Responses to climate and economic risks and opportunities across national and ecological boundaries: changing household strategies on the Mongolian plateau

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Abstract
Climate changes on the Mongolian Plateau are creating new challenges for the households and communities of the region. Much of the existing research on household choices in response to climate variability and change focuses on environmental risks and stresses. In contrast, our analysis highlights the importance of taking into account environmental and economic opportunities in explaining household adaptation choices. We surveyed over 750 households arrayed along an ecological gradient and matched across the national border in Mongolia and the Inner Mongolia Autonomous Region, China, asking what changes in livelihoods strategies households made over the last ten years, and analyzed these choices in two broad categories of options: diversification and livestock management. We combined these data with remotely sensed information about vegetation growth and self-reported exposure to price fluctuations. Our statistical results showed that households experiencing lower ecological and economic variability, higher average levels of vegetation growth, and with greater levels of material wealth, were often those that undertook more actions to improve their conditions in the face of variability. The findings have implications both for how interventions aimed at supporting ongoing choices might be targeted and for theory construction related to social adaptation.

Keywords: adaptation, climate change, survey research

Households and communities on the Mongolian plateau are vulnerable to risks from a variable and changing climate [1], but also to what has been called ‘multiple stressors’ [2]. Among these stressors are economic and social changes in the region occurring, at least for now, at a faster pace than changes in climate [3–5]. Such changes include economic and land-use policies, substantial external investments, interventions by governments and private actors, transformations in local livelihoods, and changing local institutions for managing land and other terrestrial resources [6, 7]. How households respond
to changing circumstances have major effects on their current and future well-being.

Our paper examines household strategies to managing climate and other risks and opportunities on the Mongolian plateau. Using survey and remote sensing data, we assess whether the implicit agreement that adaptation actions are taken as a consequence of greater environmental and other stresses is indeed well founded and whether it explains observed variations in adaptation strategies in the region. Focusing on the household level, we build on existing work on climate adaptation and vulnerability [8] to analyze the extent to which variations in adaptation strategies are associated with the risks versus the opportunities households face.

Much of the existing research on adaptation strategies views them as responses to risks and environmental stresses [9–11]. The relationship between stress and adaptation is assumed in both conceptual and empirical contributions [12–14]. Scholars recognize the possibility that adaptation may be a response to available opportunities [15–17], but nonetheless tend to focus more on risks when discussing adaptation more concretely [18–21]. This is not surprising since adverse changes in climatic and environmental contexts are more likely on the average, particularly in the longer run [22, 23].

Our data and analyses suggest, however, that it is important to consider the extent to which lower environmental exposure and higher levels of economic opportunities might provide stronger explanations of household-level adaptations. Our comparative study of Mongolia and Inner Mongolia in China is based on data and analyses at the household level, and provides useful evidence for thinking about future adaptation and the design of adaptation policies. If lower levels of exposure and greater economic opportunities are significant drivers of the range of adaptation options that households use, the adverse impacts of climate change and variability on average levels of surplus may undermine effective responses to climate change even more than has been recognized.

In contrast to many existing studies of adaptive capacity and adaptation typologies [24–26], our paper focuses on the actual household strategies that might be viewed as adaptation. It is important to address how households respond to environmental constraints and opportunities for three reasons. First, a better understanding of the reasons for variations in household choices made as adaptations to contemporary circumstances is necessary to identify the interventions most likely to support ongoing choices made by households in response to change. Second, patterns of relationships between contextual variables and household choices show how different kinds of adaptive responses cluster by ecological context and country, and thereby enable location- and case-specific interventions to manage environmental risks. Finally, such an approach is also necessary to build a more grounded theoretical architecture of social adaptations [27]. To build better theories it is necessary to develop better empirical understanding of how responses to risks and opportunities vary. After all, households and their strategies are the direct point of interface between environmental risks and social responses.

