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Analysis

The Impact of Snowstorms, Droughts and Locust Outbreaks on Livestock Production in Inner Mongolia: Anticipation and Adaptation to Environmental Shocks

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ABSTRACT

Unanticipated environmental shocks impact the livelihoods of many resource users around the world. These shocks are likely to be more unpredictable as the effects of climate change continue to mount. Yet how households adapt to these changing climatic conditions especially in the context of rapidly changing market conditions in most areas of the world, is poorly understood. These interactions have wide implications for both smallholder livelihoods and sustainable use of natural resources. In this paper, we examine the relationship between environmental shocks and stocking rates in livestock herds in the Inner Mongolian grasslands of northern China. We uniquely examine three types of shocks and how households adapt livestock production strategies in response to each. Separately and in aggregate, we look at three common shocks in Inner Mongolia: droughts, snowstorms, and locust outbreaks. We use a difference-in-differences approach to estimate changes in stocking rates among households that experience shocks versus those that do not with a panel dataset from 2009 to 2014 of 597 households. While we find no clear impact from locusts, our results suggest droughts and snowstorms have opposite effects: droughts are associated with increases in herd sizes, but snowstorms result in decreased herds. We suggest these differences are due to interactions between shocks, emerging options to borrow on credit, and livestock markets. Household adaptation to climate change will be strategic and take advantage of both available resources as well as market conditions.

1. Introduction

Human livelihoods are increasingly subject to processes of global environmental change. Most notable among these processes is climate change, which is increasing average temperatures and variability in precipitation patterns worldwide (Schipper and Pelling, 2006). These shifts are leading to more unpredictable environmental shocks, such as droughts and other unexpected natural disasters, which pose great risks to the billions whose livelihoods are based on the use of primary resources (Trenberth, 2011). Such populations often have limited capacity to buffer their livelihoods against the occurrence of these shocks, risking loss of crops, livestock, other assets, or worse (IPCC, 2007). At the same time, other processes of change, such as population and economic growth, land use change, and natural resource depletion exert a growing influence on livelihoods and create complex dynamics in combination with each other and with the effects of climate change.

Shocks can have negative impacts on livelihoods, but communities also have the ability to adapt to, prevent, or develop strategies to mitigate the effects of environmental change (Jones and Thornton, 2009; Smit and Wandel, 2006). Additionally, socio-economic changes such as improvements in social safety nets, increased income, and better access to credit allow for adaptation strategies that were not available to previous generations (Mertz et al., 2009). In supporting and developing adaptation strategies for coping with global environmental change, primary resource users, policymakers, and researchers could gain understanding from existing survival strategies of people living in historically shock-prone ecosystems (Berman et al., 2015).

Grasslands and other drylands present good opportunities to study adaptation to environmental shocks, because these regions are characterized by erratic precipitation patterns, which have historically forced pastoralists to deal with regular but unpredictable droughts and snow storms (Engler and von Wehrden, 2018). On the Mongolian Steppe, traditional adaptation strategies have included the use of *otor*, a practice of seasonal migration, which has been especially important as a

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response to major winter storms, or *dzud* (Ahearn, 2018; Du et al., 2018; Mijiddorj et al., 2019). Pastoralists herding yaks on the Tibetan Plateau (Levine, 1999), cattle in the East African Savannah (Scoones, 1992), reindeer in Norway (Næss and Bårdsen, 2013), as well as sheep and goats in East Africa (Bertram-Huemmer and Kraehnert, 2018) are known to expand their herds during favorable conditions. Environmental constraints historically prevented unsustainable increases in stocking rates and helped maintain balance in the social-ecological system. Yet in many cases, these constraints have been relieved by more modern adaptation strategies enabled by economic, market, and policy changes in pastoral areas, which now make it easier to buffer herds against environmental shocks (Gongbuzeren Huntsinger and Li, 2018; Robinson et al., 2017). As environmental conditions have become less of a constraint, herd sizes have also increased in many places, with overgrazing becoming a widespread and urgent sustainability problem in many rangelands (Suttie et al., 2005). This suggests that while traditional strategies of coping with environmental shocks can be a constructive adaption to changing conditions, some may be ill-suited to new conditions and present new challenges, and understanding government responses to aid such cases is poorly understood (Miyasaka et al., 2017).

Environmental shocks on grasslands, such as droughts, snowstorms, and locust plagues, can result in significant losses to herds. This is especially damaging as livestock are often a major component of herders' overall wealth (Dercon, 1998), and can provide a crucial buffer during years when income is low (Jarvis, 1974; McPeak, 2004). Studying the effect of environmental shocks on pastoral household production is therefore important for at least two reasons: first, for its effects on herder vulnerability and, second, for how these vulnerabilities in turn influence ecological outcomes on rangelands. Studies assessing the impact of shocks on herder behavior often focus on reductions in productivity (Dercon, 1998; Little et al., 2001; Lybbert et al., 2007) or loss of a portion of the herd (McPeak, 2004; Næss and Bårdsen, 2013). Rigorous assessments of how household livelihood strategies react and adapt to dynamic market, climate, and resource conditions are limited.

In this paper, we examine the relationship between environmental shocks and stocking rates in herds in the Inner Mongolian grasslands of northern China. Separately and in aggregate, we look at three main types of shocks that are known to occur in Inner Mongolia: droughts, snowstorms, and locust outbreaks. Our methods construct a counterfactual estimate of how shocks affect herding households relative to other similar households that did not experience shocks through a difference-in-differences (DID) statistical approach. Our data come from a large panel dataset that recorded household level production information, including stocking rates, in 2009 and 2014, and environmental shocks that occurred during this 5-year period. Our contribution to the literature is twofold. First, we uniquely separate extreme events into distinct shock categories to assess whether shock types relate to different outcomes. Second, using these disaggregated results, examine how distinct environmental factors can related to different measures of adaptation.

2. Materials & Methods

2.1. Study Area

The Inner Mongolia Autonomous Region (hereafter Inner Mongolia), is China's third largest province-level administrative division, with an area of nearly 1.2 million km^2, or 12% of the country's total area (Yang et al., 2008). Annual precipitation is below 500 mm throughout most of Inner Mongolia, with a precipitation gradient that increases from west to east (Wu et al., 2015). The climate is characterized as continental, with average July temperatures ranging from 16 °C to 26 °C and average January temperatures ranging from −28 °C to −8 °C (Wu et al., 2015). Environmental conditions vary widely from east to west and represent a variety of grassland and rangeland types including meadow steppe, typical steppe, sandy steppe, desert steppe, and desert (Ding et al., 2014).

There are likely several aspects that influence herders' decisions regarding how many livestock to keep on their land. Policies have been implemented in recent years to limit overgrazing by imposing maximum stocking rate limits which are enforced with the use of economic incentives, namely subsidies and fines (Hua and Squires, 2015). However, these policies have had limited success due to, among other things, lack of enforcement (Kolås, 2014) and insufficient monetary compensation (Xie et al., 2015). Regardless, winter limits grassland productivity and has historically been the main constraint on livestock production in Inner Mongolia (Robinson et al., 2017), though currently herders at least perceive drought to be the most damaging type of shock, followed by winter snowstorms (Li et al., 2013). Historically pastoralist communities on the Mongolian Plateau coped with most shocks through herder mobility. However, current grassland policies, projects, and general economic development have enabled Inner Mongolian herders to adopt more modern mechanisms for adaptation to drought and snowstorms (Li and Jin, 2013; Robinson et al., 2017). For example, the Beijing-Tianjin Sandstorm-Control Program, the Grassland Eco-Compensation Program, and the Return Grazing Land to Grassland Program all involve paying herders to reduce the stocking rate on grasslands, which is achieved by keeping livestock in sheds on a seasonal basis. To achieve the policy aims of reduced stocking rates, programs have been carried out to help herders build warm sheds and sheds for storing forage. Besides the improvement in infrastructure, forage markets have also been fostered during last 20 years, and have gradually become the main strategy for shock resistance (Han and Hou, 2011; Li et al., 2013).

