Global Environmental Change xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Climate adaptation, local institutions, and rural livelihoods: A comparative study of herder communities in Mongolia and Inner Mongolia, China

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ARTICLE INFO

Article history:
Received 7 October 2012
Received in revised form 21 August 2013
Accepted 28 August 2013

Keywords:
Climate adaptation
Local institutions
Rural livelihoods
Herder communities
Mongolian grasslands

ABSTRACT

Climate variability has been evident on the Mongolian plateau in recent decades. Livelihood adaptation to climate variability is important for local sustainable development. This paper applies an analytical framework focused on adaptation, institutions, and livelihoods to study climate adaptation in the Mongolian grasslands. A household survey was designed and implemented in each of three broad vegetation types in Mongolia and Inner Mongolia. The analytical results show that livelihood adaptation strategies of herders vary greatly across the border between Mongolia and Inner Mongolia, China. Local institutions played important roles in shaping and facilitating livelihood adaptation strategies of herders. Mobility and communal pooling were the two key categories of adaptation strategies in Mongolia, and they were shaped and facilitated by local communal institutions. Storage, livelihood diversification, and market exchange were the three key categories of adaptation strategies in Inner Mongolia, and they were mainly shaped and facilitated by local government and market institutions. Local institutions enhanced but also at times undermined adaptive capacity of herder communities in the two countries, but in different ways. Sedentary grazing has increased livelihood vulnerability of herders to climate variability and change. With grazing sedentarization, the purchase and storage of forage has become an important strategy of herders to adapt to the highly variable climate. The multilevel statistical models of forage purchasing behaviors show that the strategies of livestock management, household financial capital, environmental (i.e., precipitation and vegetation growth) variability, and the status of pasture degradation were the major determinants of this adaptation strategy.

1. Introduction

Grasslands occupy about 50% of Earth's terrestrial surface (and 38% of the Asian continent). They are generally characterized by single-stratum vegetation structures dominated by grasses and other herbaceous plants. They provide about 70% of the forage for domesticated livestock globally (Brown and Thorpe, 2008). In the semiarid and arid grasslands of the world, such as Africa and Inner Asia, migrations over long distances have been a particularly important livelihood adaptation strategy of pastoralists living with a highly variable climate and vegetation productivity (Fernandez-Giménez and Le Febre, 2006; Humphrey and Sneath, 1999; Mwangi, 2007). For centuries, traditional institutions like flexible property boundaries and reciprocal use of pastures have allowed pastoralists to use pastures efficiently and to cope with frequent climate hazards. Those institutions have evolved over centuries and are well suited to the biophysical characteristics of the local environment. Grasslands are the dominant ecosystem types on the Mongolian plateau, including most parts of Mongolia and the Inner Mongolia Autonomous Region (IMAR), China. About 84% (1.26 million km^2) and 66% (0.78 million km^2) of the total areas of Mongolia and Inner Mongolia, respectively, are classified as grasslands (Angerer et al., 2008; Zhang, 1992). Similar to other traditional grazing systems, herders on the Mongolian plateau have adapted to the highly variable climate by altering their mobility patterns, shifting livelihood strategies, varying herd compositions, and undertaking market activities (Fernandez-Giménez, 1997; Humphrey and Sneath, 1999; Williams, 2002).

Climate on the Mongolian plateau is continental with cold winters and warm summers. Drought and Dzud (severe winter snowstorms) are the major types of climate hazards on the Mongolian plateau (Martin, 2010). In recent decades, climate on

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http://dx.doi.org/10.1016/j.gloenvcha.2013.08.014

Please cite this article in press as: Wang, J., et al., Climate adaptation, local institutions, and rural livelihoods: A comparative study of herder communities in Mongolia and Inner Mongolia, China. Global Environ. Change (2013), http://dx.doi.org/10.1016/j.gloenvcha.2013.08.014

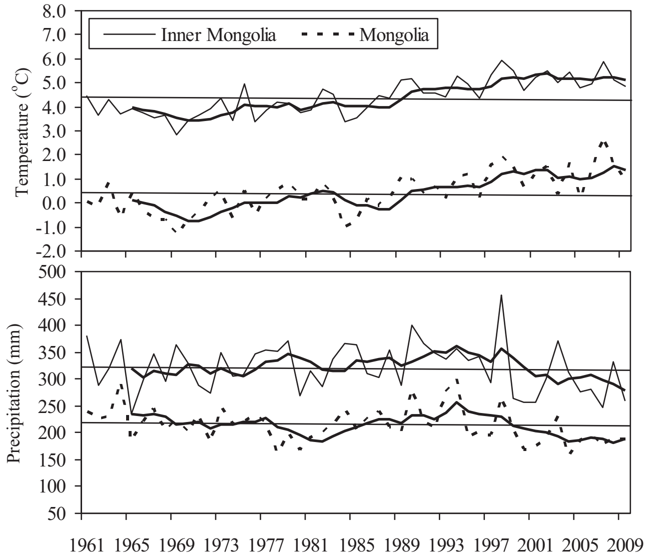

Fig. 1. The temporal variability of annual mean temperature (a) and annual precipitation (b) in Inner Mongolia and Mongolia with multi-year means and five-year moving averages (1961–2009).

the Mongolian plateau has been getting warmer and drier (Fig. 1). Climate dynamics affects rural communities through changes in both mean values of key climate variables and their variability (Lemos et al., 2007). Between 1961 and 2009, annual mean temperature increased about 2.1 °C in Mongolia and about 2.0 °C in Inner Mongolia, and annual precipitation decreased about 7.0% in Mongolia and about 6.6% in Inner Mongolia (Wang et al., 2013). The frequencies of climate hazards in Mongolia have increased since the early 1960s (Fernandez-Giménez et al., 2012; MMS, 2009). The worst droughts and Dzuds that Mongolia experienced in recent decades were in the consecutive summers and winters of 1999, 2000, 2001, and 2002, which affected 50–70% of the total territory. About 12 million livestock perished in that period (Wang et al., 2013). The 2010 Dzud was the worst ever, resulting in the death of about 8.5 million livestock or 20% of the 2009 national livestock populations in Mongolia (Vernooy, 2011). Pasture degradation has further increased livelihood vulnerability of the natural-resource-dependent herders in Mongolia and Inner Mongolia. The results of large-scale field ecological surveys show that the average grassland biomass productivity in Inner Mongolia and Mongolia decreased from 1871 to 900 kg/ha and from 804 to 369 kg/ha, respectively, between 1961 and 2010 (IMIGSD, 2011; IOB, Mongolia, 2011). Poverty has been prevalent in herder communities of Mongolia and Inner Mongolia (Coulombe and Altankhuyag, 2012; Griffin, 2003; Mearns, 2004; Nixson and Walters, 2006; Olonbayar, 2010; Zhang, 2007).

Future climate scenarios project that in the next 30 years annual mean temperature on the Mongolian plateau will increase 0.4–1.6 °C, especially in summer and autumn (0.8–1.6 °C), and there will be no increase of annual precipitation in most parts of the Mongolian plateau (Tang et al., 2008). IPCC AR4-A1B future climate scenarios (mean projections of 21 models, Christensen et al., 2007) show that comparing the end of this century (2080–2099) with the end of last century (1980–1999), the average winter temperature on the Mongolian plateau will increase 3–5 °C; the average summer temperature will increase 2.5–4 °C; the average winter precipitation will increase 5–30%; and the average summer precipitation in most parts of the Mongolian plateau will increase 5–10%. The livelihoods of herders on Mongolian plateau will be more vulnerable to future adverse climate conditions.

