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THE IMPACTS OF CLIMATE CHANGE ON NOMADIC LIVESTOCK HUSBANDRY IN MONGOLIA*

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This study conducts cross-sectional analysis to investigate impact of climate change on livestock sector in Mongolia using data gathered from a household survey and aggregate soum (district) level data. The soum-level analysis reveals the marginal effect of precipitation has a positive effect on livestock/ha up to 26 mm/mo and thereafter a harmful effect. The marginal effect of warming on livestock/ha is not significant until annual temperatures exceed 0.4°C whereupon warming is strictly harmful. The household-level analysis suggests warming will decrease earnings per animal while overall earnings per household increases with a small change in climate but declines with larger changes. However, the household data also suggests warming would increase the total value of livestock. The results of the different analyses are therefore conflicting suggesting one or more of the analyses are plagued by missing variables.

Keywords: Climate change; impact; livestock density; net revenue; Mongolia.

1. Introduction

Over the last 60 years, Mongolia's average temperature has increased by 1.9°C, which is more than the world average of 0.6–0.7°C (UNFCCC, Mongolia's Initial National Communication, 2001).[1] The location of the country between the great Siberian taiga and the Central Asian desert at more than 1284 m above sea level explains the short, hot summer and long, cold winter. The location also explains the relatively high number of cloudless days and low annual average precipitation. Rainfall is about 300–350 mm in the Khangai, Khentii, and Khuvsgul mountain ranges, 250–300 mm in

*This article contains supplementary material available on the journal website. The supplementary material includes physical, climatic and socio-economic characteristics of Mongolia, sample selection and summary statistics of data used in the regressions, and detailed information about the climate projection models used in the study.
[1]http://unfccc.int/resource/docs/natc/mongnc1.pdf.

Mongol Altai and forested areas, and 50–150 mm in the Gobi Desert area. In the past 60 years, the annual average precipitation has decreased by 10% nationally. Due to higher temperatures, it is expected that more water will be lost to the atmosphere through evapotranspiration. The impact will be less severe in the western and eastern regions, where there has been increased rainfall (Integrated Water Management National Assessment Report I, 2012).

One of the key concerns about climate change in Mongolia is its impact on the agriculture sector. Concerns are high because a large fraction of the population, especially the rural and most vulnerable, is strongly dependent on the sector, and especially on herding livestock. Millennium Development Goals (MDGs) are directed at eradicating the extreme poverty in rural areas by 2030 (UN Mongolia, 2017). The Government of Mongolia's action on climate change (SDG13) aims to strengthen resilience and adaptive capacity to climate-related hazards, as well as to implement early warning systems and mechanisms for capacity building applicable to climate change-related management and planning.

The agricultural sector accommodates up to 30% of Mongolia's work force (Lam *et al.*, 2003). However, evidence-based research on the impacts of climate change on agriculture in Mongolia is in a state of infancy. 80% of the agricultural sector in Mongolia relies on herding (Mahul and Skees, 2007). A vulnerability assessment report (Smith *et al.*, 1996) argues that the impact of climate change on Mongolia's agriculture, forestry, and natural resources will be considerably negative. Due to a rise in temperature and reduced rainfall, the amount of arid and semi-arid areas will likely increase. This report suggests that high temperatures might result in a change of the composition of crops and in investments in irrigation systems. But there is no economic analysis in the report.

The lack of economic analyses is a constraint to policy makers in formulating effective policy responses to support ongoing autonomous adaptation efforts and to facilitate planned adaptation. Without a detailed understanding of the impacts of climate change on the agricultural sector across households and across different regions in Mongolia, policy makers will be hard pressed to identify and introduce targeted policy responses. Adaptation is a highly localized action where context matters.

In order for Mongolia to increase the resilience of its livestock sector, including understanding potential effects on the revenues of herders, numerous developmental and environmental challenges will need to be addressed. The aim of this study is to assess the vulnerabilities of the livestock sector to climate change and to understand how climate change will impact the incomes of herders. Once this is understood, further analysis will be possible to understand the choice that herders make about the composition of their livestock and other changes that might help them adapt. The paper provides evidence-based policy insights that are targeted towards supporting policy makers involved in the National Adaptation Plan (NAP) process to better understand the impact of climate change on the agricultural sector. It provides insights into the choices that farmers and livestock herders (the mainstay of the agriculture sector) are likely to make as the climate changes. It also provides an example of a methodology that Mongolia's policy makers can employ when preparing or refining their NAP.