2.2. Data Collection, Cleaning, & Preparation

A detailed household-level panel dataset of herding households across Inner Mongolia was collected in 2010 (on household production activities in 2009) and 2015 (on 2014 activities). The survey design focused on household production activities, assets, income, expenditures, demographics, and socio-economic characteristics (see Appendix Table A.1 for a summary of the question modules). The survey sample design used a stratified random sampling strategy to ensure representation across the five grassland types mentioned above. Three counties or *banners* (a designation for a county-level administrative region in IMAR) were randomly selected in each grassland type, three townships within each county, and then around 20 households from each town. The sample size in the first wave was 900 households. In spring 2015, the survey team revisited households to conduct the follow-up survey. The final panel dataset consists of 750 households that were interviewed in 2010 and 2015, representing 83% coverage of the baseline with good consistency across all counties.

Most households raise sheep and goats, but some also hold horses, cows, or camels. To account for livestock types in a standardized way, following standard international convention, we convert all livestock holdings into standard sheep units (SSU). An SSU describes the number of "sheep equivalents" other livestock represent based on energy requirements. General conversion ratios are developed as international standards (e.g., Chilonda and Otte, 2006) but are often regionally tailored to local animal varieties and environmental condition. We follow the SSU conversion ratios used by the Chinese Academy of Agricultural Sciences in Hohhot, Inner Mongolia where the ratio of an animal to sheep for a goat is 0.8:1, a dairy cow is 8:1, a horse or beef cow is 7:1, and a camel is 9:1 (Li et al., 2018).

A goal of this paper is to improve our understanding of the effects of extreme environmental events, what we refer to as "shocks", on herder livelihoods. In the region, we identified three main shock types that aimed to examine based on literature and our experience in the field: droughts (Li et al., 2007; Wang and Zhang, 2012; Wang et al., 2014), snowstorms (Du et al., 2018; Joly et al., 2018; Rao et al., 2015), and locust outbreaks (Cease et al., 2015; Cease et al., 2012). To avoid the difficulty in defining what constitutes a droughts, snowstorms, or locust “shock” across varying conditions, we asked respondents to subjectively assess how many times they perceived that a given shock occurred between our two survey waves (i.e., between 2009 and 2014). While this is subject to some interpersonal measurement error, our analysis aggregates the *frequency* of a shock to a dichotomous assessment of whether a shock occurred or not. We also simply ask if a shock occurred, not for an assessment of the severity or magnitude of any shock event, as this would also be difficult to measure in a standard way. We lose information by simplifying to a dichotomous ‘shock/no shock’ variable, but this makes the data less prone to subjectivity bias. We prompted respondents that *drought* should refer to shocks caused by inadequate rainfall during the growing season, a *snowstorm* indicates “white disasters” or *dzud*, as they are known by local herders, and a *locust outbreak* is when locusts reach abnormal populations typically resulting in vegetation damage.

We analyze only a balanced panel, including households that were sampled in both survey waves, for several reasons. First, our survey only asked households about shocks they experienced during the second wave of data collection, so those sampled in 2010 only do not have any associated drought, snowstorm, or locust information and thus cannot be included in our analysis. We sampled some households in 2015 only, and for these we do have shocks data. See Table A.2 for a summary of shocks for each sample type (2010 only, 2015 only, or sampled in both years). There is no significant difference in the natural logarithm of the stocking rate (our dependent variable in models below), but the amount of grassland held, livestock sales income, and household sizes are greater for households that were only sampled in the 2nd wave compared to households with repeated measures (Table A.3). To keep identification of the impact of shocks as clean as possible and to take into account that households sampled in 2015 appear somewhat different from the households with repeated measures, we only include the latter in the main presentation of our results. Regardless, testing models with both samples included result in qualitatively similar results (coefficient point estimates differ but the magnitude and direction of effect is similar).

A number of considerations required us to exclude some of the households surveyed to focus on the effects of unanticipated shocks on natural resource dependent households. First, we excluded 44 households for whom a stocking rate value was missing in either year. We also dropped 22 households did not have livestock in one of our study years. Third, we excluded 31 other households whose production was dairy-oriented, and therefore primarily grain-based rather than grassland-dependent. Finally, we exclude 56 outlier households whose stocking rates were in the 95th percentile (above 5.8 SSU/ha) of the surveyed distribution, as these likely indicate industrial operations. These exclusions resulted in all households sampled in Ewenke banner being removed ($n = 44$ hh). This seems appropriate since many villagers in Ewenke uniquely graze in part on public lands, making their ‘stocking rate’ a different measure than in other households with only private land and, second, many households in Ewenke are dairy producers. In the end we analyze 597 households for this study (Table 1).

As a summary metric of socioeconomic status among herders, we created an index that assigns a relative score to households based on their asset holdings. The asset index was calculated by multiplying weights from the first component from a principal components analysis by the quantity of each asset (Filmer and Pritchett, 2001; Sahn and Stifel, 2003). Assets are often a better measure of durable wealth (Carter and Barrett, 2006) than simple income, since income can fluctuate dramatically over time, thereby introducing measurement error, especially in developing economies (Booysen et al., 2008). Our survey recorded asset information on housing, buildings, machinery, vehicles, and various household appliances. We did not include livestock as an asset in this calculation to avoid a lack of independence in our measure of socioeconomic status and the stocking rate, which will be our dependent variable. We reviewed the correlation among asset variables to ensure they are all positively related (thus increasing quantities all justifiably represent increasing wealth) and checked that none are over- or under-represented in our dataset as being $>95\%$ or $<5\%$ of the population, respectively. Several appliances were strongly correlated with other variables, so in the end were excluded from the asset index. See Table A.4 for the assets included and the first principal component weights that make up the asset index (Fig. 1).

Table 1
Grassland holdings, livestock holdings, and ethnicity of the study population.

Year	Average (range) grassland used, ha	Average (range) # livestock, SSU	Mongol, %	Han, %
2010	620 (27–7000)	548 (35–4602)	77	23
2015	689 (20–5331)	570 (6–4014)	78	22

Note: Neither *average grassland used* nor *# livestock* are statistically different over the two panel years ($p = .11$ and $p = .46$, respectively).

2.3. Study Population

In 2010 grassland holdings ranged from 27 to 7000 ha, with an average value of 620 ha per household. By 2014 households held 20 to 5331 ha with an average holding of 689 ha (not statistically significantly different; $p = .11$). Over 77% of households identified as Mongolian and 22% as Han, and a single household was Manchu. On average households owned 548 and 570 sheep units in 2010 and 2014, respectively ($p = .46$).

Table 2 presents the number of shocks households reported experiencing, by category, between 2009 and 2014. The most frequent type of shock reported by households was drought ($\mu = 1.30$ per household; $\sigma = 1.68$). Snowstorms were reported with less frequency ($\mu = 0.47$; $\sigma = 0.91$), followed by locust outbreaks ($\mu = 0.05$; $\sigma = 0.36$). While most households reported at least one shock of any type (71.9%) ($\mu = 1.83$; $\sigma = 1.93$), no individual shock type was experienced by a majority of the herders. Large numbers of herders reported experiencing droughts (49.2%, max = 5) and snowstorms (38.0%, max = 12). Comparatively few experienced locust outbreaks (3.0%, max = 5). Cumulatively, almost all households report the total number of all shocks experienced as no more than 7, with only three households reporting more – one reported 8 shocks, one reported 14, and another reported 15.