Vulnerability, social adaptation, and adaptive capacity are interrelated concepts used in the analysis of the potential effects of climate and other stressors on local communities and their potential responses to them (Adger, 2006; Eakin, 2005; Smit and Wandel, 2006; Turner et al., 2003). Humans have constantly adapted to changes in the conditions and dynamics of the climate they experience. Social adaptation to climate change can happen at multiple scales (Adger et al., 2005). Adaptation can result from top-down changes in policies and institutions and bottom-up household-level autonomous responses (Agrawal, 2009). The effectiveness of social adaptation depends on a variety of environmental and social contextual factors that are both internal and external to local communities. Research based on extensive case studies shows that local institutions play a key role in shaping livelihood adaptation strategies of rural communities and households to climate change (Agrawal, 2010). Institutions include both formal laws and policies and informal norms that structure human interactions and govern interactions between human and environment (North, 1990; Ostrom, 1990). Local formal institutions are the instruments of national policies and institutions, and they can also evolve locally to structure human interactions. Local institutions can either enhance or undermine adaptive capacity of rural communities for climate change (Adger, 2000; Li and Huntsinger, 2011). To reduce climate-related vulnerability, it is important to understand how local institutions have shaped climate adaptation, and how local institutions can enhance adaptive capacity of rural communities for future climate change.

Agrawal (2010) argued that in the context of climate as a major stressor on rural communities, local institutions can influence rural livelihoods and their adaptations in three major ways: (1) they shape the impact of climate change on rural communities; (2) they shape the ways that rural communities respond to climate change; and (3) they are the intermediaries for external support to local climate adaptation. External interventions that facilitate climate adaptation can work through provisions of information, technology, finance, and leadership. In the framework focused on adaptation, institutions, and livelihoods developed by Agrawal (2009), local institutions were classified as local public/governmental, private/market, and civic/communal institutions. Livelihood adaptation strategies in the context of climate risks to livelihoods are assigned into five major types: (1) mobility, which pools climate risks across space; (2) storage, which pools and reduces climate risks over time; (3) livelihood diversification, which reduces climate risks across assets owned by households or collectives; (4) common pooling, which pools climate risks across households in local communities; and (5) market exchange. All of these adaptation strategies can only work in certain formal (e.g., property rights) and informal (e.g., trust and reciprocity) institutional arrangements, i.e., adaptation never occurs in an institutional vacuum. Based on the framework focused on adaptation, institutions, and livelihoods (Agrawal, 2009), we analyze the interactions among climate-related vulnerability, livelihood adaptation strategies, local institutions, and external interventions related to the herder communities of Mongolia and Inner Mongolia, China.

Social institutions related to livestock grazing have changed dramatically on the Mongolia plateau over the past decades (Neupert, 1999; Sneath, 1998; Upton, 2009). Mongolia and Inner Mongolia experienced social transformations from traditional "communal" forms of ownership to collective economies during the early 1960s and late 1950s, respectively. They also experienced privatization in the early 1990s and mid-1980s, respectively (Fernandez-Giménez, 1997; Jiang, 2005; Wang et al., 2013). In Mongolia, pastures are managed under a combination of customary rights and formal-use rights. Due to the lack of effective resource institutions, conflicts related to pastures use have

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increased (Upton, 2009). Although mobile grazing is still the dominant livestock management strategy in Mongolia, the distances and frequencies of migrations have decreased, especially in areas with fertile pastures and water resources (Humphrey and Sneath, 1999; Olonbayar, 2010). Since economic reforms in Mongolia in the early 1990s, herders in Mongolia have lost support from the government for migration-related transportation and forage in the winter and spring seasons. Herders with limited endowments tend to migrate less frequently or to be sedentary. In addition, the collapse of the collective economy and livestock privatization has led to an increase in the domestic subsistence orientation in Mongolia (Humphrey and Sneath, 1999).

In Inner Mongolia, most pastures are contracted to individual households and fenced under the “household production responsibility system” (HPRS) (Li et al., 2007; Williams, 2002; Zhang, 2007). Livestock grazing in most parts of Inner Mongolia has been sedentarized, with localized fodder production, stall-feeding, and grazing. The implementation of HPRS has been recognized as a major cause of pasture degradation in Inner Mongolia (Humphrey and Sneath, 1999; Li et al., 2007; Sneath, 1998; Zhang, 2007). Since the early 2000s, the Chinese national government has been making and implementing a range of policies to break a self-reinforcing cycle of a declining resource base and poverty (Waldron et al., 2010). One of these policies, known as “Grain to Green,” involves converting pastures and farmland to grasslands (Liu et al., 2008). In Inner Mongolia, the market economy is growing rapidly, and herders benefit from livelihood opportunities generated by the thriving economy and strong governmental investments.

Although several studies have been conducted to investigate social vulnerability and adaptation to climate on the Mongolian plateau (Fernandez-Giménez et al., 2012; Li and Huntsinger, 2011; Li and Li, 2012; Murphy, 2011; Sternberg, 2010; Vernooy, 2011; Zhang, 2007), more empirical studies of the livelihood adaptation strategies of herders and associated local institutions in Mongolia and Inner Mongolia are still necessary. In this study, we advance existing knowledge about livelihood adaptation strategies of herders to climate variability and the ways local institutions enhance and undermine adaptive capacity of herder communities on the Mongolian plateau. We also aim to identify the constraints on livelihood behavioral adaptations. Addressing these constraints can help enhance the adaptive capacity of herder communities for future climate change. Specifically, we implemented a survey questionnaire to collect data for comparative studies of livelihood adaptation strategies of herders in Mongolia and Inner Mongolia, China. Comparative analyses of the livelihood adaptation strategies of herders under different institutional arrangements are also expected to advance our understanding of the relationships among climate adaptation, local institutions, and rural livelihoods.

Our study focuses on the following questions: (1) What were the major livelihood adaptation strategies of herders on the Mongolian plateau over the past ten years? (2) Did those livelihood adaptation strategies vary between Mongolia and Inner Mongolia? and (3) What were the determinants of the variations in livelihood adaptation behaviors? We hypothesized that: (1) livelihood adaptation strategies of herders varied clearly between Mongolia and Inner Mongolia, and these differences reflected differences in local institutions; and (2) local institutions, accessibility to markets, household capital, and environmental variability were the major determinants of livelihood adaptation behaviors of herders on the Mongolian plateau. Following the introduction, we provide brief descriptions about the household survey design and implementation in Section 2. In Section 3, we introduce the methods for analyzing livelihood adaptation strategies and the determinants of livelihood adaptation behaviors of herders. The results are presented in Section 4. Finally, we summarize the findings of this work and discuss the implications of the results.