The study conducts four analyses of Mongolian livestock. The purely economic analysis adopts the Ricardian method to value the magnitude of climate change damages. The Ricardian method, first introduced by Mendelsohn *et al.* (1994), has a rich history of application to study climate change impacts on households in Africa (Kurukulasuriya *et al.*, 2006), Latin America (Seo and Mendelsohn, 2008), India (Dinar *et al.*, 1998) and China (Wang *et al.*, 2009) and across many other locations. Currently there is no other study that applies the Ricardian method to examine the impacts of climate change in Mongolia. This study aims to fill this gap in the literature. The Ricardian approach compares how well herders do in one climate versus a different climate. One of the method's major advantages, especially in research on the impacts of climate change as opposed to impacts of weather, is that it does not rely on observing economic agents over time, but instead, across space. Other advantages include the flexibility of the model and ease of implementation. Collecting household data is relatively easier and more practical than collecting panel data over years.

There are limitations to the Ricardian method that can pose problems in adequately estimating the impact of climate change. The main limitation of using the Ricardian approach to study nomadic herdsmen is that it is not possible to determine how much land each herdsman uses. One way we address this problem in this study is to calculate the net revenue per animal owned by the herdsman. We complement this analysis with a study of the number of animals/km^2 that can be sustained in a soum (district). We regress the number of animals per km^2 on climate, market access, and other available control variables. The purpose of this analysis is to measure the carrying capacity of the land depending on its productivity. The product of the net revenue per animal times the number of animals provides an estimate of the total net income of herding for each soum. Summing this value across soums gives a national aggregate measure.

An alternative analysis we employ is to regress the net revenue per household of herders on climate, market access, and other controls. Although this analysis does not control for land, it does provide a direct measure of the income each herder is obtaining in his soum. To the extent that climate affects net revenue directly, this approach should detect climate effects.

A final analysis conducted is to understand what determines the total value of the livestock of each household. This is a direct measure of each household's assets rather than their income. However, it should provide useful information concerning how climate will change the household's wealth. In this analysis, each household's total value of livestock is regressed on climate, market access, and other controls.

The paper is structured in the following manner. Section 2 presents the econometric models used to evaluate the impact of climate change on livestock density, household revenue per animal, net revenue per household, and total livestock value per household. Section 3 explains the empirical results. Section 4 shows some forecasts of future changes depending on climate scenarios. Section 5 presents conclusions and policy recommendations.

2. Data and Methodology

2.1. *Data*

2.1.1. *Secondary data sources*

Soum level data on total livestock numbers were obtained from the National Statistical Office of Mongolia (NSO). The total livestock was calculated by multiplying each livestock with its conversion factor given by NSO. Total livestock data used in the analysis was expressed in sheep units. Data on estimated grassland area available in each *soum* was obtained from the Mongolian Land Authority. In addition, data on the total area of the *soum,* along with number of wells and streams in each *soum,* were obtained from the Environmental Information Center (EIC). Although the soum level data cannot determine the land used by each herder, it does measure the total amount of land that the herders in that soum can use. Data on human population density were also obtained from NSO, while data on distance from Ulaanbaatar to *soum* center were obtained from EIC.

Climate data for the equivalent of each district (2nd level administrative region) in Mongolia is from WorldClim-Global Climate data website. Climate data were downloaded using the latitude and longitude coordinates of each location (defined to be centroid of each 2nd level administrative region). The climate data used in the analysis are the 30-year average temperature and precipitation values, which reflect the long-term climate for each location. The soil data used in the analysis are obtained from the FAO digital soil map database, which provides details on the texture of the soil and the dominant slope of the land at each location. This data also provides information on the dominant soil groups in each location.

2.1.2. *Household-level survey data*

In additional to secondary data, the analysis also used the household-level data collected from a customized survey that was implemented in Mongolia in 2013 for this study. In total, the survey covered 96 soums in 20 provinces (representing six agro-ecological zones). Within each soum, five households were selected based on a stratified random selection approach. Distance to the soum center and farm size were both factors in selection. The National Institute of Meteorology and Hydrology, with a nationwide network, conducts monitoring on hydrology, meteorology, and the environmental conditions throughout its network. The household survey was also conducted using its vast network, as it has the technical capacity to collect, monitor, and process information.