Table 3 shows how the number and type of shocks vary by grassland type, with 49 to 145 households in each grassland type. There is also variation in the number of households experiencing droughts (17–96%) and snowstorms (9–78%) in each grassland type, while the percentage of households experiencing locusts falls in a narrower range (0–10%). Table 3 also provides a description of how stocking rates vary between treatment households (those experiencing at least one shock during 2009–2014) and control households (those experiencing no shocks during 2009–2014) in the baseline and follow-up panels. The average stocking rate decreases between 2009 and 2014 from 1.52 to 1.32 SSU/ha.

Appendix Fig. A.1 and Table A.5 illustrate these patterns by county. Differences between counties are statistically significant using an ANOVA test, so we control for county-level fixed effects in the models presented below.

In our dataset, reports of snowstorms and droughts show nearly no correlation ($r = -0.081$, $p = .05$). To further assess and validate measuring snowstorms and droughts separately, we check whether snowstorms and drought co-occurred in a single year or occurred sequentially in multiple years using county-level monthly precipitation data collected by the China Meteorological Service from 1959 to 2019 (912 county-year precipitation observations total). Using 30%

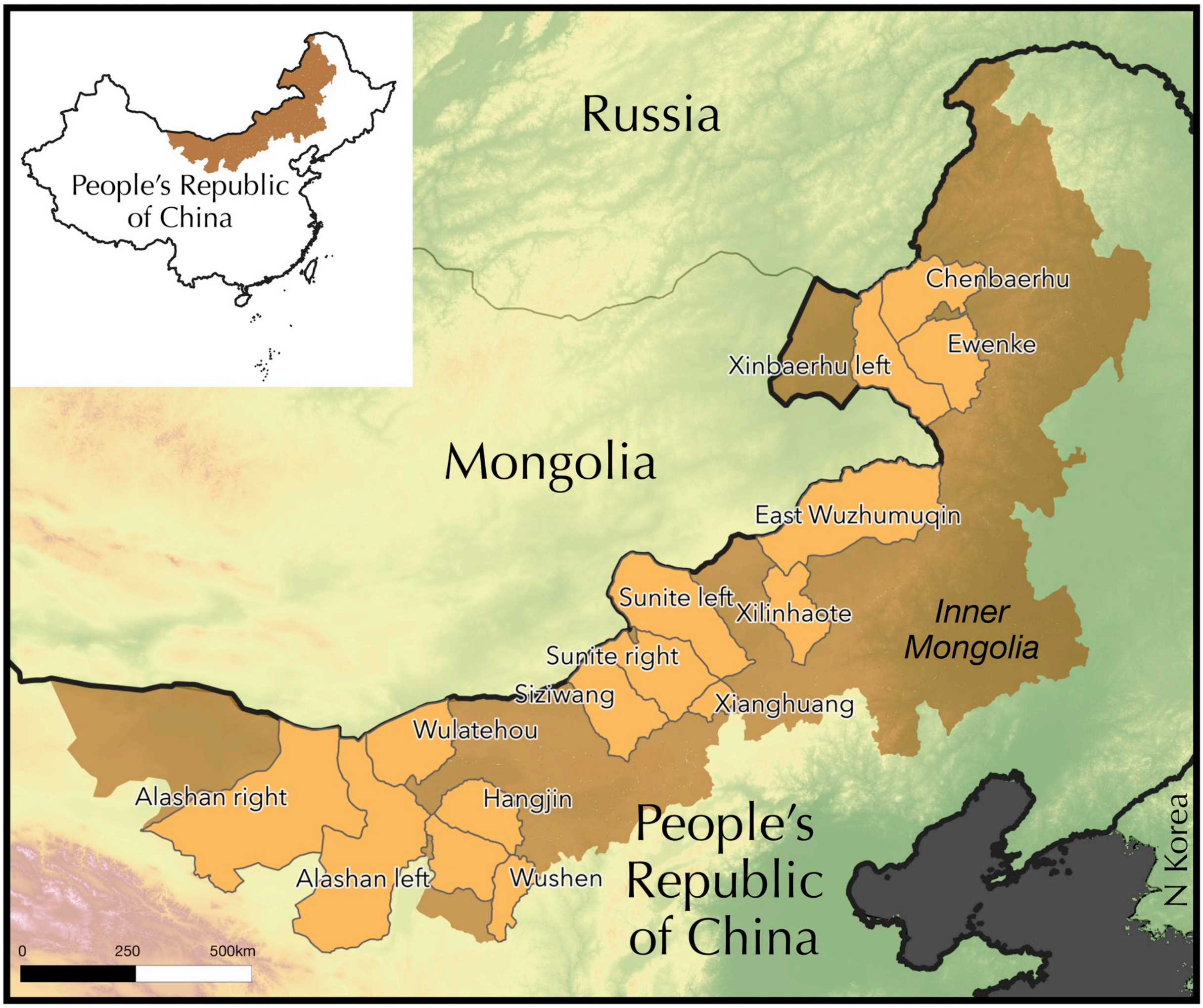

Fig. 1. Sampled counties in Inner Mongolia in light orange; non-sampled counties of Inner Mongolia are dark orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Distribution of household-reported shocks by number and shock type.

# Shocks	% households reporting shock type			hh cumulative total[a]
	Droughts	Snowstorms	Locusts	
0	50.8	62.0	97.0	28.1
1	14.9	32.7	1.8	29.2
2	10.6	4.7	0.8	13.4
3	10.2	0.2	0	11.6
4	4.2	0	0	4.4
5	9.4	0.2	0.3	9.7
6	0	0	0	2.2
7	0	0	0	1.0
8	0	0	0	0.2
9	0	0	0	0
12	0	0.3	0	0
14	0	0	0	0.2
15	0	0	0	0.2

[a] The column labeled "hh cumulative total" refers to the percent of households who experienced that number of the sum of all shocks. For example, one household (0.17% of all households) reported 5 snowstorms and 3 instances of drought, so cumulatively reported 8 shocks total over the 2009–2014 period.

deviation from average to define a drought or snowstorm, the probability of a summer drought and winter snowstorm in the same year in Inner Mongolia is just 3.7%. The likelihood of a snowstorm shock in a winter and a drought in the following summer is 5.5%. Among the 912 records, three counties recorded heavy snow in winter in 2010 and drought in 2011. Records indicate Xinbaerhu left banner had heavy snow in 2009 and 2010 and then drought in summer of 2010. Snow, drought, and snow again is only present in 1.2% of possible cases, drought-snow-drought just 0.8%, drought in consecutive years is 2.7%. Some herders mention "continuous shocks" during conversations, but mostly in reference to known events in the 1960's, 1980's, and an event around 2000.

2.4. *Analytic Approach*

Our goal is to understand how unexpected shocks affect household livelihoods. If we simply looked at the relationship between changes in household livelihoods and the number of shocks they report experiencing, we would implicitly assume there is no 'background' temporal trend in our outcome of interest. However, in most contexts, and particularly given China's rapidly growing and changing market conditions, assuming outcomes would not have otherwise changed between two points in time is a poor assumption. To understand how shocks impact households, we construct a "control" group of households that are subject to similar background trends and conditions but did not experience any of the shocks, which we can use as a basis for comparing households that do experience shocks.

A difference-in-differences (DID) model allows us to assess associations between a variable of interest (here, shocks) which one portion

Table 3
Shock and stocking rate statistics by grassland type.