2. Household survey design and implementation

2.1. Survey design

We designed a household survey to study livelihood adaptation strategies of herders on the Mongolian plateau. The survey included four major sections: (1) basic socioeconomic and demographic information, land-use and management behaviors, livestock management strategies, household incomes and expenditures, and grazing and living facilities owned by the household; (2) livelihood adaptation strategies of herder households and associated local institutional facilitators (i.e., government, market, and communal institutions); (3) climate hazards and fluctuations in the prices of livestock products (2000–2009); and (4) formal and informal resource institutions (i.e., environmental policies, traditional grazing norms, social connections, and agricultural cooperatives). We first identified 51 livelihood adaptation strategies by interviewing local people, including local herders, governmental officials, and grassland scientists. The 51 preselected adaptation strategies were categorized into five major types: mobility, storage, communal pooling, livelihood diversification, and market exchange (Agrawal, 2009). Herders were asked to select the strategies they had used in the last ten years and, for each adaptation strategy, to select among three types of institutional facilitators (i.e., government, market, and communal institutions). Besides mobile grazing, mobility in the study area also included urban–rural and rural–urban migrations. The livelihood adaptation strategies of herders can result from multiple stressors, such as climate variability and change, pasture degradation, socioeconomic change (e.g., fluctuations in the prices of livestock products), and changes in resource policies and institutions. In the questionnaire, we also asked questions related to socio-institutional changes. The survey questions were pretested and revised iteratively on the basis of open-ended interviews with local herders.

2.2. Survey implementation

The household survey was implemented to sample herder households from a range of ecological settings within Mongolia and Inner Mongolia (Table 1). The surveyed households were distributed in four provinces of Mongolia (Dornod, Sukhbaatar, Umnugobi, and Dornogobi) and three counties of Inner Mongolia

Table 1
The biophysical characteristics of the field sites in Mongolia and Inner Mongolia, China.

Country	Field site	Vegetation type	Precipitation[a] (mm)	Precipitation$_{CV}$[b] (%)	Elevation (m)
Mongolia	Dornod	Meadow steppe	259.53	26	793.57
	Sukhbaatar	Typical steppe	205.18	29	1070.11
	Dornogobi	Desert steppe	126.90	35	1022.48
	Umnugobi	Desert steppe	92.37	37	1329.26
Inner Mongolia, China	Ewenke	Meadow steppe	299.61	25	895.70
	Xilinhot	Typical steppe	243.75	30	988.54
	Wulatezhong	Desert steppe	162.80	33	1289.86

[a] Mean annual precipitation (1961–2009).
[b] The interannual variability of precipitation measured by the coefficient in variation (CV) of annual total precipitation.

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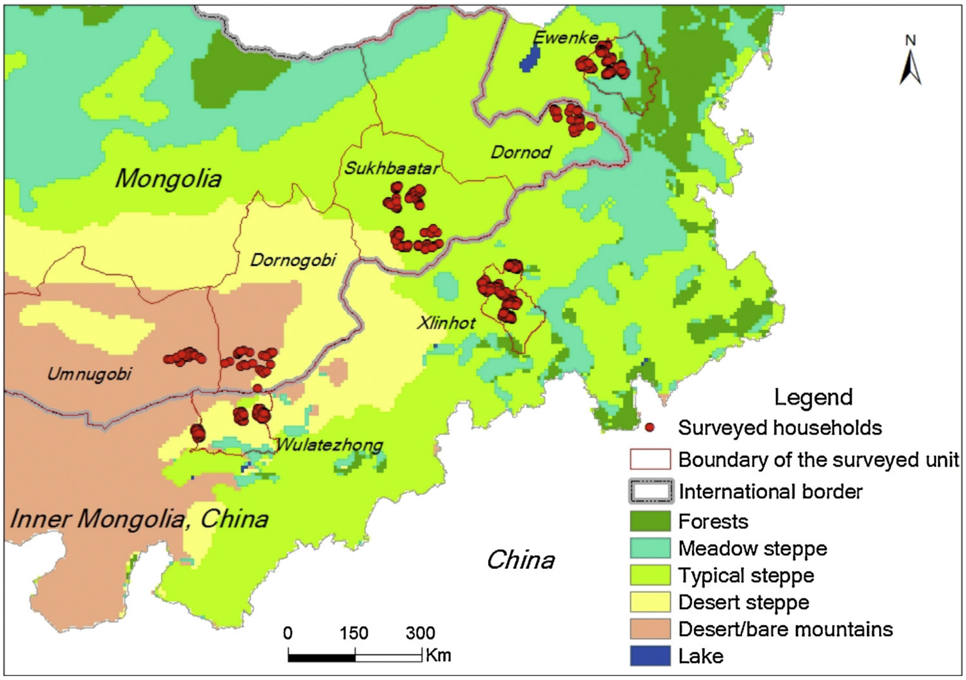

Fig. 2. The major vegetation types (shaded color) and the surveyed households (red dots) on the Mongolian plateau. The vegetation maps of Mongolia and Inner Mongolia were made by the Institutes of Botany, Mongolia (1980s) and China (1990s), respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

(Ewenke, Xilinhot, and Wulatezhong) (Fig. 2). Field sites with different social-institutional and ecological settings were selected to ensure that the surveyed households sufficiently covered a wide range of livelihood adaptation strategies adopted by different social groups of herders. Matched sites in each of three broad vegetation types (i.e., meadow, typical, and desert steppes) in the two countries helped to reduce the differences in the underlying ecological variability across the two countries. By holding the ecological base constant, we could focus on differences in livelihood adaptation strategies and associated institutional facilitators across the border between Mongolia and Inner Mongolia, China.

The household survey was implemented in Inner Mongolia and Mongolia, in autumn 2010 and spring 2011, respectively. For each of the six field sites, villages in Inner Mongolia and soums (towns) in Mongolia were first stratified based on the following variables: distances to local towns/markets, densities of human and livestock populations, and the average number of livestock owned by each household. Then, we selected villages/soums from different categories. In each village/soum, all of the herder households in that administrative unit were first numbered. Then, a random sample was selected from each village/soum with a random number generator. In each village/soum, we surveyed at least 30 herder households. If an administrative unit had fewer than 60 herder households, we surveyed all of them in that unit for the purpose of investigating social connections of herder households. Overall, we surveyed 15 villages in Inner Mongolia, including 541 herder households, and seven soums in Mongolia, including 210 herder households. Local grassland survey experts from the Institute of Botany (IOB), Mongolia, and the Inner Mongolian Institute of Grassland Survey and Design (IMIGSD), China, assisted us in implementing the household surveys.

3. Analysis methods

3.1. Descriptive analyses of climate adaptation and local institutions

To understand the differences in livelihood adaptation strategies of herders between Mongolia and Inner Mongolia, we first ranked the frequencies of the 51 livelihood adaptation strategies cited by the surveyed households and calculated the percentages of the surveyed households citing those adaptation strategies. Second, we labeled the types of local institutions that facilitated those adaptation strategies. Then, we were compared the livelihood adaptation strategies of herders and associated institutional facilitators in Mongolia and Inner Mongolia. Moreover, we calculated summary statistics to describe incomes and expenditures of the surveyed households across meadow, typical, and desert steppes in the two countries. These descriptive statistics were intended to reveal variations in the livelihoods of herders between the two countries and across ecological settings.

3.2. Modeling forage purchasing behaviors of herders

Modeling the determinants of livelihood adaptation behaviors of herders is helpful for identifying the constraints of livelihood adaptation behaviors. We focused on modeling the determinants of forage purchasing behaviors of herders. Based on pre-analyses of the cited livelihood adaptation strategies, we found that the purchase and storage of forage was one of the frequently cited adaptation strategies in both Mongolia and Inner Mongolia. The purchase and storage of forage has become increasingly important as opportunities for migratory grazing have decreased in the two countries (Humphrey and Sneath, 1999; Li and Huntsinger, 2011). We interpreted more forage purchasing as an indicator that households were experiencing effects from climate variability and/or pasture degradation. These two are the major environmental stressors that local herders on the Mongolian plateau have to face in recent years.