The goal of this study was to understand current adaptation strategies and how they vary relative to both ecological and national-level variations. We hypothesize that adaptive responses are different in both quantity and quality (type) in different settings. We further hypothesize that household-level attributes affecting availability of social, financial, material, and human capital affect adaptive choices.

1. Contrasting environments and institutions

Our empirical analysis focused on paired sites arrayed along an ecological gradient and matched across the national border in Mongolia (MN) and the Inner Mongolia Autonomous Region (IMAR), China (figure 1). Different institutions and economic, social, and resource policies in these two countries affect the challenges and opportunities that households face. The term institutions in this context refers to the formal and informal arrangements at multiple scales of organization that constrain and facilitate the livelihood choices of households [28, 29]. Transitions from collective to market-based economies in both countries, beginning in the mid-1980s, involved re-allocation of pastures to households in IMAR, as part of the household responsibility system, and state ownership of pastures but privatization of livestock in MN where, due to relative lack of effective resource institutions, pastures are managed under a combination of both formal and informal institutional arrangements. Whereas discontinuation of Soviet support has left the MN government with limited resources for infrastructure development and resource management, IMAR has seen investments in ecological restoration efforts and infrastructure [30]. In MN, the removal of Soviet-era collective institutions and investments has reduced the ability of grazers to carry out long-distance migrations and water facilities have fallen into disrepair [31], whereas in IMAR strong national economic growth together with efforts by the national government to invest in ecological restoration programs, have resulted in a greater variety of livelihood options and better resource infrastructure [30].

A strong southwest to northeast precipitation gradient presents striking variation in environmental challenges and opportunities. Average annual precipitation in the region varies from less than 50 mm in Gobi Desert, southwestern Mongolia, to greater than 400 mm along the Russian border. This precipitation gradient supports desert in the west, through multiple types of steppe, to deciduous forest in the far north. Along this gradient, vegetation has been described in terms of three dominant steppe vegetation zones (or ecological regions) with vegetation communities that vary with increasing moisture from desert steppe to typical steppe to meadow steppe. Productivity is higher in the meadow steppes to the east, with an average annual net primary productivity of 243.3 g m⁻² in IMAR, compared to 162.2 g m⁻² and 44.63 g m⁻² in typical and desert steppes, respectively [32].

Greater levels of productivity along the environmental gradient create opportunities for a greater range of livelihood choices: with greater precipitation, land can support more
livestock, more people, and therefore a greater diversity of activities. This greater range of opportunities in the more productive meadow steppe is reflected in the livelihoods of households. In earlier published results from the survey we report here, we found that while products from livestock (including meat, dairy, and wool) are the single most important category of income for the majority of herder households, greater proportions of income came from livestock in the desert compared to the meadow and typical steppe regions [33]. Livestock products make up over 85% of incomes in Mongolia, overall, with the balance coming from subsidies. Incomes in IMAR are more diversified, with substantial fractions coming from off-farm work, businesses, and some grain production. Grain production was much more common in the meadow and typical steppe regions of IMAR than in the desert steppe [33].

Based on instrumental records, the region has experienced both warming and drying. Mean annual temperatures increased in MN by 2.1 °C (1940–2007) and by 2 °C in IMAR (1961–2006), precipitation decreased between 6 and 7% in these areas, respectively, over comparable periods [34, 35]. There is some evidence that climate variability, experienced by herders as frequency of drought and dzud (winter snow disasters), has also increased over the last 60 years [33, 36]. These climatic trends have reduced grassland productivity, as estimated using NDVI, but productivity is also affected by grazing intensity [37]. The combined effect of management and climate has been substantial reductions in productivity, as confirmed in field based surveys in both MN and IMAR [30].