Grassland type	Total # hhs	% reporting drought	% reporting snowstorms	% reporting locust outbreaks	Mean stocking rate (SSU/ha)					
					Baseline (2009)			Follow-up (2014)		
					Treatment (# shocks > 0)	Control (# shocks = 0)	Overall	Treatment (# shocks > 0)	Control (# shocks = 0)	Overall
Desert	145	34.49	15.17	10.35	0.99	0.77	0.87	0.91	0.65	0.77
Desert steppe	137	95.62	45.26	0	0.98	0.43	0.98	0.87	0.49	0.87
Meadow	49	22.45	77.55	0	2.51	3.01	2.57	2.39	2.00	2.34
Sandy steppe	123	63.41	8.94	0	1.77	1.67	1.74	1.96	1.77	1.90
Typical steppe	143	16.78	65.74	2.1	2.19	2.02	2.13	1.53	1.35	1.47
All grassland types	**597**	**49.25**	**38.02**	**3.02**	**1.57**	**1.40**	**1.52**	**1.39**	**1.15**	**1.32**

of the population experiences (the "treated" group), compared to a group that does not have exposure to that variable (the "untreated" group). A DID approach requires information on both treated and untreated groups both before and after the "treatment" and assumes that, in the absence of shocks, both groups would follow the same average trends over time (the "parallel trend" assumption). While the DID approach assumes background trends are the same, it can also control for time-invariant differences in the groups (e.g., grassland type, managerial ability, skill, etc.) that are unrelated to whether they experience shocks. Assuming the parallel-trend assumption holds, comparing the change in stocking rate between 2009 and 2014 of treatment relative to control households, we can better isolate the effect of the environmental shocks on stocking rates. A DID approach estimates the impact of a treatment variable as:

$$Z_{DID} = [E(y_t \mid D = 1) - E(y_{t'} \mid D = 1)] - [E(y_t \mid D = 0) - E(y_{t'} \mid D = 0)] \quad (1)$$

where y is the outcome of interest, here, the stocking rate; D represents whether a household experiences a shock (1) or not (0); t' and t are times before (2009) and after (2014) the treatment, respectively; and E is the expectation operator.

Econometrically, the DID model takes the form:

$$y^j{}_{it} = \beta_0 + \beta_1 P_t + \beta_2 D^j + \beta_3 (P_t \bullet D^j) + \beta_4 \mathbf{x} + e^j{}_{it} \quad (2)$$

where $y^j{}_{it}$ is the natural log of the stocking rate for household i at time t in treatment group j. Stocking rates are measured as the maximum (summer) herd size (SSU) in the summer divided by the total amount of grassland (ha) used by the household. We use herders' summer (as opposed to winter) stocking rate since herders seldom feed animals market-purchased forage during summer, meaning summer stocking rates better reflect actual grassland dynamics. Additionally, winter herd sizes are generally reported as the number of animals around January of a given year, so would not likely reflect the impact of a year's extreme winter events. For these reasons, we think summer herd size is the better measure. This equals the number of animals held by the household at the start of the year, plus those that were bought or born, prior to sale in the autumn. The variable P_t is a dummy variable equal to 0 if the measurement is from the 2009 panel and 1 if the measurement relates to 2014 data. The variable D^j is binary and equals 0 if the household experienced no shock (the control group) or 1 if the household experienced a shock (the treatment group). The interaction term $P_t \cdot D^j$ is 1 if the measurement is taken after the treatment *and* the individual is in the treatment group, and 0 otherwise. The first three coefficients to be estimated are β_0 (the y-intercept), β_1 (the average trend over time), and β_2 (the average difference between treatment and control groups). β_3 represents Z_{DID} and is the primary effect of interest, interpreted as the effect of experiencing a shock relative to those that do not. The vector $\mathbf{x}$ represents other covariates that help control for non-random differences in the treatment and control groups. The error term is denoted by $e^j{}_{it}$.

Our outcome of interest is the stocking rate in SSU per hectare. Although imperfect, stocking rates have long been the primary management metric available to rangeland managers (Westoby et al., 1989). We are also concerned that there may be a non-linear relationship between shocks and stocking rates due to the size or intensity of households' livestock holdings. That is, the impact of a shock may be very different for a household that starts with a stocking rate of 0.4 versus 4.5 SSU/ha. Therefore as a robustness check we also estimate a second set of models using the proportional change in household stocking rates as the outcome that are presented in the Appendix Table A.7. Final robustness models were run that treated each shock independently in a singular model, following literature that assesses multiple treatment arms (Fricke, 2017), which are given in the Appendix Table A.8. To indicate which households had or had not experienced the given shock type between 2009 and 2014, we created a dummy variable for each of the three shock types, and one for all three in aggregate.

Since our data were not collected to randomize across shocks, we test models that include covariates that we hypothesize could impact households' stocking rate decisions. We assume the stocking rate choice is determined by local (a) environmental variability, (b) plot characteristics, (c) household demographics, and (d) socioeconomic context. We proxy these categories with independent variables in our models that include, respectively, (a) frequency and type of environmental shocks, (b) area of grassland owned per household and bioregional grassland type classification, (c) household size, household age composition and dependency ratio (number of healthy working age adults divided by the household size), and (d) assets, educational attainment, alternative income sources and income from livestock. We include these multiple demographic characteristics since household structure can play a large role in stocking choices by determining opportunities for migration (e.g., young laborers seeking work in nearby cities), wage earning opportunities (elderly household members may engage more in farm work), and incentives for investment (e.g., invest in the farm productivity vs a child's education). All models reported below use the natural log of stocking rates as dependent variables. The statistical software Stata (StataCorp, 2016) was used to perform the DID analysis (Villa, 2012).

3. Results

Table 4 shows results of a set of DID models that estimate the impact of different shock types – (I) drought, (II) snowstorms, (III) locust outbreaks, and (IV) all in aggregate – on the natural log of the stocking rate. Each model controls for covariates and ecological classifications of grassland type. We present separate models for each shock type including the most basic DID specification (i), a model which includes grassland-type controls (ii) and one which includes grassland type and county-level fixed effects (iii). As we will see in Table 4, our models show relative stability – the direction and order of magnitude of effects

Table 4
Difference-in-differences coefficient estimates based on the natural log of the stocking rate. Main treatment effects are in bold italics.

	I. Drought			II. Snowstorms			III. Locust outbreaks			IV. All shocks		
	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)
Second period (2014)	−0.197**	−0.171**	−0.174***	−0.0391	0.006	0.0023	−0.084	−0.0606	−0.0638	−0.181	−0.150*	−0.153*
Treatment group	−0.309***	−0.116*	−0.104	0.409***	0.174**	0.128*	0.163	0.143	0.126	0.141	0.016	0.035
Impact of shock	0.209*	0.213**	0.211**	−0.146	−0.185**	−0.183**	−0.346	−0.115	−0.124	0.120	0.116	0.116
Used grassland ('000 ha)		−1.317***	−1.245***		−1.304***	−1.239***		−1.307***	−1.235***		−1.309***	−1.234***
Used grassland^2 ('000 ha^2)		0.173***	0.159***		0.170***	0.157***		0.171***	0.158***		0.172***	0.157***
HH size		0.0447**	0.038*		0.043**	0.037*		0.043*	0.037*		0.044**	0.037*
# under 16		−0.0119	−0.004		−0.015	−0.006		−0.011	−0.004		−0.009	0.000
# over 60		−0.0573	−0.055		−0.054	−0.055		−0.060	−0.059		−0.057	−0.054
Dependency ratio		−0.0871	−0.115		−0.097	−0.128		−0.096	−0.127		−0.085	−0.112
Asset index		0.050***	0.044***		0.050***	0.044***		0.050***	0.044***		0.049***	0.043***
Education level		0.035	0.027		0.034	0.026		0.034	0.026		0.032	0.023
Seek outside work		0.132*	0.081		0.135*	0.086		0.134*	0.083		0.133*	0.083
Use 'otor' (pasture mobility)		0.127*	0.166**		0.140*	0.169**		0.120*	0.163**		0.126*	0.163**
Livestock sales ('0,000 ¥)		0.022***	0.023***		0.022***	0.023***		0.022***	0.023***		0.022***	0.023***
Constant	0.215***	0.003	0.674***	−0.092*	−0.095	0.564***	0.058	−0.054	0.632***	−0.038	−0.041	0.585***
Fixed effect controls												
Grassland type	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
County	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.02	0.58	0.60	0.04	0.58	0.60	0.00	0.57	0.60	0.01	0.57	0.60
AIC	3110.0	2137.2	2082.8	3087.5	2137.3	2085.0	3128.5	2145.5	2092.0	3116.5	2141.5	2085.2
N	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194