Field data associated with livelihood adaptation strategies were collected at both household and village/soum levels. Multilevel statistical models are designed for dealing with nested data, i.e., lower-level observations that are members of several groups at higher-levels (Gelman and Hill, 2007). For multilevel statistical models, the dependent variable is affected by independent variables, which are measured at both individual and group levels. Multilevel statistical models can be categorized as fixed-effects

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Table 2
The household-level and village/soum-level variables used in this study.

Variable	Measurement item	Measurement unit
Household-level		
Livestock management	Percentage of stall-fed livestock	%
	Percentage of seasonally grazed livestock	%
Market influence	Percentage of sold livestock	%
Human capital	Grazing experience	Years
Financial capital	Total annual income	RMB
Material capital	Grazing and living facilities and instruments	RMB
	Number of livestock	SFU
Natural capital	Accessibility to water resources (using pump irrigation)	Yes/No
Village/soum-level		
Total precipitation	Total precipitation between January and July of 2009	mm
Precipitation variability	Coefficient of variation in annual total precipitation	Unitless
Temperature variability	Standard deviation of annual mean temperature	Unitless
Vegetation change	Coefficient of variation in mean growing season NDVI	Unitless
Elevation	ASTER DEM data	m
Livestock population	Density of livestock populations	SFU/ha
Human population	Density of human populations	Person/ha
Livestock management	Percentage of households with seasonal grazing	%
Resource condition	Percentage of degraded pastures	%

and random-effects models (Gelman and Hill, 2007). Fixed-effects models are used when the samples of interest are assumed to not be randomly selected and no generalizations are going to be made. Otherwise, random-effects models, in which the variance that exists between groups is modeled explicitly by including random terms, may be used. Introducing random terms to models can also prevent model residuals from being heteroskedastic (Overmars and Verburg, 2006).

Based on the correlation structure of household-level variables, we selected only a few variables for inclusion in the multilevel statistical models (Table 2). For the household-level variables, the proportion of stall-fed livestock and the proportion of seasonally grazed livestock were used as indicators of livestock management strategies of herders. About 12% of the surveyed households in Inner Mongolia undertook seasonal migrations, and the rest of them adopted the combined strategies of stall feeding and local grazing. In Mongolia, animals were managed by combined strategies of migratory grazing and local grazing. The proportion of sold livestock was used as an indicator of the commercialization of livestock production and market influences. Livestock production was more closely linked to markets in Inner Mongolia than in Mongolia. Among the surveyed households, the average proportions of sold livestock per household in Inner Mongolia and Mongolia were 25% and 12%, respectively. Household variables were used to represent capital available to the surveyed households in five major types: human, financial, material, natural, and social capitals. Social capital variables were not included in the model because we were not able to collect high quality field data related to this category.

Grazing experience and total annual income were used as indicators of household human and financial capitals, respectively. Among the respondents, the values of the average grazing experience of households were similar in Inner Mongolia and Mongolia. Total annual income was calculated in Chinese RMB, using an exchange rate of 225 Mongolian Tugrik per RMB. Our survey data show that the average total annual income of households was about 3.6 times higher in Inner Mongolia than in Mongolia. The number of livestock measured in sheep forage unit (SFU) and the endowments of grazing and living facilities and instruments were used as indicators of household material capital. The values of SFUs for sheep, cow, camel, horse, goat are 1, 5, 6, 7, and 0.9, respectively (Fernandez-Giménez et al., 2012). Household endowments of grazing and living facilities were estimated in Chinese RMB. Among the respondents, the average number of livestock owned by each household was about 1.8 times higher in Mongolia than in Inner Mongolia. The average value of grazing and living facilities owned by each household was about two times higher in Inner Mongolia than in Mongolia. The areas of pastures owned by the surveyed households were not comparable because the property rights of pastures in Mongolia and Inner Mongolia were different (Humphrey and Sneath, 1999). Therefore, we did not include the area of pastures owned by each household in the model. We used the accessibility to water resources (i.e., whether using pump irrigation or not) as the only indicator of household natural capital. Among the respondents, about 32% and 12% of the households in Inner Mongolia and Mongolia, respectively, had access to pump irrigation.

For the village-level variables, the status of pasture degradation was a hypothesized determinant of forage purchasing behaviors. We used data from pasture degradation surveys conducted by the Institute of Botany, Mongolia, and the Inner Mongolian Institute of Grassland Survey and Design, China, in the year 2009. The indicators measured at each sample location were slightly different in the two countries. Both monitoring programs measured changes in vegetation cover, height, and biomass productivity and biophysical characteristics of soils by comparing the surveyed grassland communities with the grassland communities without degradation. In Inner Mongolia, monitoring efforts also included changes in the indicator species for pasture degradation and soil erosion. The percentage of area in each county/soum experiencing adverse changes was calculated at four different levels of severity (i.e., not degraded, slightly degraded, moderately degraded, and severely degraded). An overall measure of the area in each county/soum experiencing pasture degradation at each level of severity was created by calculating the area of pastures experiencing degradation at each level of severity on at least half of the measured items. This overall measure of degradation provided reasonable comparability between the two countries. We then calculated the percentage of pastures classified as non-degraded and degraded pastures by combining the slightly, moderately, and severely degraded categories.

We modeled the influence of pasture degradation on forage purchasing behaviors in a two-stage process because pasture degradation may be correlated with other independent variables that influence forage purchasing behaviors. First, we diagnosed the correlates of pasture degradation at the village/soum-level. Then, the independent variables that were diagnosed as not statistically significant in the resulting model were added together with the pasture degradation variable into the multilevel statistical models as the group-level variables. We hypothesized that densities of

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human and livestock populations, total precipitation (January–July), the interannual variability of climate variables (i.e., temperature and precipitation), elevation, and the proportion of households with migratory grazing within the surveyed villages/soums were correlated with the status of pasture degradation (Table 2). Most of the above variables were measured in the year 2009, except elevation and the interannual variability of climate variables.

The densities of human and livestock populations were measured in persons per hectare and SFU per hectare, respectively. Elevation can influence biomass productivity by affecting micro-climate and slope position, and consequently moisture and nutrient availability. We used the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model (DEM) data (http://asterweb.jpl.nasa.gov/gdem.asp). Total precipitation was calculated between January and July of 2009 because grassland biomass, which was a monitoring item of pasture degradation, was measured in early August. The coefficient of variation in annual total precipitation was used as a measure of the interannual variability of precipitation, and the standard deviation of annual mean temperature was used as a measure of the interannual variability of temperature. In calculating the interannual variability of climate variables, we compiled climate data from the national standard meteorological stations of Mongolia (17 stations) and Inner Mongolia (47 stations). We spatially interpolated the climate data (1980–2009) using universal kriging and used zonal statistics to calculate mean values within the surveyed villages/soums. All of the variables included in the statistical models were rescaled to ranges between zero and one based on their observed minimum and maximum values.