2. Methods

2.1. Survey design and implementation

We combined satellite data on vegetation greenness (i.e., NDVI) and a household survey that captures information about economic, demographic and land-use characteristics; livelihood adaptation strategies; and experience with climate hazards and fluctuations in prices of livestock products. Our analysis focuses on households engaged in herding activities, and variations in reported livelihood adaptation strategies. We asked respondents about strategies their households have used to improve economic status in the past ten years, drawing upon similar work in other semi-arid regions [8]. By asking about livelihood changes and framing the period over which such changes occurred by connecting them to major experienced events, we are able to analyze adaptations over time from a single survey. Additionally, while we interpret what these responses tell us about potential responses to climate change, we are interested in all adaptation options herder households have pursued, regardless of the cause. Although causal attribution will further improve our understanding of adaptation choices, our analysis provides important directions in which to investigate causal relationships further and is useful for showing how ecological and potential social causes of adaptation choices differ across social-ecological contexts.

We field tested the survey in the summer of 2010 with an initial list of possible adaptation and coping actions, then
Table 1. Survey and remote sensing variables used in analysis.

| Variable name                        | Units | Mean IMAR | Mean MN |
|--------------------------------------|-------|-----------|---------|
| Household variables                  |       |           |         |
| Total income                         | RMB   | 54,696    | 69,145  | 17,474  |
| Total assets                          | Count | 3.67      | 4.62    | 1.28    |
| Number of cattle and horses           | Count | 19.50     | 7.41    | 50.62   |
| Number of goats and sheep             | Count | 227.80    | 209.90  | 273.90  |
| Ave. grazing experience               | Years | 14.45     | 16.00   | 12.00   |
| Price variability                    |       |           |         |
| 1: None                              |       | 1.97      | 2.33    | 1.10    |
| 2: A little                          |       |           |         |
| 3: A lot                             |       |           |         |
| Environmental variables              |       |           |         |
| Mean NDVI                            | Unitless | 0.30      | 0.32    | 0.27    |
| NDVI CV                              | Unitless | 0.13      | 0.13    | 0.14    |
| Diversification strategies           |       |           |         |
| Reduce expenses by consuming less     | Yes/No | 0.55      | 0.56    | 0.83    |
| Reduce livestock, surpluses or savings| Yes/No | 0.45      | 0.37    | 0.63    |
| Sublease land                        | Yes/No | 0.34      | 0.30    | 0.44    |
| Eat different foods                  | Yes/No | 0.17      | 0.23    | 0.01    |
| Start a business                     | Yes/No | 0.27      | 0.29    | 0.20    |
| Livestock management strategies      |       |           |         |
| Apply different feed to animals      | Yes/No | 0.49      | 0.47    | 0.54    |
| Improve storage of food              | Yes/No | 0.51      | 0.43    | 0.73    |
| Buy animals to increase herd size    | Yes/No | 0.41      | 0.41    | 0.42    |
| Buy animals to improve breed quality/productivity | Yes/No | 0.44 | 0.40 | 0.53 |
| Adopt new animal species             | Yes/No | 0.42      | 0.39    | 0.52    |
| Sell animals                         | Yes/No | 0.57      | 0.50    | 0.78    |
| Change the herd composition          | Yes/No | 0.36      | 0.32    | 0.45    |
| Stall-feed more livestock            | Yes/No | 0.32      | 0.31    | 0.34    |

modified that list based on the field test and feedback from our local collaborators. We developed the final survey in English, then translated it to Mandarin and Mongolian. Both translations were then translated back to English to clarify meanings among the translators. The survey was conducted by staff at the Inner Mongolian Institute of Grassland Survey and Design using Mandarin in China, during autumn 2010, and Mongolian in Mongolia, during spring 2011. All surveyors had previous experience with household surveys in the region, and were provided with three days of training on this particular survey.

The survey sample was created, first by identifying clusters of counties in IMAR and soums in MN within the meadow, typical, and desert steppe regions. Within each cluster, we stratified villages in IMAR and soums in MN by distances to towns/markets, densities of human and livestock populations, and household herd sizes. Villages/soums were then selected to represent the range of conditions in each region. Based on a numbered list of households in each village/soum, we randomly selected 30 households, but interviewed all available households if the village/soum had fewer than 60. Transportation and access was significantly more challenging in MN. For that reason, we reduced our targets, and interviewed ultimately 30, 120 and 60 households in meadow, typical and desert steppes, respectively.