* = $p < .05$.
** = $p < .01$.
*** = $p < .001$.

are consistent for all shock types and all model specifications. Further, the variables selected for our model show no worrisome multicollinearity issues as there is no pairwise over |0.40|, and an ordinary least squares model shows no variance inflation factor over 8.3. Thus, we have good confidence our results are not due to variable selection or model specification.

Given that the dependent variable is log-transformed, coefficient estimates approximately indicate the percent change in stocking rate that is associated with a unit change in an independent variable, on average and all else equal. The first three variables in Table 4 are the main components in a DID analysis: the effect of being from in the latter panel year β_1, effectively controlling for the overall time trend, the average effect of being in the treatment group β_2, and the "impact of shock" estimates, β_3, where the shock type is indicated differentially by the different models I-IV. All other independent variables that follow are covariates to help control for other characteristics that could affect stocking rate decisions.

Several results are noteworthy. Primarily, we see droughts are significantly associated with an *increase* in stocking rate across all model specifications, while snowstorms are associated with a *decrease* in stocking rate when any level of controls are included. These effects are statistically significant to at least the 99% confidence level. Interpreting these results directly, we would conclude that households reporting the occurrence of droughts are associated with a stocking rate increase of 21.1% (Model I.iii) relative to those that report no droughts over the time period of our data. Households that report the occurrence of snowstorms are associated with a stocking rate decrease of 12.1% (Model II.iii). In contrast, locust outbreaks are not significantly related to changes in stocking at any level of statistical significance, and the positive drought and negative snowstorm effects seem to cancel each other out when combining all shocks in aggregate. Indeed, models that combine different shock types (results not shown) reveal *droughts* + *snowstorms* aggregated has no significant impact on stocking rates, *droughts* + *locusts* report a significant positive effect (the drought effect dominates), and *snowstorms* + *locusts* show a significant negative effect (i.e., the snowstorm effect dominates).

Other covariates seem important in helping explain stocking rates. Coefficients associated with covariate data have consistent magnitudes and levels of significance across model specifications and shock types. Across all models, larger grassland holdings are associated with lower stocking rates, at a rate that becomes weakly stronger with increasing grassland size (likely due to decreasing economies of scale or the fact that larger landholdings are also often in less productive grasslands). Larger and wealthier households (those with a higher asset index indicating greater wealth) are also associated with higher stocking rates. Many grassland type and county fixed effects are significant (results not shown), indicating the importance in taking account of these level effects.

Livestock income was included in the model to control for households that were more market-oriented and also as a medium through which we might see a household response to shocks. The latter reason means that this variable simultaneously determined with stocking rates, our dependent variable, so we also test models without livestock sales included (Table A.6). R^2 and AIC measures prefer the model with livestock sales included, so the models presented have this included, though models without livestock sales show qualitatively equivalent results for snowstorms, droughts, and locusts. The results in Table 4 show that livestock sales are consistently associated with higher stocking rates (at greater than a 95% confidence level).

The use of 'otor', a traditional Mongolian mobile herding strategy that allowed herders to seek food and water resources for their herds on others' lands, is also a control variable that might indicate a practice that could influence stocking rates but also be a responses to a shock. We see models that include 'otor' show it is important and positively associated with stocking rates. Still, models that exclude the 'otor' variable show nearly equivalent coefficient estimates for the impact of shock in all model cases.

Overall, our results are remarkably stable across alternate models. Table A.7 provides estimates looking at the change-ratio in stocking rate between panel years. We further tested OLS, fixed effect, and random effect models that include droughts, snowstorms, and locust shocks as independent treatment variables within the same model (Table A.8). In all cases, the main coefficients of interest are of the same direction and significance (and magnitude, in the case of Table A.8) as results presented in Table 4.

4. Discussion

4.1. Impact of Droughts on Stocking Rates

We interpret these results with a contextual understanding of how herders respond and adapt to droughts and snowstorms differentially. Droughts are a major stress for herders and, at first, the finding that droughts are associated with higher stocking rates may appear counter-intuitive as it is in contrast with conventional wisdom and empirical studies from other areas (e.g., Desta and Coppock, 2002; Hart and Carpenter, 2005; Rao et al., 2015). Based on anecdotal evidence from the field, descriptive responses from herders, and our own experience, we suggest this is largely a strategic response to increasing market opportunities.

Droughts limit the grassland's ability to support animal growth and health. When the animals do not gain enough weight over the summer growing season, they have limited market options for two reasons. First, animals that do not weigh enough will sell for poor prices, if saleable at all. Second, the markets to sell livestock operate mostly during the autumn. During drought years, there is then a cumulative supply-demand effect where all herders either want to sell off their livestock and cut their losses for the year, or supplement grassland grazing with purchased forage. Indeed, most households suggested their first line of defense when facing a drought is to purchase forage. This shock to the market drives the cost of forage up and the price for animals down. Therefore, to gain higher prices for livestock, and indeed sometimes in order to simply find a willing buyer at all, herders may forego income from livestock sales in a drought year and keep their livestock until forage and livestock markets stabilize. This allows sheep and goats to reach a saleable weight. Therefore, following an intense drought, herders' livestock numbers may increase. These dynamics suggest droughts create heavy financial burdens for herders who increasingly have the option to buffer against drought by purchasing hay and feed, though often on borrowed capital (Nadin et al., 2016).

Further, a production system in which reproduction is built on herders' stock of ewes, a larger number of animals means there is more opportunity to expand production in a good season. Thus, herders hold higher stocking rates in anticipation or adaptation to droughts (Li et al., 2013). However, the effects of this adaptive activity depend on livestock markets as well as precipitation. In cases of multi-year sequential droughts, larger herd sizes will increase production costs and may stress forages and water resources. Still, when the next season is favorable, a herder starting the season with a larger herd will have more opportunity to recover from the drought by quickly expanding their livestock numbers. The livestock market in Inner Mongolia has fluctuated but generally increased over the last ten years, which has encouraged herders to hold onto larger stocks during bad years (Ma et al., 2016).

4.2. The Impact of Snowstorms on Stocking Rates

Snowstorms have very different characteristics relative to droughts, which may give rise to the negative effect we see from snowstorms on stocking rates. We think there may be two complementary issues that lead to this. The first reason relates to the direct effects of the weather shock on livestock. Snowstorms are quick and not easily anticipated, with sometimes fast-acting and intense effects on livestock that may make adaptation difficult. In the country of Mongolia, for example, severe winter weather killed over 20% of the country's livestock on just 2 separate occasions between 1999 and 2012 (Fernández-Giménez et al., 2012; Rao et al., 2015). Thus, snowstorms may represent legitimate surprises with significant mortality rates, to which herders find it difficult to adapt or rebound.