First, we used a simple multiple linear regression (MLR) model to diagnose the correlates of the pasture degradation within the surveyed villages/soums.

$$y_i = \beta_0 + \beta_i x_i + r_i \tag{1}$$

where y_i is the proportion of degraded pastures within the surveyed villages/soums, x_i are the explanatory variables, and r_i is the random-error term. The ordinary-least-squares (OLS) method was used to estimate model parameters using SPSS (IBM, New York, USA, 2012).

Second, we built five multilevel statistical models with different levels of complexity to model forage purchasing behaviors of herders. In all models, the dependent variable was the proportion of income spent on forage. Model 1 was a random-intercept model without any explanatory variables. The village/soum-level effects were included in the model as the random-component. In this model, the variance of the dependent variable was parsed into two parts: one was the household-level variance, and the other was the village/soum-level variance.

$$y_{i,j} = \gamma_{00} + U_{0j} \tag{2}$$

where $y_{i,j}$ is the dependent variable measured at household i in village/soum j. r_{00} is the intercept, and U_{0j} is the random-error term of village/soum j. Model 1 was used as the baseline model to estimate if the group-level variance in the dependent variable was statistically significant. Different groups of independent variables were included in the subsequent models to explore their influences on the variance.

In Model 2, we included a group of independent variables related to livestock management strategies and market influences on livestock production at the household-level.

$$y_{i,j} = \gamma_{00} + \gamma_{10}x_{1i,j} + \cdots + \gamma_{q0}x_{qi,j} + U_{0j} \tag{3}$$

where $\gamma_{00} + \gamma_{10}x_{1i,j} + \cdots + \gamma_{q0}x_{qi,j}$ is called the fixed-effects of the model, γ_{q0} is the regression coefficient, $x_{qi,j}$ is the explanatory variable of household i in village/soum j, and U_{0j} is the random-term of village/soum j. In Model 3, we included a group of independent variables related to household capital. For Models 2 and 3, those two groups of household-level variables were added into the models separately because we wanted to explore whether including the variables related to household capital can significantly increase the predictability of the model. The increased model predictability was measured by the reduced variance at the group-level.

We included village/soum-level variables in Models 4 and 5. The group-level variables were selected based on the diagnostic analyses of the correlates of pasture degradation within the surveyed villages/soums. Besides the group-level variables related to the correlates of pasture degradation, we also included the interannual variability of mean growing season Normalized Difference Vegetation Index (NDVI; April–September, 2000–2009) in the county/soum as an indicator of the interannual variability of vegetation cover, which was related to forage availability. We used the 1-km resolution Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI (MOD13A2) acquired from the NASA Reverb database. The coefficient of variation in mean growing season NDVI, rescaled to the range zero to one, was used as a measure of the interannual variability of mean growing season NDVI.

$$y_{i,j} = \gamma_{00} + \gamma_{10}x_{1i,j} + \cdots + \gamma_{q0}x_{qi,j} + \gamma_{01}z_{1j} + \cdots + \gamma_{0r}z_{rj} + U_{0j} \tag{4}$$

where $\gamma_{01}z_{1j} + \cdots + \gamma_{0r}z_{rj}$ is the fixed-effects of village/soum-level independent variables, γ_{0r} is the regression coefficient, and z_{rj} is the explanatory variable of village/soum j. The proportion of variance in dependent variables that was accounted for by group-level independent variables ($\rho(U_0)$) was calculated by dividing the variance at the group-level ($\mathrm{var}(U_0)$) by the total variance of the models. The multilevel statistical models were estimated using the restricted maximum likelihood (REML) method using HLM 6.08 (Raudenbush et al., 2012).

4. Results

4.1. Climate adaptation and local institutions

Based on the analyses of the survey data, we found that livelihood adaptation strategies of herders varied greatly between Mongolia and Inner Mongolia, but they varied slightly across three broad vegetation types (i.e., meadow, typical, and desert steppes). For this reason, we focused on describing country-level differences in livelihood adaptation strategies and associated institutional facilitators. Overall, mobility was the dominant category of livelihood adaptation strategies used by herders in Mongolia. Herders changed the beginning, end, and duration of their migrations to adapt to climate variability and change. Surveyed households chose to "migrate more frequently" more often than "migrate less frequently." Some of the herders changed the distance, direction, and locations of their migrations to adapt to climate variability. Among the respondents, 17.14% chose to migrate permanently to urban areas. In Mongolia, mobility-related livelihood adaptation strategies were mainly facilitated by communal institutions (Table 3). In Inner Mongolia, mobility strategies were uncommon. Most of the mobility-related adaptation strategies were selected by fewer than 7% of respondents, and 86.9% of respondents cited "stop migration." This adaptation strategy was mainly shaped by governmental institutions. Most pastures in Inner Mongolia have been allocated to individual households and fenced. The "Grain to Green" policy (i.e., including grazing ban in Inner Mongolia) further constrained grazing

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Table 3
The livelihood adaptation strategies of herders and institutional facilitators in Mongolia and Inner Mongolia, China (2000 – 2009).

Adaptation type	Livelihood adaptation strategies	Mongolia			Inner Mongolia		
		Percentage[a]	Rank[b]	Institutions[c]	Percentage[a]	Rank[b]	Institutions[c]
Mobility	Alter the beginning of migration	25.71	6	C	6.10	29	C & M
	Alter the period/duration of migration	28.10	4	C	5.73	30	C & M
	Alter the end dates of migration	28.57	3	C	4.44	31	C & M
	Alter distance of migration	19.05	15	C	4.44	32	C
	Migrate more frequently	22.86	11	C	3.33	37	C
	Migrate less frequently	16.67	20	C	3.51	34	G
	Stop migration	0.00			86.88	1	G
	Move all the time	17.14	17	C	13.12	20	C
	Migrate to different locations	20.00	14	C	3.51	35	G
	Temporary migration to urban areas or abroad	17.14	18	C	0.92	48	C
	Temporary migration to other rural areas	19.05	16	C	0.37	51	C
	Permanent migration to urban areas	17.14	19	C & G	0.74	49	G
Storage	Improve the storage of forage	24.29	9	C	65.25	8	C
	Stall-feed more livestock	0.00			43.81	16	G & M
	Start hay cutting earlier or later	0.00			10.91	24	C
	Stop hay cutting	0.00			3.33	38	C
	Use manure of family herd on the field	0.00			6.84	28	C
	Reduce expenses by consuming less	22.38	12	C	67.65	6	C
	Reduce livestock, surpluses or savings	0.95	30	C	61.55	9	G & C
	Use irrigation	0.00			3.51	36	C
	Build Mini dams	0.00			2.03	42	C
	Use pump or manual irrigation	16.19	21	C	8.50	25	C
	Improve management of water points	12.38	22	C	12.20	23	C
	Build permanent houses	0.00			77.08	2	G
	Build a new or improve winter shelters	7.14	23	C	70.06	4	G
	Begin new veterinary practices	0.00			55.64	12	G
Communal pooling	Dig wells together with other people	24.76	8	C	15.34	19	C & G
	Start communal water harvesting	0.00			1.66	44	C
	Pool pastures together for communal use	100.00	1	C	4.25	33	C
	Join agricultural cooperatives	0.00			24.95	18	M & G & C
Livelihood diversification	Increase the time of off-farm working	2.86	26	C & M	0.74	50	C & M
	Apply different feed to animals	1.90	27	C	67.65	7	C & G
	Adopt new animal species	0.00			58.78	10	G & M
	Start home-garden agriculture	1.90	28	C	7.02	27	C
	Change kind of crops being cultivated	0.00			2.22	40	C & M
	Change use of plots for grazing or agriculture	0.00			1.66	43	C
	Sell handicrafts	0.00			2.22	41	C
	Start tree nursery	0.00			2.96	39	C & M
	Sublease land	0.00			46.58	15	G & M
	Eat different foods	23.33	10	C	14.23	21	C
	Start a business	0.00			37.15	17	C & M
	Collect traditional herb medicine	0.48	31	C	1.11	45	C
	Start harvesting wild plants	25.24	7	C	1.11	46	C
	Plant fruit trees	0.00			1.11	47	C & M
	Take loans from banks/governments	34.29	2	G	70.24	3	G
Market exchange	Buy animals to increase herd size	21.43	13	M	48.98	14	M
	Buy animals to improve breed productivity	6.67	25	M	57.86	11	M & G
	Sell more animals	26.19	5	M	69.50	5	M & G
	Change the herd composition	1.43	29	M	49.17	13	M & G
	Sell more agricultural or animal products	7.14	24	M	14.97	20	M
	Start early animal breeding	0.00			7.21	26	G & M