The Institute of Meteorology and Hydrology organized training, as part of its regular capacity building programme, for all the local engineers from provinces and counties in April, 2013. During the training, a special session was dedicated to introduce the agriculture survey questionnaire and to provide guidance to the engineers who would be involved in the data collection exercise. The survey team leaders were at hand to answer questions asked by the engineers. Timely instructions and guidance were also provided to engineers who conducted the field surveys through telephone and email.

2.2. *Methodology*

To estimate the impact of climate change, a series of econometric models presented in this section are used. In each of the models outlined below, a dependent variable is regressed against a series of independent variables. Various statistical tests are also conducted to determine the robustness of the regressions.

The models in this study aim to bolster understanding of the relationship between a livestock measure and climate variables. The first set of analyses focus on understanding the impact of climate change on livestock density (animals/km^2), L_k. Livestock density in each soum is regressed on several exogenous variables including climate, C, (annual temperature and precipitation), population density, P, of the *soum* in 2012, distance from *soum* center to Ulaanbaatar city (km), D, (a proxy for access to market), and the number of streams/km^2, W, (a proxy for access to water). Note that both a linear and quadratic term are included for climate in order to capture nonlinearities in that relationship. Additional models included other variables such as the different agro-ecological zones, E, or terrain slope, S.

$$L_k = \alpha_1 + \beta_1 C_k + B_2 C_k^2 + \beta_3 P_k + \beta_4 D_k + \beta_5 W_k + \beta_6 E_k + \varepsilon_k, \quad (1)$$

$$L_k = \alpha_1 + \gamma_1 C_k + \gamma_2 C_k^2 + \gamma_3 P_k + \gamma_4 D_k + \gamma_5 W_k + \gamma_6 S_k + \varepsilon_k, \quad (2)$$

$$L_k = \alpha_1 + \delta_1 C_k + \delta_2 C_k^2 + \delta_3 P_k + \delta_4 D_k + \delta_5 W_k + \delta_6 E_k + \delta_6 S_k + \varepsilon_k. \quad (3)$$

These models share many independent variables in common. It is helpful to compare the model with and without agro-ecological zones because these zones are correlated with climate.

In each of the three models above, the dependent variable, L_k, is similar and represents the livestock density in *the* kth *soum* in Mongolia. It is measured by the total *soum* livestock in sheep units divided by the total area (i.e., number/km^2). The team explored different measures to combine animals. The first method used the price of each animal relative to the price of sheep. The second approach merely measured the percentage of each type of animal. The third approach used the equivalent impact on the grasslands relative to sheep (NSO conversion coefficient). It is a biological measure of grassland pressure. After testing the regressions for the three different dependent variables, the team found that the results are robust across all the measures and so we present the results using the NSO conversion.

In addition to the models exploring annual climate variables, the paper also explores seasonal climate variables. Equations (4)–(6) present a similar model as (1)–(3), this time using seasonal climate variables instead of annual values. The seasonal climates are intended to capture three month periods with winter covering November through February and spring, summer, and autumn reflecting the three month periods following.

$$L_k = \alpha_1 + \varphi_1 C\_S_k + \varphi_2 P_k + \varphi_3 D_k + \varphi_4 W_k + \varphi_5 E_k + \varepsilon_k, \quad (4)$$

$$L_k = \alpha_1 + \omega_1 C\_S_k + \omega_2 P_k + \omega_3 D_k + \omega_4 W_k + \omega_5 S_k + \varepsilon_k, \quad (5)$$

$$L_k = \alpha_1 + \Phi_1 C\_S_k + \Phi_2 P_k + \Phi_3 D_k + \Phi_4 W_k + \Phi_5 E_k + \Phi_6 S_k + \varepsilon_k. \quad (6)$$

For all these regressions, models (1)–(6), the team used Ordinary Least Square (OLS) to estimate the results.