Second, we think that increasingly market dynamics likely play a role. The ability to procure and store forage for the winter offers the possibility of buffering herds from high mortality rates. Further, since snowstorms happen early in the year, animals have a longer period for their body weight to recover from the winter shock by the time the livestock market opens in the autumn. Some herders are able to prevent animal deaths from snowstorm by having a winter supply of forage on hand and/or keeping livestock in protective sheds. Households in our sample, on average, report that snowstorms only sometimes result in livestock death – usually the main effects are increase in costs or loss in livestock body weight. Still, the supply and demand dynamics that result in the wake of these shocks increases the cost of forage significantly. Therefore herders that purchase feed supplements in winter at these high costs often feel they must be offset by selling more animals in autumn. This can lead to a decreased stocking rate in the year after.

4.3. Locusts and Stocking Rates

Despite locusts being reported as a major pest in Inner Mongolia (Cease et al., 2012), locust outbreaks do not appear to have a strong relationship with stocking rates. While this shock type was recorded in a number of households, it was clustered in a few specific regions and did not appear to have widespread impacts during our study period. Thus, the impact of locusts, at least over this period, did not impose significant livelihood constraints for the average herder in Inner Mongolia. Further, pest control in Inner Mongolia has likely become more effective in recent years, limiting the impact of locusts. When herders find locusts in their fields, they can call the local grassland management station and team is sent in to spray insecticide. This is funded by the central government, making it a no- or low-cost option for herders.

4.4. The Heterogeneity of "Shocks" and Policy Implications

The results show the advantage of separately identifying and analyzing specific shock types. Looking simply at what households identified as "shocks to production" in aggregate misses the very different impacts that appear to come from droughts and snowstorms. Historically, stocking rates rose due to herd maximization strategies, but were balanced by downward pressures from mortality due to natural shocks and strategic responses to market conditions. Loans are taken out to purchase supplemental feed as an adaptation to droughts during the summer and results in an increased stock of animals.

Snowstorms, by contrast, also require purchases to keep animals alive, but the timing leads to greater sales of animals over the winter. The differential impacts associated with these two shock types reflect different capacities and capabilities to adapt to different climate *and* market conditions. The ability to anticipate and plan for these impacts, both in the near and medium term, change how herders are able to develop resilient and adaptive livelihood strategies.

While climate shocks inherently lack predictability, livestock markets are designed and constructed. In this context, the short-term and singular autumn market for sheep and goat sales appears to be a major constraint in allowing markets to operate flexibly and smoothly. One sale period means that supply and demand dynamics all hinge on a single period, so allowing some herders to sell early before much damage is done, and others to hold onto a herd that needs time to recover, forces all to react to the same market pressures, likely exacerbating high feed costs and low animal values during intense shock years. Allowing greater opportunities for year-round markets would likely serve producers and consumers well. Market-based instruments such as index insurance programs for grasslands could also play a role (Jin et al., 2015; Vroege et al., 2019). A livestock-based insurance program in Mongolia was effective in buffering losses and smoothing consumption during a 50-year snowstorm event (Bertram-Huemmer and Kraehnert, 2018).

Government interventions to improve the timing of markets would be a novel policy approach for Inner Mongolia. Grassland protection and livelihood improvement policies have focused mainly on privatization (Rangeland Household Contract Policy (RHCP)), stocking rate limitations, access to subsidies and credit, ecological construction (Rangeland Ecological Construction Projects (RECP), and herder resettlement (Nomad Settlement Policy (NSP)). Most of these policies have yielded mixed results, suggesting these policies could benefit from being more flexible and adaptable to local conditions (Gongbuzeren Huntsinger and Li, 2018; Li and Li, 2012; Wang et al., 2013). Recently herders have reduced the practice of *otor* even these resources were rendered scarce by environmental shocks (Xie and Li, 2008). Our results show that environmental shocks have significant effects on herds, and government policies to promote year-round access to livestock markets could help to reduce herd sizes without exposing herders to economic risk or pressuring them to give up on herding. Importantly, we suggest livestock markets should not only focus on animals for sale for slaughter but add in sales that facilitate a year-round breeding or exchange markets for livestock at different age stages. Such markets could be government supported and largely be facilitated through online platforms to connect smallholder buyers and sellers.

Because shocks were measured in this study as a binary (households either did or did not experience the given shock between 2009 and 2014), our study was not able to capture the effects of differing shock severity on stocking rates. Our data collection strategy could also capture a period when households just happened to be in the midst of 'buildup' and recovery years from droughts and at the same time could have been a period of particularly devastating winter of snowstorms. We also recognize there is large spatial heterogeneity in climate conditions over Inner Mongolia. Our DID analysis gives us households average effects, which may mask more locally-specific adaptation mechanisms. Future studies that take these issues into account would help deepen our understanding of these relationships.

5. Conclusion

The Inner Mongolian case shows that droughts are associated with increases in livestock stocking rates, while snowstorms are associated with decreases in stocking rates. We hypothesize these differential effects reflect a combination of herd management strategies and strategic reactions to existing market conditions. The tendency of Inner Mongolian herders to expand their herds as much as possible in good times was well suited to historic conditions under which natural disasters would inevitably bring herd populations back to a stable and sustainable level. However, markets now facilitate trade and access to financial and material resources which mitigate livestock mortality. Our results suggest that slow-moving droughts allow for herders to build up livestock numbers and respond with forage-purchase strategies that prevent the sale-off of their herd. Faster snowstorms can kill livestock, and their timing seems to lead to greater selling-off of livestock since access to forage is limited following those shock types. The interaction of herd management strategies and the availability of market resources and modern adaptation strategies leads to a situation where there is a decoupling of the local social-ecological system and, potentially, over-exploitation of resources.

Looking ahead, global climate change will lead to an increase in the number or intensity droughts, storms, or other unfavorable climate events for some regions. Instead of changing stocking rates reactively and suddenly, herders need to be able to respond to shocks strategically with the help of resources already available in modernizing grazing economies such as savings, credit, insurance, or other government support. Policy makers could support herders in building capacity to use these modern strategies to enhance their resilience to climate changes and shocks. In the presence of a strong state or high level of market integration, policymakers should aim to shape more markets for breeding and trade of livestock at different life stages throughout the year, provide safety nets that support welfare, include measures that discourage opportunistic resource exploitation, and be well-targeted to situations where people are vulnerable to extreme climate events. While it can be difficult to forecast the severity of droughts or snowstorms, proxies for herd health can sometimes be used to forecast the vulnerability of herds to climate events (Joly et al., 2018). Government interventions would benefit from better understanding how strategies can avoid eliciting unintended responses from herders.