We grouped the list of 51 different adaptation strategies from which the herder households could choose into eight categories: mobility, livestock management, agricultural practices, diversification, communal pooling, water management, infrastructure development, and ‘other’. For two of these categories there was sufficient variability and statistical evidence to support a further analysis (table 1): diversification and livestock management. The household-level attributes we gathered represent financial, material, human, and social, capitals (table 1). Our measure of financial capital was total income. Our measures of material capital included numbers of livestock (grouped as cattle and horses versus sheep and goats) and total number of assets, which was a crude total across different categories of assets, including: rooms in the house, four-wheeled vehicles, agricultural machines, televisions, computers, refrigerators, livestock shelters, and wind generators. The human capital variable was average years of grazing experience. Our measure of social capital, based on reports of help received from neighbors and friends, produced an unreliable scale and is not included here.

We measured exposure to market stresses using a question about whether respondents had experienced no, a little, or a lot of variability in the price they received for their primary livestock product. In addition, we used the geocoded household locations to extract information about exposures in the local environment. A continuous series of NDVI values
at 8-km resolution was created from the GIMMS AVHRR (1982–1999) and MODIS (2000–2009) data sets by degrading the 1 km MODIS NDVI data to 8 km resolution and then using regression analysis on the two datasets when they were both operating (2000–2006) to standardize their values. We extracted for each household the average and coefficient of variation (CV) in average growing season NDVI (mid-April through September) for the period 1982–2009 for the 8-km pixel in which they were located [37].

2.2. Regional variation in adaptive responses

We started our analysis by constructing and analyzing composite measures of adaptation strategies. Confirmatory factor analyses were conducted using a weighted least squares mean and variance estimation procedure with a polychoric correlation matrix to model the categorical data representing the different diversification and livestock management choices. After obtaining a good factor structure with acceptable factorial validity (i.e., a good model fit and large standardized factor loadings), internal consistency reliability (α) coefficients were computed to assess the reliability of each scale. The factor scores for the diversification and livestock management factors were then used as dependent variables in the multivariate analysis of variance (MANOVA), which tested whether they were significantly affected by country and ecological region and as criterion variables for the spatial error regression models.

2.3. Modeling regional and household correlates of adaptive responses

Although ecological region and country variations are informative by themselves, we further sought to understand the correlates of variations within and between regions. In GeoDa [38], we tested whether the household-level and environmental predictor variables were significantly related to diversification and livestock management.

To understand the contribution of each predictor variable, we tested the following models: (1) models using the entire sample, (2) models fit separately for each country, and (3) models fit separately for each ecological region. Because the sample sizes were too small, we were not able to produce suitable results for separate ecological regions within countries. Because we found significant spatial autocorrelation in the residuals of model fit using ordinary least squares (OLS) regression (i.e., the Moran I statistics were statistically significant), we report the results of spatial error models, which include a lagged error term to account for spatial autocorrelation. Including the spatial error term, which uses weights based on a threshold of distance determined by the smallest distance for all observations to have at least one neighbor, reduces the chance of type I errors. We report the coefficients of all models, as well as the model fit using pseudo-$R^2$. Pseudo-$R^2$ is calculated as the square of the correlation coefficient ($r$) calculated between the observed and model-predicted values. We also report the coefficient (lambda), which is related to the strength of the spatial effect in the error distribution.

3. Results

In general, herder households in IMAR had more financial capital and material assets, but experienced greater levels of price variability than those in MN (table 1). Livestock herds were generally larger in MN, especially in terms of cattle and horses. Livestock herds were dominated by cattle and horses in the meadow steppe, and by sheep and goats in desert steppe. Environmental exposure was greater in MN than IMAR, with lower average and greater variability in NDVI, and in the desert and typical steppe compared with meadow steppe. Consistent with rainfall and productivity differences among ecological regions, average NDVI was 0.48, 0.31, and 0.13 in the meadow, typical, and desert steppes, respectively. Variation in NDVI (i.e., NDVI CV) was notably lower in meadow steppe (0.085) than in typical and desert steppe (both 0.15 and 0.15).