The second set of analyses utilize the household data collected in the survey of herders. There are three regressions of these Ricardian models that use a different dependent variable but the identical independent variables as were used in the earlier regressions. The first regression examines the net revenue per household, *RH*. The second regression examines the net revenue per animal, *RL*. The third regression examines the total value of livestock per household, *RV*.

$$RH_{ik} = \alpha_1 + \beta_1 C_k + \beta_2 H_{ik} + \beta_3 P_k + \beta_4 WH_k + \beta_5 S_k + \varepsilon_{ik}, \quad (7)$$

$$RL_{ik} = \alpha_1 + \gamma_1 C_k + \gamma_2 H_{ik} + \gamma_3 P_k + \gamma_4 WH_k + \gamma_5 S_k + \varepsilon_{ik}, \quad (8)$$

$$RV_{ik} = \alpha_1 + \delta_1 C_k + \delta_2 H_{ik} + \delta_3 P_k + \delta_4 WH_k + \delta_5 S_k + \varepsilon_{ik}. \quad (9)$$

One concern with Ricardian models is the potential omission of important variables that may influence net revenue. If such omitted variables are correlated with climate, they could bias the climate coefficients. Another limitation is that prices are assumed to remain constant, which is likely to be a strong assumption. If climate change causes large swings in prices, these effects need to be taken into account. Much like agronomic studies, the consequence of price changes can be taken into account by post-processing the results with an agricultural general equilibrium model.

Whereas the first analysis sought to explain the variation in livestock density using soum data, the Ricardian analysis measures welfare impacts to the herder household. The net revenue per animal multiplied by changes in the number of animals can measure changes in income to each household. The net revenue per household generates a direct measure of herder income. Finally, the total value of livestock measures the assets of the herder household. All of these measures should capture the effect of climate change on herders.

3. Empirical Results

3.1. *Livestock density at the soum level*

The regressions results for models (1)–(3) are presented in Table 1. Models (1)–(3) perform well and explain 55% of the variance of livestock density. The climate

Table 1. Regression results on the determinants of livestock density at the soum level with annual climate variables.

Variables	Livestock density (total *soum* livestock in sheep units by NSO divided by total *soum* area)		
	(1)	(2)	(3)
Annual Precipitation (mm/month)	1.790***	2.002***	1.633***
	(4.47)	(5.34)	(4.22)
Annual Precipitation squared	−0.035***	−0.044***	−0.034***
	(−4.05)	(−4.98)	(−3.98)
Annual temperature (°C)	0.078	0.102	0.056
	(0.32)	(0.47)	(0.23)
Annual temperature squared	−0.058**	−0.082***	−0.071***
	(−2.54)	(−3.55)	(−2.95)
Population density in 2012	5.913***	5.585***	5.658***
	(4.94)	(4.99)	(4.86)
Distance to Ulaanbaatar	−0.002	−0.002**	−0.002**
	(−1.59)	(−2.35)	(−2.28)
Streams/km^2	138.8***	134.9***	132.8***
	(2.88)	(2.83)	(2.73)
Forest steppe zone	−1.862		−2.495
	(−0.99)		(−1.25)
High mountain taiga zone	−7.559***		−7.715***
	(−4.83)		(−4.23)
Desert steppe zone	−2.264*		−2.409**
	(−1.94)		(−2.11)
Desert	−0.789		−1.838
	(−0.45)		(−1.02)
Flat land		1.833	1.411
		(0.72)	(0.54)
Undulating land		−2.517*	−2.970**
		(−1.97)	(−2.07)
Constant	−6.424	−5.829	−1.089
	(−1.44)	(−1.41)	(−0.24)
Observations	301	301	301
$R-$squared	0.557	0.555	0.567

Notes: Robust $t-$statistics in parentheses; (***), (**), and (*) significant at 1%, 5%, and 10%, respectively.

coefficients are reasonably stable across all three models, implying that there is limited correlation between the climate variables and ecological zones and topography. The linear temperature coefficient is insignificant but the squared term is negative and significant. This implies the relationship between density and temperature is hill-shaped. Both the linear and squared terms of rainfall are significant. The squared term for rainfall is negative again implying a hill-shaped relationship for rainfall. Several other control are also significant implying that distance to Ulaanbaatar, high mountains, desert steppes, and hilly land all reduce animal density. In contrast, having higher stream density increases livestock density as water is a scarce element in this landscape.

The seasonal climate results of models 4–6 are shown in Table 2. Seasonal climate variables provide better measures of climate than the annual climate variables. The goodness-of-fit of models 4–6 are better than models 1–3. The seasonal linear and squared precipitation variables are significant except for spring. All the linear

Table 2. Regression results of livestock density at the soum level with seasonal climate variables.