Declaration of Competing Interest

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

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Appendix A

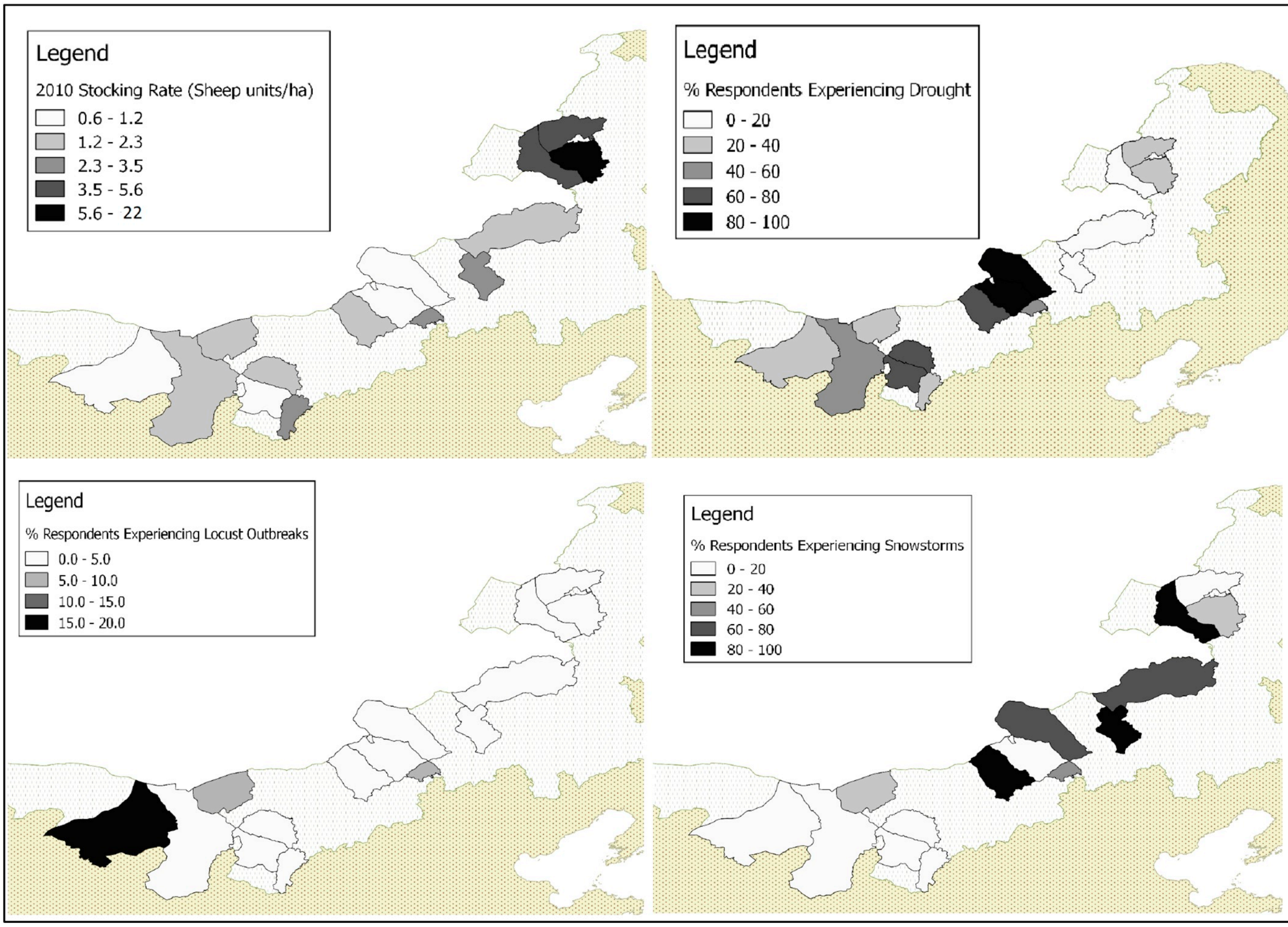

Fig. A.1. Stocking rates and environmental shock occurrence across counties.

Table A.1
Question modules in household survey.

Question module	# of variables
Household demographics (age, gender, education level, employment status, ethnicity etc. of members.	56
Herd composition (Number of each species, number of adults, young and fertile females, animals and animal by-products bought and sold by species.	134
House and homestead characteristics (number; types; area, material; price, incl. Houses, wells, fencing, sheds etc.)	79
Environmental shocks (drought, snowstorms, locusts, other)	7
Adaptation (Climate adaptation strategies, government assistance for adaptation, amount and type of subsidies, cooperation among neighbors)	87
Assets (e.g. cars, trucks, motorcycles, tractors, mowers, refrigerator, DVD player, cell phone)	53
Income (sources; amount by source, including livestock income, other income, perceived trends)	55
Costs (amount by various categories, including herding & non-herding costs)	63
Grassland property (area contracted, area rented in/out; area used for grazing, hay, crops etc.)	30
Animal feed (types, amount bought/grown by weight, unit price if bought/sold)	48
Grazing practices (e.g. whether or not herders fatten animals or practice *Otor*)	18

Table A.2
Shocks for each household sample type.

Shock type \ shocks:	Sampled 2010 only		Sampled 2010 & 2015 (sample analyzed in paper)		Sampled 2015 only	
	Experienced	Did not	Experienced	Did not	Experienced	Did not
Any shock	.	.	1062 (858)	438 (336)	114	32
Droughts	.	.	714 (588)	786 (606)	78	68

(*continued on next page*)

Table A.2 (*continued*)

Shock type \ shocks:	Sampled 2010 only		Sampled 2010 & 2015 (sample analyzed in paper)		Sampled 2015 only	
	Experienced	Did not	Experienced	Did not	Experienced	Did not
snowstorms	.	.	578 (454)	922 (740)	63	83
locusts	.	.	40 (36)	1460 (1158)	5	141
# unique hhs	160		750 (597)		146	
# observations	160		1500 (1194)		146	

Table A.3
Difference in means (paired *t*-tests) for key variables for household sample types.

Variable	Difference in means between single-observation and two-observation households	
	1st wave data (2010 only)	2nd wave data (2015 only)
	$\mu_{2010\|single\ obs} - \mu_{2010\|two\ obs}$	$\mu_{2015\|single\ obs} - \mu_{2015\|two\ obs}$
ln(stocking rate)	−0.14	0.14
Raw stocking rate	−0.94***	−0.36**
Grassland held	168.11**	162.51**
Household size	0.26*	0.39***
Under 16	−0.00	−0.06
above60	0.04	0.14*
Dependence ratio	−0.01	0.00
Asset index	1.65***	0.18
education	−0.03	0.04
working	0.00	0.07*
Livestock sales	14.03*	68.36***

* $p \leq 0.10$.
** $p \leq 0.05$.
*** $p \leq 0.01$.

Table A.4
Assets included in the asset index and first principal component weights.

Asset variable	1st Principal component
ln(house area)	0.4501
Total shed area	0.2624
# Wells	0.4020
# Passenger cars	0.3817
# Motorcycles	0.2277
# Tractors	0.4591
# Mowers	0.3982
# Trucks	−0.0009

Table A.5
Shocks and stocking rate statistics by banner.

Banner (county)	Total # hhs	% Reporting drought	% reporting Snowstorms	% Reporting locust outbreaks	Mean stocking rate (SSU/ha)				Grassland type
					Baseline (2009)		Follow-up (2014)		
					Treatment (# shocks >0)	Control (# shocks = 0)	Treatment (# shocks >0)	Control (# shocks = 0)	
Alashan left banner	46	39.13	8.70	0.00	0.97	0.89	0.76	0.59	Desert
Alashan right banner	52	34.62	3.85	17.31	0.93	0.40	0.90	0.58	Desert
Chenbaerhu banner	16	43.75	43.75	0.00	2.91	2.88	2.94	2.30	Meadow
East Wuzhumuqin banner	53	3.77	71.70	0.00	1.76	1.69	1.40	1.24	Typical steppe
Etuoke banner	48	64.58	2.08	0.00	1.24	1.16	1.38	1.45	Sandy steppe
Hangjin banner	44	68.18	15.91	0.00	1.81	2.00	1.85	1.42	Sandy Steppe
Siziwang banner	37	86.49	64.86	0.00	1.46	–	1.10	–	

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Table A.5 (*continued*)

Banner (county)	Total # hhs	% Reporting drought	% reporting Snowstorms	% Reporting locust outbreaks	Mean stocking rate (SSU/ha)				Grassland type
					Baseline (2009)		Follow-up (2014)		
					Treatment (# shocks > 0)	Control (# shocks = 0)	Treatment (# shocks > 0)	Control (# shocks = 0)	
									Desert steppe
Sunite left banner	46	97.83	69.57	0.00	0.99	0.43	0.71	0.49	Desert steppe
Sunite right banner	54	100.00	11.11	0.00	0.66	–	0.85	–	Desert steppe
Wulatehou banner	47	29.79	34.04	12.77	1.07	1.10	1.02	0.83	Desert
Wushen banner	31	54.84	9.68	0.00	2.61	2.04	3.12	2.53	Sandy steppe
Xianghuang banner	42	47.62	42.86	7.14	2.35	2.39	1.58	1.60	Typical steppe
Xilinhaote	48	4.17	79.17	0.00	2.55	1.65	1.81	1.10	Typical steppe
Xinbaerhu left banner	33	12.12	93.94	0.00	2.36	3.26	2.27	1.40	Meadow
All counties	**597**	**49.25**	**38.02**	**3.02**	**1.57**	**1.40**	**1.39**	**1.15**	

Table A.6
Full Models, excluding livestock sales.