Notes: G represents governmental/public institutions. M represents market/private institutions. C represents communal/civic institutions.
[a] The percentage of households cited that adaptation strategy.
[b] The order of the percentages of the cited adaptation strategies.
[c] The types of local institutions that facilitated those adaptation strategies.

mobility. Therefore, migratory grazing in Inner Mongolia has become less feasible (Li and Huntsinger, 2011).

Storage strategies were not commonly used in Mongolia. “Use pump or manual irrigation” and “improve the storage of forage” were two frequently cited adaptation strategies of herders in Mongolia. All of the storage-related adaptation strategies in Mongolia were facilitated by communal institutions. In contrast, storage was the dominant category of livelihood adaptation strategies in Inner Mongolia. “Build permanent houses,” “build a new or improve winter shelters,” “reduce expenses by consuming less,” “improve storage of forage,” and “reduce livestock, surpluses or savings” were among the most commonly cited adaptation strategies in Inner Mongolia. These adaptation strategies were also related to “stop migration” in the mobility category. These strategies were mainly facilitated by national environmental policies for reducing livestock grazing intensity and recovering grassland quality in Inner Mongolia. Local governmental institutions are the instruments for the implementation of national environmental policies (e.g., the “Grain to Green” policy). Only a few of the storage-related adaptation strategies in Inner Mongolia were facilitated by civic/communal institutions, such as “use pump or manual irrigation” and “start hay cutting earlier or later” (Table 3). These were bottom-up adaptation strategies, which were mainly implemented through decentralized decision making.

Communal pooling strategies were frequently cited by herders in both Mongolia and Inner Mongolia. Communal pooling in Mongolia was mostly subsistence-oriented activities in the form of pooling pastures together for migratory grazing. Pooling pastures

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for communal use was a kind of self-organized cooperation for pooling climate risks across space and improving the efficiency of pasture-use. This kind of community-based natural resource management was mainly facilitated by communal institutions, such as flexible property boundaries and reciprocal use of pastures (Fernandez-Giménez and Le Febre, 2006). In contrast, communal pooling in Inner Mongolia was mostly market-oriented cooperation in the form of organizing agricultural cooperatives for increasing their benefits from livestock production. Agricultural cooperatives were mainly facilitated by government and market institutions. Our survey data show that more than 90% of the agricultural cooperatives mentioned by the respondents in Inner Mongolia were organized by local governmental officials (e.g., village leaders). "Pool pastures together for communal use" was also cited by herders in Inner Mongolia. However, this was not among the more commonly cited adaptation strategies in Inner Mongolia. "Dig wells together with other people" was an important adaptation strategy of herders in the two countries to adapt to the increasingly warmer and drier climate. The local government of Inner Mongolia also provided financial support for herders to dig wells and to improve livestock production efficiency.

The livelihood diversification category included subsistence-oriented activities (e.g., harvesting wild plants) and off-farm incomes (e.g., starting home-based business). These strategies were not dominant in Mongolia. Only "take loans from banks/government," "start harvesting wild plants," "eat different foods" were commonly cited by herders in Mongolia. The less developed market economy in Mongolia created fewer opportunities for herders to have off-farm jobs. Livelihood diversification in Mongolia was mainly facilitated by communal institutions. In contrast to Mongolia, the rapidly growing Chinese economy has created many off-farm work opportunities for herders in Inner Mongolia. Our survey data show that about one-third of the surveyed households in Inner Mongolia started their own businesses. The income structure of herders was more diversified in Inner Mongolia than in Mongolia (Fig. 3A). Moreover, market incentives also stimulated herders to "adopt new animal species" for increasing livestock productivity. Pasture rental markets, which were represented by the "sublease land" strategy, have been emerging and are under development in Inner Mongolia. Herders can sublease their contracted pastures to other herders. This can increase pasture-use efficiency and decrease climate-related vulnerability to herders. Livelihood diversification in Inner Mongolia was mainly facilitated by governmental and market institutions. Half of the respondents in Inner Mongolia and one-third of the respondents in Mongolia took loans from banks or their governments. Governmental subsidies were important income sources for herders in the two countries (Fig. 3A).

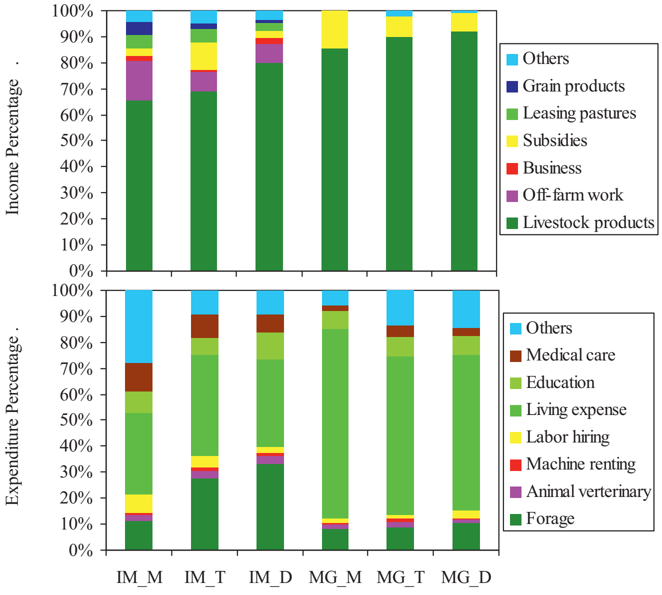

Fig. 3. Incomes (A) and expenditures (B) of the surveyed households in Inner Mongolia and Mongolia. IM_M, IM_T, IM_D, MG_M, MG_T, and MG_D mean the field sites in meadow, typical, and desert steppes of Inner Mongolia and Mongolia, respectively.

Market exchange was an important adaptation strategy of herders in both Mongolia and Inner Mongolia. "Sell more animals" and "buy animals to increase herd size" were both important livelihood adaptation strategies of herders in the two countries (Table 3). Improving breed quality and productivity by introducing the "improved" foreign breeds was also an important adaptation strategy, especially in Inner Mongolia. Market exchange in the two countries was mainly facilitated by market/private institutions. In Inner Mongolia, market exchange was also facilitated by governmental institutions. For example, the local government of Inner Mongolia provided incentives for herders to adopt foreign livestock species in order to improve breed productivity. Goat grazing has been forbidden in Inner Mongolia since the early 2000s, and the local government of Inner Mongolia also tried to reduce grazing pressures on pastures by providing incentives for herders to sell more animals and to start early animal breeding (Table 3).