Variables	Total *soum* livestock in sheep unit by NSO divided by total *soum* area		
	(4)	(5)	(6)
Winter precipitation	5.857***	7.160***	6.004***
	(2.79)	(3.34)	(2.79)
Winter precipitation squared	−0.665***	−0.813***	−0.683***
	(−2.82)	(−3.31)	(−2.82)
Summer precipitation	0.565**	0.873***	0.590**
	(2.19)	(3.40)	(2.26)
Summer precipitation squared	−0.004**	−0.007***	−0.005**
	(−2.07)	(−3.45)	(−2.14)
Autumn precipitation	−1.819**	−2.358**	−1.988**
	(−2.08)	(−2.56)	(−2.19)
Autumn precipitation squared	0.053**	0.061**	0.056**
	(2.29)	(2.45)	(2.32)
Spring precipitation	1.557	1.191	1.456
	(1.47)	(1.10)	(1.36)
Spring precipitation squared	−0.072	−0.040	−0.066
	(−1.56)	(−0.83)	(−1.39)
Winter temperature	−6.957**	−6.304*	−6.854**
	(−2.12)	(−1.84)	(−2.04)
Winter temperature squared	−0.061	−0.059	−0.062
	(−0.83)	(−0.76)	(−0.82)
Summer temperature	−16.253***	−14.069***	−15.358***
	(−3.54)	(−2.84)	(−3.20)
Summer temperature squared	0.136	0.116	0.121
	(0.84)	(0.66)	(0.71)
Autumn temperature	10.602***	8.468***	10.303***
	(3.43)	(2.76)	(3.35)
Autumn temperature squared	−0.057	−0.125	−0.060
	(−0.18)	(−0.39)	(−0.19)
Spring temperature	5.809***	5.825***	5.514***
	(4.44)	(4.07)	(4.00)
Spring temperature squared	−0.075	−0.029	−0.068
	(−0.41)	(−0.16)	(−0.36)
Population density in 2012	1.093***	1.081***	1.094***
	(15.55)	(15.90)	(15.92)
Distance to Ulaanbaatar	−0.009***	−0.008***	−0.009***
	(−5.30)	(−5.25)	(−5.24)

Table 2. (*Continued*)

Variables	Total *soum* livestock in sheep unit by NSO divided by total *soum* area		
	(4)	(5)	(6)
Number of streams/km^2	24.967	42.586	26.478
	(0.52)	(0.88)	(0.55)
Forest steppe	−2.448		−2.588
	(−1.53)		(−1.52)
High mountain taiga	−12.448***		−12.055***
	(−5.22)		(−4.98)
Desert steppe	−2.625**		−2.698**
	(−2.34)		(−2.35)
Desert	−0.510		−0.873
	(−0.30)		(−0.51)
Flat land		1.822	0.971
		(0.90)	(0.46)
Undulating land		−1.242	−1.255
		(−0.99)	(−0.93)
Constant	120.2**	96.5	113.9*
	(2.13)	(1.59)	(1.95)
Observations	303	303	303
$R-$squared	0.712	0.698	0.713

Notes: Robust $t-$statistics in parentheses; (***), (**), and (*) significant at 1%, 5%, and 10%, respectively.

temperature coefficients are significant except for winter. However, none of the squared terms for seasonal temperature are significant implying that temperature has a linear effect on animal density.

Table 2 also reveals that human population density is positively related to livestock density, while distance to Ulaanbaatar is negatively related to livestock density.[2] Higher distance implies less access to the market and higher transport costs, making it harder to raise livestock. The higher population density may also reflect access to a local market. Alternatively, the higher population density may be an effect of livestock density as the herding requires people.

The results in Table 2 continue to show that the desert steppe and especially the high mountains have lower livestock density than the other agro-ecological zones. However, the remaining topographical variables are not significant in Table 2 compared to Table 1. Stream density and hilly topography no longer have any effect. It appears that the seasonal climate variables are highly correlated with these variables and do a better job of predicting livestock density.

[2]Note that it is typically hard to interpret human population density in this model because the causality direction is difficult to pin down — do more people mean more animals or do more animals mean more people? We interpret this result as correlation.

Table 3. Marginal effect of temperature and precipitation on livestock density.