3.1. Regional variations in adaptation responses

Confirmatory factor analyses for the diversification and livestock management factors revealed a good fit ($\chi^2 (101) = 650.326, p < 0.001$, $CFI = 0.986$, $TLI = 0.983$, $RMSEA = 0.085$), with large standardized factor loadings ($\lambda > 0.50$) that were all statistically significant ($p < 0.001$). However, the large interfactor correlation ($r = 0.94$) suggests concerns related to discriminate validity. The internal consistency reliability (α) coefficients were adequate for the diversification (α = 0.89) and livestock management (α = 0.93) scales, with these factors representing the degree to which households made the livelihood choices included in each of these categories (table 1).

The MANOVA revealed a significant effect of country (Wilks’ lambda = 0.84, $F [2, 744] = 69.22, p < 0.001$, partial $R^2 = 0.157$), ecoregion (Wilks’ lambda = 0.59, $F [2, 1488] = 112.25, p < 0.001$, partial $R^2 = 0.232$), and country by ecoregion interaction (Wilks’ lambda = 0.91, $F [4, 1488] = 17.90, p < 0.001$, partial $R^2 = 0.046$). The results for both factors were fairly consistent (figure 2). Scores were always highest for the meadow steppe, with a sharp decrease for the typical and desert steppes. Moreover, scores were constantly higher for MN than IMAR, although the difference between countries within the meadow steppe on livestock management was not significant. The difference between the typical and desert steppe were not considerable on diversification (i.e., the lines are rather flat and were not significant in Mongolia), whereas mean scores differed more on livestock management. Other than the exceptions noted above, all pairs of points within each factor were significantly different ($p < 0.05$) after a Bonferroni adjustment.

3.2. Spatial regression models of regional and household correlates

While the residuals were always spatial autocorrelated (based on a significant Moran I statistic) when using ordinal least squares (OLS) analyses, the residuals for the spatial error model were not significantly spatially autocorrelated. This
implies the effects of spatial autocorrelation were removed from the spatial error regression models. In all but the desert steppe models, the spatial error terms were strong and significant.

In the overall diversification model, only the spatial error term was statistically significant. For the country models, average NDVI had a higher level of significance in predicting diversification for IMAR than for MN, which likely contributed to the much larger IMAR pseudo-$R^2$. Diversification increased in both countries with increases in average NDVI. Total assets was a positive predictor of diversification in meadow steppe and a negative predictor in desert steppe, with the number of cattle and horses being positively related to diversification in desert steppe. Average grazing experience had a marginally significant ($p < 0.1$) positive relationship with diversification in meadow steppe.

Average NDVI was the only significant predictor in the overall model for livestock management. Average NDVI was also a significant positive predictor of Livestock Management in both country models. NDVI CV was significant and negative in Mongolia. Price variability was marginally and negatively related to livestock management in meadow steppe and typical steppe. In typical steppe, higher scores on livestock management were also predicted by lower levels of NDVI CV and higher values of average grazing experience. The model for the desert steppe indicated that livestock management was significantly related to number of cattle and horses (positively) and total assets (negatively).

It is worth noting that while relatively few predictor variables (often one per model) were statistically significant when controlling for the other predictor variables and spatial autocorrelation in the model, the combined contribution of the variables was often significant based on the $R^2$ from the OLS analyses (available from the corresponding author) and the pseudo-$R^2$ from the spatial error models. Because the residuals exhibited strong spatially autocorrelation, the pseudo-$R^2$ was typically larger (on average 0.29) than the OLS $R^2$.

### 4. Discussion

Our data and analysis allow us to examine the association between household adaptation choices and the stresses and opportunities associated with environmental and economic contexts. At regional, country, ecoregion, and household levels, and in some contrast to the orientation of a substantial literature on adaptation, we find that, where relationships are significant, households tend to adopt a greater number and range of adaptation strategies with more favorable conditions. This pattern holds for price variability, environmental conditions, and for vegetation growth.