	I. Drought	II. Snowstorms	III. Locusts outbreaks	IV. All Shocks
Second period (2014)	−0.171**	0.00451	−0.0603	−0.151*
Treatment group	−0.114*	0.121*	0.168	0.0265
Impact of shock	**0.212****	**−0.180***	**−0.127**	**0.117**
Used grassland (‘000 ha)	0.159**	0.161**	0.154**	0.156**
Used grassland^2 (‘000 ha^2)	−1.180***	−1.174***	−1.168***	−1.169***
HH size	0.150***	0.148***	0.149***	0.148***
# under 16	0.0560***	0.0547**	0.0539**	0.0545**
# over 60	−0.0142	−0.0165	−0.0131	−0.0103
Dependency ratio	−0.0683*	−0.0684*	−0.0714*	−0.0675*
Asset index	−0.142	−0.153	−0.152	−0.138
Education level	0.0675***	0.0676***	0.0678***	0.0668***
Seek outside work	0.0417	0.0404	0.0406	0.0375
Use ‘otor’ (pasture mobility)	0.0673	0.0724	0.0691	0.0693
Livestock sales (‘0,000 ¥)	–	–	–	–
Constant	0.798***	0.692***	0.753***	0.715***
Fixed effect controls:				
Grassland type	No	Yes	Yes	No
County	No	No	Yes	No
R^2	0.57	0.57	0.57	0.57
AIC	2164.5	2167.2	2172.9	2167.8
N	1194	1194	1194	1194

Table A.7
Models of Proportional Changes in Stocking Rate.

	I. Drought			II. Snowstorms			III. Locust outbreaks			IV. All shocks		
	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)
Second period (2014)	−0.197**	−0.163***	−0.165***	−0.039	−0.005	−0.006	−0.084*	−0.051	−0.053	−0.180**	−0.146*	−0.148*
Treatment group	−0.000	−0.105*	−0.092	0.000***	0.047	0.087	0.000	0.040	−0.025	0.000	−0.034	−0.046
Impact of Shock	**0.209****	**0.202****	**0.203****	**−0.146***	**−0.147***	**−0.149***	**−0.346**	**−0.340**	**−0.335**	**0.120**	**0.117**	**0.117**
Owned grassland (ha)		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Owned grassland^2 (ha^2)		0.00	0.00		−0.00	−0.00		−0.00	−0.00		0.00	0.00
HH size		0.003	−0.001		0.002	−0.002		0.003	−0.000		0.002	−0.001
# under 16		0.017	0.013		0.016	0.010		0.014	0.009		0.017	0.012
# over 60		−0.012	−0.008		−0.015	−0.010		−0.018	−0.014		−0.014	−0.011
Dependency ratio		−0.128	−0.124		−0.140	−0.136		−0.137	−0.133		−0.134	−0.134
Asset index		0.018*	0.016		0.018	0.016		0.018	0.016		0.021*	0.019
Education level		−0.046*	−0.038		−0.047*	−0.038		−0.049*	−0.041*		−0.048*	−0.039

(*continued on next page*)

Table A.7 (*continued*)

	I. Drought			II. Snowstorms			III. Locust outbreaks			IV. All shocks		
	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)	(i)	(ii)	(iii)
HH seeks outside work		0.047	0.048		0.053	0.052		0.048	0.048		0.0476	0.0478
Livestock sales ('000 RMB)		−0.001***	−0.001***		−0.001***	−0.001***		−0.001***	−0.001***		−0.001***	−0.001***
Constant	0.001	0.151	0.268	−0.001	0.086	0.190	0.001	0.124	0.232	0.001	0.142	0.263
Fixed controls:												
Grassland type	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
County fixed effects	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.03	0.08	0.10	0.02	0.07	0.10	0.01	0.07	0.10	0.01	0.07	0.09
AIC	1977.1	1940.7	1929.3	1988.6	1945.4	1934.6	1991.5	1945.9	1932.8	1992.7	1947.6	1936.9
N	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194

* = $p < .05$.
** = $p < .01$.
*** = $p < .001$.

Table A.8
Models including all shocks together (as multiple simultaneous treatments).

	I. OLS			II. Fixed effects		III. Random effects		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Impact of shock								
Drought	***0.201****	***0.203*****	***0.199*****	***0.201*****	***0.190*****	***0.201*****	***0.201******	***0.198******
Snowstorm	***−0.134***	***−0.172****	***−0.168****	***−0.134****	***−0.170*****	***−0.134****	***−0.173*****	***−0.168*****
Locusts	***−0.373***	***−0.116***	***−0.154***	***−0.373****	***−0.186***	***−0.373****	***−0.121***	***−0.157***
Treatment group								
Drought	−0.280***	−0.140**	−0.104	–	–	−0.280***	−0.141**	−0.103
Snowstorm	0.388***	0.243***	0.120*	–	–	0.388***	0.243***	0.121*
Locusts	0.222	−0.007	0.139	–	–	0.222	0.001	0.142
Independent controls								
Second period dummy	−0.131	−0.122*	−0.0991	−0.131*	−0.101	−0.131*	−0.118*	−0.100
Used grassland ('000 ha)		−1.466***	−1.236***		−1.011***		−1.428***	−1.213***
Used grassland^2 ('000 ha^2)		0.191***	0.158***		0.103***		0.182***	0.152***
Household size		0.043*	0.037*		−0.006		0.035*	0.032
# under 16		−0.005	−0.005		0.060		0.008	0.004
# over 60		−0.043	−0.052		−0.048		−0.045	−0.051
Dependency ratio		−0.076	−0.116		−0.129		−0.090	−0.118
Asset index		0.075***	0.044***		–		0.076***	0.044***
Education level		0.047*	0.028		−0.011		0.040	0.024
Seek outside work		0.015	0.085		0.013		0.014	0.072
Use 'otor' (pasture mobility)		0.102	0.166**		–		0.100	0.166**
Livestock sales ('0,000 ¥)		0.024***	0.023***		–		0.024***	0.023***
Constant	0.046	0.250	0.603***	0.063**	0.686***	0.046	0.291*	0.629***
Fixed effect controls								
Household	No	No	No	Yes	Yes	Yes	Yes	Yes
Grassland type	No	Yes	Yes	No	Yes	No	Yes	Yes
Banner	No	No	Yes	No	Yes	No	No	Yes
R^2	0.052	0.553	0.606	0.044	0.172			
AIC	3077.7	2202.7	2075.6	1135.1	980.0			
N	1194	1194	1194	1194	1194	1194	1194	1194

* $p < .05$.
** $p < .01$.
*** $p < .001$

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