Variable	Total *soum* livestock in sheep unit by NSO divided by total *soum* area		
Annual marginal effect			
Precipitation (monthly)	0.538***	0.458***	0.418***
	(3.80)	(3.65)	(3.08)
Temperature	0.187	0.256	0.189
	(0.81)	(1.18)	(0.83)
Seasonal marginal effect			
Winter precipitation	2.881**	3.522***	2.947**
	(2.50)	(3.04)	(2.51)
Summer precipitation	0.136	0.156	0.139
	(1.36)	(1.45)	(1.39)
Autumn precipitation	−0.634	−1.006**	−0.748
	(−1.39)	(−2.13)	(−1.59)
Spring precipitation	0.290	0.495	0.303
	(0.60)	(1.02)	(0.64)
Winter temperature	−4.646***	−4.072***	−4.497***
	(−6.51)	(−6.36)	(−6.67)
Summer temperature	−12.053***	−10.488***	−11.598***
	(−7.73)	(−7.35)	(−7.86)
Autumn temperature	10.668***	8.615***	10.373***
	(3.81)	(3.10)	(3.72)
Spring temperature	5.738***	5.798***	5.450***
	(4.23)	(3.96)	(3.83)

Notes: Robust $t-$statistics in parentheses; (***), (**), and (*) significant at 1%, 5%, and 10%, respectively.

Table 3 presents the marginal effect on livestock density of temperature and precipitation evaluated at the mean climate. The marginal effect of annual precipitation from Table 1 is positive implying that a small increase in rainfall would lead to higher livestock density. The marginal annual temperature effect from Table 1 was small and insignificant. Using the seasonal coefficients in Table 2, the marginal seasonal effects shown in Table 3 are highly significant. A wetter winter increases livestock density though a wetter autumn decreases it. The winter effect is larger implying the marginal effect of annual precipitation is positive. Warmer winter and especially summer temperatures have a negative marginal effect on livestock density but warmer spring and autumn temperatures increase livestock density. These offsetting seasonal effects imply that the annual marginal effect of temperature is not significant.

3.2. *Ricardian results of household survey*

The Ricardian regression results for models (7)–(9) are presented in Table 4. Most of the independent variables are statistically significant with the expected sign. The climate variables are insignificant in the net revenue per household regression implying

Table 4. Regression results on the determinants of livestock net revenue (OLS regression results).

Variables	Net revenue per household (USD)	Net revenue per animal (USD)	Value of livestock per household (USD)
	(7)	(8)	(9)
Annual precipitation	213.2	−2.82***	4,790.2***
	(1.06)	(−2.98)	(2.73)
Annual precipitation squared	−7.81	0.050**	−112.9**
	(−1.46)	(2.21)	(−2.49)
Annual temperature	167.0	−1.97***	3,733.6***
	(1.27)	(−2.93)	(2.94)
Annual temperature squared	−14.65	−0.319***	97.58
	(−0.70)	(−2.65)	(0.47)
Years herding experience	28.60	−0.106	636.3***
	(1.28)	(−0.99)	(2.59)
Dummy agricultural extension	1288.5***	−3.87	8307.1*
	(2.61)	(−1.43)	(1.85)
2012	−8.21***	0.021	−28.87
	(−3.08)	(0.557)	(−1.45)
Number of wells per square km of soum area	45,372.2*	188.0	57,686.1
	(1.88)	(1.61)	(0.27)
Number of streams per square km of soum area	61,208.4**	−134.7	519,846.7**
	(2.14)	(−1.59)	(2.31)
Flat land $0 < \text{slope} < 8\%$	41.38	−3.02	1.13
	(0.05)	(−0.72)	(0.00)
Undulating land $8\% < \text{slope} < 30\%$	277.4	−4.95	3,153.7
	(0.48)	(−1.63)	(0.55)
Constant	3,684.6**	61.16***	−21,111.3
	(2.07)	(4.63)	(−1.27)
Observations	442	442	442
R−squared	0.105	0.078	0.098

Notes: Robust t−statistics in parentheses; (***), (**), and (*) significant at 1%, 5%, and 10% respectively.

they have no effect. However, the climate variables are significant in both the net revenue per animal and total value of livestock regression. Precipitation has a U-shaped relationship with net revenue per animal and a hill-shaped relationship with total livestock value. Temperature has a hill-shaped relationship with total livestock value and a positive linear effect on total livestock value.

Some control variables are significant. Herder experience increases livestock total value. Government extension and stream density increase both the net revenue of the household and total livestock value.

Table 5 calculates the marginal effect of temperature and precipitation in each regression evaluated at the mean climate. The marginal effect of climate is not significant in the net revenue per household regression. The marginal effect of precipitation and

Table 5. Marginal effect of temperature and precipitation on livestock net revenue (from Table 4).