Overall, diversification and livestock management approaches were used more frequently in meadow steppe, which had the highest average NDVI and lowest variability (CV) of NDVI. This overall pattern is also present at the level of the individual strategies that constitute the scores for diversification and livestock management. Individual strategies were all more frequently used in the meadow steppe, with the exception of ‘eat different foods’, which was used more often by households living in desert steppe zones. The adaptation strategies were also more frequently adopted in MN versus IMAR. While MN experienced a slightly greater degree of environmental exposure compared to IMAR (average NDVI = 0.27 versus 0.32 and NDVI CV = 0.14 versus 0.13, respectively), it experienced far less reported exposure to price variability (PV = 1.10 versus 2.33, respectively). The only individual adaptive responses cited more frequently in IMAR were ‘start a business’ and ‘eat different foods’.

When they were significantly related to variables in the household-level model, uses of diversification and livestock management strategies were most commonly related to increases in vegetation growth (i.e., average NDVI) and decreases in economic and environmental variability (i.e., price variability and NDVI CV). The effects of material wealth in the models may provide further indication that favorability of circumstances can facilitate adoption of adaptations, but the effect is weak overall. ‘Total assets’ was significantly and positively related to diversification in the meadow steppe, negatively in the desert steppe. That total assets became negative when included in the desert steppe model may be an artifact of the large differences in assets between the countries. The significant effect of number of cattle and horses, which was positively associated with diversification and livestock management in desert steppe, provides another indicator of how households respond based on their material assets.

Our two main adaptation outcomes—diversification and livestock management—both had a positive association with average NDVI in IMAR and Mongolia. This finding is consistent with the finding that these strategies were more common in the meadow steppe, the region with the greater vegetation productivity. This positive association with average NDVI, together with the overall household livelihood profiles in these regions [37], suggests that households with greater grassland productivity have more options than they can realistically avail. Indeed, their use of diversification and

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**Figure 2.** Mean values (with standard errors) on the diversification and livestock management factors for households in different countries and ecological regions. Note, the pairwise comparisons are made only within each factor and means should not be compared across factors.
livestock management strategies with greater frequencies indicates that the relative security of a productive resource facilitates greater experimentation and diversification. Indeed, we did not find strong evidence that greater climatic or economic stresses are more conducive to the use of a larger number of different adaptation strategies. A sense of available grounds for experimentation to cope with risks. We do not examine whether greater opportunities provide more fertile contexts where livelihoods depend chiefly on primary sector occupations. In rapidly changing contexts, implementing multiple strategies helps households spread risks more. That the pattern of average adaptation factor scores across ecological regions is consistent in MN and IMAR, where the surveys were conducted in different languages, lends support to the overall comparability of the survey results.

The differences between the results from the diversification and livestock management are also instructive. The variables describing variability in the environment (both natural and economic) entered the models as significant predictors for livestock management, but not for diversification. Decreased price variability (in meadow and typical steppe) and NDVI CV (in Mongolia and typical steppe) were strongly associated with increased use of livestock management adaptations. This suggests that lower price and ecological variability facilitate experimentation by herder households, allowing them to test alternative livestock management practices. Diversification was not significantly related to these variability indicators, indicating either that we do not have an adequate sample size, or that these strategies are not affected systematically by variability.

Our data do not allow us to address the effectiveness of adaptation options. Our measure of adaptation is based on the number of different strategies employed. If, in some particular contexts, a single adaptation strategy (e.g., starting a new business) has a higher economic return, then the number of strategies may not be an appropriate indicator of efficient adaptation. Nonetheless, a single economic strategy is also more vulnerable to changes in economic and climatic contexts where livelihoods depend chiefly on primary sector occupations. In rapidly changing contexts, implementing multiple strategies helps households spread risks more.