4.2. Causal factors of pasture degradation

The proportion of households undertaking seasonal migrations was the only independent variable that had a statistically significant relationship with the proportion of degraded pastures within the surveyed villages/soums (Table 4). The interannual variability of temperature and precipitation had positive but insignificant relationships with the percentage of degraded pastures. Total precipitation (January–July) and elevation had negative but insignificant relationships with the levels of pasture degradation. The densities of human and livestock populations were not strong predictors of pasture degradation. We can conclude that in the surveyed sites it was the way that pastures were used (not only numbers of humans and livestock) that was the most important indicator of pasture degradation. The highest levels of pasture degradation were found in the field sites with the lowest levels of livestock mobility. The status of pasture degradation in the field sites of Mongolia was much less serious than the field sites of Inner Mongolia. A possible reason for the phenomena was that livestock grazing in Mongolia was always managed in such a way that it allowed virtually full recovery of grass productivity. Based on these results, the proportion of households with seasonal migrations was not added together with

Table 4
The estimates of the correlates of pasture degradation within the surveyed villages/soums.

Independent variables	Parameters	SE
Intercept	0.552	0.239
Interannual variability of temperature	0.103	0.513
Interannual variability of precipitation	0.367	1.072
Total precipitation (January–July) of the year 2009	−0.085	0.353
Elevation	−0.036	0.122
Density of livestock populations	0.107	0.239
Density of human populations	0.124	0.106
Percentage of households with seasonal migrations	−0.638[*]	0.087
R^2	0.877	

Note: The total number of surveyed villages/soums was 22. SE means standard error.

[*] $p \leq 0.001$.

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Table 5
The estimations of the determinants of forage purchasing behaviors.

Independent variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	Parameters	SE	Parameters	SE	Parameters	SE	Parameters	SE	Parameters	SE
Fixed-effects										
Household-level										
Intercept	0.212[*]	0.032	0.206[*]	0.032	0.216[*]	0.044	0.102[‡]	0.037	0.057[‡]	0.033
Percentage of stall-fed livestock			0.226[*]	0.023	0.229[*]	0.023	0.216[*]	0.030	0.211[*]	0.028
Percentage of seasonally grazed livestock			−0.037[‡]	0.023	−0.043[‡]	0.022	−0.038[‡]	0.025		
Percentage of sold livestock			−0.020	0.021	−0.023	0.021	−0.022	0.023	−0.024	0.019
Grazing experience					−0.062	0.071	−0.047	0.066	−0.042	0.051
Total annual income					0.140[†]	0.045	0.138[†]	0.037	0.119[‡]	0.032
Grazing and living facilities and instruments					0.003	0.034	0.011	0.040	0.014	0.045
Number of livestock					0.013	0.039	0.033	0.063	0.057	0.084
Accessibility to pump irrigation					0.012	0.012	0.014	0.025	0.011	0.023
Village/soum-level										
Interannual variability of temperature							0.093	0.051	0.089	0.048
Interannual variability of precipitation							0.214[*]	0.066	0.177[*]	0.060
Interannual variability of mean growing season NDVI							0.135[‡]	0.049	0.113[‡]	0.042
Elevation							−0.014	0.056	−0.019	0.075
Density of livestock populations							0.049	0.064	0.052	0.067
Density of human populations							0.021	0.055	0.036	0.051
Percentage of degraded pastures									0.154[*]	0.038
Random-effects										
var(U_0)	0.022[*]		0.017[*]		0.016[*]		0.004[*]		0.002[*]	
$\rho(U_0)$	0.461		0.424		0.407		0.182		0.165	

Notes: The total number of surveyed households was 751. The total number of surveyed villages/soums was 22. SE means standard error. var(U_0) is the variance component at the village/soum-level. $\rho(U_0)$ is the proportion of variance at the village/soum-level to the total variance.

[*] $p \leq 0.001$.

[†] $p \leq 0.01$.

[‡] $p \leq 0.05$.

the variable of pasture degradation in the multilevel statistical model for diagnosing the determinants of livelihood adaptation behaviors.

4.3. Determinants of forage purchasing behaviors

The statistical analyses of the determinants of forage purchasing behaviors show that including the two variables describing livestock management strategies and the variable of market influence in Model 2 reduced the variance of the random component at the group-level (Table 5). The results of Model 2 show that the proportion of stall-fed livestock and the proportion of seasonally grazed livestock had positive and negative relationships, respectively, with the proportion of income spent on forage. Based on the values of the regression coefficients, the proportion of stall-fed livestock had a stronger effect on the dependent variable than the proportion of seasonally grazed livestock. The proportion of sold livestock did not have a statistically significant relationship with the proportion of income spent on forage. The results of Model 3 show that including the variables of human, financial, material, and natural capitals in the multilevel statistical model only slightly reduced the variance of the random component at the group-level. This means that the variables of household capital did not explain forage purchasing behaviors well. Grazing experience, as a measure of household human capital, had a negative but insignificant relationship with the dependent variable. Total annual income, as a measure of household financial capital, was the only type of household capital that had a statistically significant (positive) relationship with the dependent variable. Grazing and living facilities and the number of livestock, as measures of household material capital, both had positive but insignificant relationship with the dependent variable. The accessibility to pump irrigation, as a measure of household natural capital, had a positive but insignificant relationship with the dependent variable.

The results of Model 4 show that after including the group-level explanatory variables (i.e., the interannual variability of climate variables, the interannual variability of mean growing season NDVI, elevation, and densities of human and livestock populations) in the multilevel statistical model, the variance of the random component at the group-level decreased substantially. Among the variables that captured variance in the dependent variable, only the interannual variability of precipitation and the interannual variability of mean growing season NDVI had significant (positive) relationships with the dependent variable. The densities of human and livestock populations did not have statistically significant relationships with the dependent variable. In Model 5, we replaced the percentage of seasonally grazed livestock at the household-level with the percentage of degraded pastures at the group-level because the measure of mobile grazing was the only statistically significant correlate of the status of pasture degradation within the villages/soums (Table 4). The results of Model 5 show that the percentage of degraded pastures at the group-level had a significant and positive relationship with the dependent variable. The proportion of the group-level variance to the total variance only decreased slightly after including the group-level variable of pasture degradation in Model 5.

5. Discussion and conclusions

Local institutions enhanced and at times undermined adaptive capacity of herder communities in Inner Mongolia and Mongolia, and they did so in different ways. Strong government interventions and market incentives created by the rapidly growing Chinese economy have enhanced adaptive capacity of herder communities in Inner Mongolia in terms of finance, technology, information, and leadership. However, government and market institutions have undermined adaptive capacity of herder communities in Inner Mongolia by changing the social structures of herder communities and making mobile grazing less feasible (Li and Huntsinger, 2011; Williams, 2002): recall that "stop migration" was the top livelihood adaptation strategy cited by herders in Inner Mongolia (Table 3). Herders in Inner Mongolia are subsidized to stall-feed livestock to reduce grazing pressures and recovering grassland quality (Wang et al., 2013). However, sedentary grazing with substantial external inputs such as shelters and forage has increased the cost of livestock production (Li et al., 2007). Our survey data show that about 40% of the surveyed households in Inner Mongolia had negative incomes in the year 2009. The cost of forage was an important household expenditure (Fig. 3B). Moreover, herders in Inner Mongolia are encouraged by the local government to feed "introduced" high-productivity livestock species. Among the respondents in Inner Mongolia, about 58% of them cited this adaptation strategy. Because the introduced breeds are usually not well adapted to local climate, special requirements such as warm winter shelters and large inputs of forage are required. The introduction of foreign livestock breeds to the Mongolian grasslands contributed to the reduction in mobility over the past half century (Humphrey and Sneath, 1999). Empirical studies show that this kind of technology innovation has undermined adaptive capacity of herder communities in Inner Mongolia when climate hazards occur (Li and Li, 2012).