Variables	Net livestock revenue per household (USD)	Net income per livestock (USD)	Value of owned livestock at the end of the year (USD)
Annual mean precipitation (monthly)	−62.68	−1.068***	799.9*
	(−1.53)	(−3.33)	(1.70)
Annual mean temperature (daily)	189.9	−1.473***	3580.9***
	(1.625)	(−2.63)	(3.37)

Notes: Robust $t-$statistics in parentheses; (***), (**), and (*) significant at 1%, 5%, and 10%, respectively.

temperature are both negative in the net revenue per livestock regression. The marginal effect of precipitation is not quite significant in the value of livestock regression but warmer temperatures are associated with higher total livestock value.

3.3. *Forecasting the impact of climate change*

Future predicted changes in precipitation and surface temperature were taken from three General Circulation Models (GCMs): BNU, CMCC, and CanESM (Taylor *et al*., 2012).[3] Daily surface precipitation and mean temperatures from each model were averaged to produce estimates of monthly mean climatological changes for the periods 2031–2060, 2051–2080, and 2071–2100, relative to the historical 1971–2000 period. The models all assume emissions follow the Representative Concentration Pathway RCP8.5 (van Vuuren *et al*., 2011) which is on the very high end of plausible Business as Usual (no mitigation) scenarios.

The projections of the BNU model show that the temperature in Mongolia is expected to increase by 3.5°C for 2031–2050 and 5.1°C for 2071–2100. The highest projected increase in temperature comes from the CMCC model, which projects an increase of 6.1°C for 2071–2100. The models predict increases in precipitation levels, with a minimum of a 15% increase in the 2031–2050 period under the BNU model and a maximum of a 72% increase by 2071–2100 under the CMCC model.

Three predictions are made using the coefficients from Tables 1 and 3. Each prediction calculates the change in predicted outcome given the future climate scenario versus the current climate scenario. The first prediction of herder net revenue (income) combines the prediction of the number of animals (from Table 1) times the net revenue per animal (Table 3). The second prediction of net revenue uses the prediction of net revenue per household regression from Table 3. The third prediction of total livestock value uses the prediction of value of livestock per household regression from Table 3. Each of these predictions are made using each future climate scenario.

[3] http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html.

Table 6. Impact of climate change.

Variables	BNU_rcp85	CMCC_rcp85	CanESM2_rcp85
2031–2060 Climate Impact			
Percentage change in Net revenue per livestock * Total number of livestock[1]	−48.7% (−676.6)*	−37.5% (−521.9)*	−48.7% (−676.5)*
Percentage change in Aggregate Net livestock income[2]	2.5% (35.1)*	1.3% (18.8)*	−5.9% (−83.7)*
Percentage change in Aggregate Value of owned livestock[3]	27.4% (2639.1)*	21.3% (2052.5)*	19.6% (1890.3)*
2051–2080 Climate Impact			
Percentage change in Net revenue per livestock * Total number of livestock[1]	−54.6% (−758.9)*	−61.1% (−849.9)*	−67.7% (−941.7)*
Percentage change in Aggregate Net livestock income[2]	−2.2% (−31.1)*	−1.7% (−23.3)*	−16.3% (−229)*
Percentage change in Aggregate Value of owned livestock[3]	26.3% (2528)*	30.3% (2918.8)*	18.3% (1763.5)*
2071–2100 Climate Impact			
Percentage change in Net revenue per livestock * Total number of livestock[1]	−73.2% (−1017.3)*	−80.7% (−1122)*	−79.5% (−1105.7)*
Percentage change in Aggregate Net livestock income[2]	−5.1% (−71.4)*	−5.2% (−73.4)*	−28.4% (−399.8)*
Percentage change in Aggregate Value of owned livestock[3]	35% (3373)*	42.4% (4078.4)*	12.4% (1198.5)*

Notes: *In parentheses, amount of change compared to baseline is given in million USD. Number of herder households are assumed to stay constant (202, 873) excluding herders in Ulaanbaatar city. 2012 MNT/USD exchange rate is 1396.
[1]Baseline value Net revenue is 1390 million USD.
[2]Baseline value Net Revenue is 1410 million USD.
[3]Baseline value of Livestock is 9627 million USD.

The predictions assume that the other variables in the model remain the same in all the periods.

The results in Table 6 present the results of all the forecasts. The first row in each scenario calculates the impact on net revenue of combining the change in the number of animals times the net revenue per animal. The results suggest that warming will be harmful to herder incomes causing them to decline by 40–80% and or by around 600–1000 million USD between 2030–2100 depending on the climate model. The second row shows the results of the livestock net revenue per household times the total number of herder households. The results imply that smaller increase in temperature and precipitation may increase net livestock income of herder households by 1–2% but the impact turns negative with further change in climate which reduces the net livestock income by 1–28%.

