RAIN_{itm}$	Yes	—	Yes	—	Yes	—
County FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: t statistics in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Obs. = 780. Yes in the row of County FE indicates county fixed effects (i.e. county dummy variables).

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