Table 2. Estimated coefficients for spatial error models Diversification and Livestock Management. (Note: values in each column are unstandardized coefficients in the spatial error regression models of Diversification or Livestock Management for a given subset.)

| Diversification | Overall | MN | IMAR | Meadow | Typical | Desert |
|-----------------|---------|----|------|--------|---------|--------|
| Intercept       | 0.022   | -0.296 | -0.610 | 0.628 | 0.276 | 0.147 |
| Total assets    | 0.002   | 0.033 | 0.006 | 0.022 | -0.006 | -0.024 |
| Number of cattle and horses | 0.000 | 0.000 | 0.000 | 0.000 | -0.001 | 0.003 |
| Ave. grazing experience | 0.001 | 0.001 | 0.001 | 0.002 | 0.000 | -0.001 |
| Price variability | -0.027 | -0.075 | 0.010 | -0.034 | -0.055 | -0.058 |
| Ave. NDVI       | 0.548   | 1.461 | 2.092 | -0.029 | -0.394 | -0.313 |
| NDVI CV         | -0.779  | 1.296 | -1.047 | 1.111 | -1.498 | -0.495 |
| Lambda (spatial error) | 0.911b | 0.811c | 0.829b | 0.944b | 0.861a | 0.185 |
| Pseudo-R²       | 0.760   | 0.540 | 0.779 | 0.878 | 0.681 | 0.154 |

| Livestock management | | | | | |
|----------------------|---------|----|------|--------|--------|
| Intercept            | -0.196  | 0.252 | -0.822 | 0.717 | 0.014 | -0.246 |
| Total assets         | -0.003  | 0.014 | -0.003 | 0.013 | -0.028 | -0.025b |
| Number of cattle and horses | 0.000 | 0.001 | -0.001 | 0.000 | 0.000 | 0.002 |
| Ave. grazing experience | 0.001 | 0.002 | 0.001 | 0.001 | 0.004b | -0.001 |
| Price variability    | 0.012   | -0.107 | 0.025 | -0.505 | -0.103 | 0.048 |
| Ave. NDVI            | 0.872b  | 1.444c | 0.008 | -0.009 | 1.303 | -0.260 |
| NDVI CV              | -0.535  | -2.884c | 0.362 | 0.896 | -3.306a | 0.842 |
| Lambda (spatial error) | 0.894b | 0.469b | 0.029a | 0.929b | 0.777a | 0.137 |
| Pseudo-R²            | 0.714   | 0.393 | 0.746 | 0.813 | 0.604 | 0.061 |

* Indicates a statistical significance at \( p < 0.01 \).
** Indicates a statistical significance at \( p < 0.05 \).
*** Indicates a statistical significance at \( p < 0.1 \).
suggest that environmental stresses are irrelevant as a goal to experiment—but that in similar social-ecological contexts, the possibility of greater opportunities may be more conducive to the use of a greater variety of livelihood and economic strategies. Our findings indicate that risks and worsening ecological conditions in rangelands associated with climate change may reduce the ability of households to use different adaptation strategies.

Focusing on the actual actions that households have taken to improve their livelihoods grounds the work on adaptation empirically to help think more carefully about possible future responses, for understanding how responses vary with context, and for developing a more robust theoretical framework for future adaptation studies. The strongest finding from this study is that variation in adaptation strategies is driven not merely (maybe not even primarily) by the nature of the challenges households face. Rather, the opportunities presented by both the environmental and economic contexts within which households find themselves seem to be the primary factors that explain observed variations. Where households experienced less environmental and economic stress (implemented here through measures of NDVI and price variability) they were likely to undertake a greater variety of adaptation options.

Though the patterns of association vary depending on separate countries and within separate ecological regions, the general pattern is similar. Additionally, there is some suggestion that the assets a household owns, including cattle, contribute positively to their ability to undertake a number of adaptation strategies. This analysis highlights the importance of interactions between contextual and household-level variations in affecting household responses. It also points to the need to consider these contexts in planning responses to future environmental change, which may affect the opportunities of households and communities to respond to those changes.

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