In contrast to Inner Mongolia, livelihood adaptation strategies of herders in Mongolia were mainly facilitated by communal institutions in terms of mobile grazing, flexible property boundaries, and reciprocal use of pastures (Fernandez-Giménez and Le Febre, 2006). The traditional norms allowed herders to live with the highly variable climate and vegetation productivity by seasonal and interannual migrations. Mobile grazing can reduce climate-related vulnerability by pooling climate risks across space. Governmental institutions were much less influential in Mongolia than in Inner Mongolia. This was related to the retrenchment of governmental investments in Mongolia after economic reforms in the early 1990s (Sneath, 1998). The weak governmental support and investments decreased adaptive capacity of herder communities in Mongolia for climate variability and change. For example, our survey data show that the death rates of livestock species were much higher in Mongolia than in Inner Mongolia given similar climate conditions. Most animals died due to the lack of forage supplies and decreased migration in harsh climate conditions of winters and early springs. Moreover, the market economy is less developed in Mongolia than in Inner Mongolia. The income sources of the surveyed households were less diversified in Mongolia than in Inner Mongolia (Fig. 3A). In Mongolia, most households produced the same livestock products, affecting prices adversely and limiting the number of guaranteed purchasers. High transportation costs because of distant markets increase the cost of producing inputs and marketing livestock products (Humphrey and Sneath, 1999).

With the decrease in grazing mobility in both Mongolia and Inner Mongolia in recent decades (Li and Li, 2012; Olonbayar, 2010), the purchase and storage of forage has become an important adaptation strategy to cope with uncertainties in precipitation and vegetation productivity. Traditional mobile grazing was assisted by a small amount of forage inputs in winter and spring seasons. Sedentary grazing, which is characterized by a large amount of external inputs, has increased the cost of livestock production. The cost of purchasing forage has become one of the major household expenditures in Mongolia and Inner Mongolia (Fig. 3B). The results of the multilevel statistical modeling of forage purchasing behaviors show that livestock management strategies, household financial capital, environmental (i.e., precipitation and vegetation growth) variability, and pasture degradation were the major determinants of forage purchasing behaviors (Table 5).

Livestock management strategies in the study sites were mainly facilitated and shaped by local institutions. Mobile grazing in Mongolia was mainly facilitated by local communal institutions, and sedentary grazing in Inner Mongolia was mainly shaped by governmental institutions and policies (e.g., HPRS and the "Grain to Green" policy). Mobile grazing has less forage inputs than sedentary grazing. Therefore, the percentage of stall-fed livestock and the percentage of seasonally grazed livestock had positive and negative relationships, respectively, with the proportion of income spent on forage. Herder households with high annual incomes were capable of purchasing forage to feed animals during hazardous climate events. Therefore, household financial capital had significant and positive relationship with the percentage of income spent on forage. Households with limited income could not afford to buy forage, so this adaptation strategy was not available to them. Where the natural environment was more hospitable, households had less need to purchase forage and other adaptation options available to them. The interannual variability of mean annual precipitation and the interannual variability of mean growing season NDVI were both positively related to the proportion of income spent on forage.

Pasture degradation was less serious in Mongolia than in Inner Mongolia. The decreased biomass productivity could be one of the major reasons that the percentage of income spent on forage was higher in Inner Mongolia than in Mongolia. Moreover, our analyses show that the level of mobile grazing was the only variable that had statistically significant relationship with pasture degradation (Table 4). A greater proportion of households using mobile grazing strategies in the counties and soums of the region was associated with a smaller proportion of grassland area identified as degraded. This was consistent with the results showing that the percentage of degraded pastures and the proportion of seasonally grazed livestock had positive and negative relationships with the proportion of income spent on forage, respectively. However, the possible bidirectional causal relationships between forage purchases and pasture degradation (i.e., the endogeneity problem in the models) limited our ability to interpret the causal direction between forage purchases and pasture degradation. More income spent on forage could be one of the reasons for pasture degradation, because forage inputs could lead to artificially high stocking rates in the grazing season that result in pasture degradation (Li et al., 2007). Since the early 2000s, the local government of Inner Mongolia has been implementing very strict environmental policies to control the stocking rates of different types of pastures. Therefore, forage purchases of herders in Inner Mongolia could be mainly driven by pasture degradation. Additionally, our survey data do not permit the exploration of the possible effects that differential availability of forage in markets may have on forage purchasing behaviors. We did not ask about overall availability of, distances traveled for, or prices paid for forage. The difference in the supply of forage in markets could be one of the reasons that herders in Mongolia buy less forage than herders in Inner Mongolia.

Climate variability and pasture degradation have increased livelihood vulnerability of herders on the Mongolian plateau. Changing livelihood strategies as a form of social adaptation is important for livelihood sustainability of herders in the context of climate change. Livelihood adaptation strategies of herders varied greatly between Mongolia and Inner Mongolia. Local institutions, including governmental, market, and communal institutions, played important roles in shaping and facilitating livelihood adaptation strategies of herders. Mobility and communal pooling were the top two categories of livelihood adaptation strategies observed in Mongolia, and they were mainly facilitated by local communal institutions. Storage, livelihood diversification, and market exchange were the top three categories of livelihood adaptation approaches in Inner Mongolia. Adaptation strategies in these groups were mainly shaped and facilitated by local governmental and market institutions. The results of this work imply that the governmental policies for facilitating climate change adaptation and sustainable governance of grassland resources should be different in Mongolia and Inner Mongolia.

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For example, in Mongolia, increasing governmental support and investment in herder communities could help herders better adapt to future climate variability and change. In Inner Mongolia, relaxing the state-control related management strategies and allowing herders to self-organize (e.g., the development of communal institutions) may help to recover grassland quality and build the adaptive capacity of herder communities.

Acknowledgements

This work was conducted with financial support from the NASA Land-Cover and Land-Use Change Program (NNX09AK87G). We would like to acknowledge the help from people in the Inner Mongolian Institute of Grassland Survey and Design, China, and the Institute of Botany, Mongolia, for assisting us in implementing the household surveys and providing grassland and socioeconomic data. Dr. Yichun Xie from the Eastern Michigan University provided lots of efforts in communicating with local collaborators for data collections. The graduate student Jie Dai from the University of Michigan helped us clean the original survey data.

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Please cite this article in press as: Wang, J., et al., Climate adaptation, local institutions, and rural livelihoods: A comparative study of herder communities in Mongolia and Inner Mongolia, China. Global Environ. Change (2013), http://dx.doi.org/10.1016/j.gloenvcha.2013.08.014