The third row shows the results of the value of livestock per household prediction times the total number of herder households. The results imply increase in value of livestock owned by the herder households by 20–42% between 2030–2100.

There are a number of caveats that should be mentioned. First, the model assumes the same level of technology and prices across the different future scenarios. This is not likely. Second, the model only considers a very high emission scenario which is also not likely. Third, the model does not consider any other land use, just herding.

4. Conclusion and Policy Recommendations

This paper tests the climate sensitivity of the livestock sector in Mongolia. The analysis depends on a combination of soum level data and household survey data. Two different measures of herder welfare are explored. The net revenue per herder household is used to reflect the impact of climate change on herder income. The total value of livestock is used to measure the effect of climate change on herder assets.

The study uses a cross-sectional empirical analysis to estimate the impact of climate change on Mongolia's livestock sector. The data includes official livestock statistics collected by soum and a household survey of herders throughout Mongolia. The research leads to mixed results. The marginal effect of warmer seasonal temperatures are predicted to be offsetting suggesting no impact on livestock density at the soum level. The marginal effect of precipitation, however, is expected to increase livestock density. The marginal effect of climate is not predicted to have any effect on net revenue per household. In contrast, the marginal effect of both temperature and precipitation is expected to reduce net revenue per animal. Finally, the marginal effect of temperature is expected to increase livestock value per household. These conflicting results cannot all be true suggesting that there remain questions with the analysis that deserve further research.

The climate forecasts for future climate scenarios also have mixed messages. Combining the results for livestock density multiplied by net revenue per animal suggests that warming is strictly harmful. In contrast, the results using total livestock value suggest warming is strictly beneficial.

There are other important results of the study. First, the study shows that water resources are essential for livestock density. Stream density dictates what grasslands are suitable for livestock and which ones are not. Streams can be supplemented with wells but groundwater is a scarce resource. Rural drinking water supplies depend exclusively on groundwater. Other economic activities such as mining also rely on groundwater supplies. The government must carefully plan how to use Mongolian groundwater.

Based on climate projections, the team was able to analyze the impact of future changes in temperature and precipitation on farmers' net revenue. Results indicate that temperature is expected to rise by 3.5°C in the 2031–2050, by 3.75°C in 2051–2081, and by 5.12°C in the 2071–2100 periods. The level of precipitation, as measured in percentage points, would grow significantly in 2031–2050 by 15.11, in 2051–2081 by 26.5, and in 2071–2100 by 34.7 (based on BNU-ESM estimator). These changes would result in dramatic losses in farmers' net revenue. The impact of climate change in the 2031–2060 projections would result in a loss of US$ 11.558 in net revenue per livestock. Losses would increase over time, reaching a peak value of US$ 20.581 in 2071–2100 projections. Temperature also plays an essential role in reducing farmers' net revenue and accounts for 78% in the 2031–2060 projections, 71% in the 2051–2081 projections, and 77% in the 2071–2100 projections.

One implication arising from these results concerns the impact of climate change on the agriculture sector. Given the absolute dependence of the economy on the livestock sector and the projected losses in farmers' earnings, the sector will contract by 2030 if no measures are taken. Climate change would inevitably impact the labor market by gradually reducing farmers' net revenue up to a point where they would start looking for new opportunities. Government agencies should ensure that nonfarm employment opportunities are available across the country. Other actions that might support rural livelihoods need to be considered. Establishing early warning systems for extreme weather events such as cold and droughts should also be considered.

This analysis sheds light on the vulnerabilities of the livestock sector in Mongolia to climate change. The analysis examines the determinants of livestock net revenue for households including the marginal impact of climate change on revenues. The results suggest that if no efforts are undertaken by 2060 to combat climate change and its adverse effects, farmers in Mongolia could lose as much as 50% of their earnings. The results suggest that livestock farmer' choices will change with climate change. As seen earlier, agriculture employs 28.6% of the total population (as of 2014), which means that climate change could have a direct impact on the country's labor market. These results could serve as a guide to policy makers, who need to focus on supporting livestock farmers with adaptation measures. It is possible that adaptation measures such as improving livestock health and reproduction could help mitigate the damage from climate change.

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